YIELD RESPONSES OF SWISS CHARD UNDER IN-FIELD RAINWATER HARVESTING TECHNIQUES IN LIMPOPO PROVINCE

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DECLARATION

I, Maluleka Tiyiselani Welcome, do hereby declare that this mini-dissertation submitted to the University of Limpopo, for the degree Master of Science in Agriculture (Horticulture) has not previously been submitted or presented by me for a degree at this or any other university, that it is my work in design and in execution, and that all the material contained herein has been duly acknowledged.

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ABSTRACT

Rainwater harvesting is an old age practice used in water-scarce rainfed crop production areas. It is practiced to supplement additional water for crops with insufficient amounts of rainfall for optimum production. The aim of this study was to assess yield responses of Swiss chard under In-field rainwater harvesting techniques (IRWH) and catchment areas. The trials were conducted at two sites, University of Limpopo experimental farm (Syferkuil) and on farmer's field at Apel. The main plots were two catchment areas (2 m (1 m runoff strip plus 1 m basin)) and (3 m (2 m runoff strip plus 1 m basin)), while the subplots were five IRWH techniques namely; Control (farmers practice), Rainfed, IRHW (without mulch + irrigation), IRWH+Mulch and IRWH+Mulch+Irrigation. The results obtained showed no significant differences in yield of Swiss chard in relation to catchment areas of 3 and 2 m respectively. However, significant differences in plant height, plant vigour, number of leaves and chlorophyll contents were obtained under different IRWH techniques. Significantly, highest average plant height of 40.75 cm was obtained in IRWH+Mulch compared to Rainfed with the lowest average 28.50 cm at Syferkuil. A similar trend was obtained at Apel. There were significant differences in number of leaves under IRWH techniques; the highest mean of 16.00 was obtained in the control (farmers practice) treatment, while the lowest mean of 9.00 was obtained in IRWH treatment at Apel. At Syferkuil, significantly highest average number of leaves was obtained in the IRWH+Mulch+irrigation treatment, while the lowest average number of leaves was obtained in the rainfed treatment. Regarding the yield of Swiss chard, the significantly highest average yield was obtained under IRWH+Mulch+irrigation and 3 m catchment treatment combination which was 84.86 t ha^{-1} compared to 20.66 t ha^{-1} in rainfed and 3 m catchment treatment combination at Syferkuil. Similar trend was found at Apel with the highest average yield recorded in IRWH+Mulch+irrigation treatment combination. Hence, IRWH technique with mulch and irrigation could be adopted by growers in a water-scarce environment like the Limpopo Province of South Africa.

Keywords: Catchment areas, Mulch, Irrigation, IRWH techniques

DEDICATION

I dedicate this work to my late father, Samuel Hlengani Maluleka.

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CHAPTER 1

INTRODUCTION

1.1 Background

The South African government is confronted with the challenge of feeding and empowering a large section of the populace where the majority lives in rural areas and practices dry-land agriculture (Kahinda *et al*., 2008). South Africa is a water scarce country with an average annual rainfall of 500 mm (60 percent of the world average). Only a narrow region along the south eastern coastline receives good rainfall, while the greater part of the interior and western part of the country is arid or semi-arid (DWA, 1994).

To improve the reliability of rural water supply and the productivity of small-scale rainfed agriculture, South Africa needs to further investigate unconventional water sources such as the infield rainwater harvesting technique (Worku, 2006). Crop production in South Africa is predominantly under rainfed conditions due to the large number of small scale farmers, most of which is demoted by water stress. The optimum utilisation of rainwater is therefore of utmost importance. The challenge, for researchers is finding ways to reduce unproductive water losses especially through soil evaporation and runoff from the soil surface, and optimise rainwater productivity (Nhlabatsi, 2010).

The revelations of the RWH studies are that, crop production systems employing rainwater harvesting have been shown by many researchers and workers in Africa to result in significant crop yield increases (Mwakalila and Hatibu, 1993; Kronen, 1994; Gicheru *et al.,* 1998; Ojasvi *et al.,* 1999). A technique that has given good results in semi arid areas of South Africa is in-field rainwater harvesting as described by (Hensley *et al*., 2000). The technique is also known as mini catchment runoff farming (Owesis *et al*., 1999). This technique led to maize yield increases of between 25% and 50%, compared to conventional tillage in semi arid areas on crusting clay and duplex soils that have high water storage capacity (Botha *et al.,* 2003; Botha, 2007).

The study will focus on infield rainwater harvesting technique (IRWH), in which the basic structure comprises of a (2 m) runoff strip along the slope of the field (catchment area) and (1 m) basin storage area across the slope of field at the end of the runoff strip (figure 1) (Hensley *et al.,* 2000), practiced on agronomic crops such as maize and sunflower. IRWH techniques have not yet been tested on horticultural crops. Botha (2007), however, stated that the basic structure of the IRWH system can be altered by the use of different mulches in the basin and runoff area, the mulch can be organic (crop residue or grass) or inorganic (rocks) and is applied either in the basins or the runoff surface.

The IRWH structure developed by Hensely *et al.,* (2000) could be different in terms of catchment areas for vegetables such as Swiss chard. Swiss chard (*Beta vulgaris* L.cicla) also known as spinach beet, is a biennial but is grown as an annual. Spinach beet has high soil moisture requirements and is grown mainly under drip irrigation. This means that findings obtained from previous literature about IRWH, could differ from those of spinach beet as it is high water demanding (Hemy and Kochlar, 1984). The study will be conducted at two different sites which are research managed (Syferkuil) and farmer-managed (Apel).

1.2 Problem statement.

South Africa is recognised as a water scarce country in terms of the commonly used definition, namely that of the average total actual renewable water resources (TARWR) per person per year. Using this definition, South Africa is the 29th driest country out of 193 countries, with an estimated 1110 cubic metres (m^3) of water per person in 2005 (UNESCO-WWAP, 2006). Water scarcity affects rainfed crop production and directly threatens the livelihood of millions of people, particularly in the developing countries and especially Sub-Saharan Africa. The possible solution is to store water on small-scale for irrigation purposes during periods of water shortages. Therefore, it is important to revive some of the traditional practices such as rainwater harvesting systems, so that all water can be used for vegetable production. The researcher proposes to use infield rainwater harvesting and mulching as moisture conservation strategies for improved vegetable crop production in Limpopo Province.

1.3 Motivation of the study

It is well documented that low and erratic rainfall in the arid and semi-arid regions of South Africa, such as the Limpopo Province, results in soil water deficits at some critical stages of crop growth (Worku, 2006). This contributes to low crop yields and sometimes total crop failure with no yield. Crop variety selection and plant breeding alone are unsuccessful strategies to achieve optimum crop production and sustainability. Vegetables in particular, have high water demand and therefore suffer considerably from moisture stress. It is therefore necessary to seek for suitable water conservation techniques such as infield rainwater harvesting and mulching, which could combat the soil water shortages and improve crop production (Hlanganise, 2010).

1.4 Purpose of the study

1.4.1 Aim

The aim of the study was to evaluate yield responses of Swiss chard under infield rainwater harvesting techniques using different catchment areas (1 m and 2 m with and without mulch).

1.4.2 Objectives

The specific objectives of the study were to:

- To asses growth and yield responses of Swiss chard to infield rainwater harvesting techniques.
- To determine the effectiveness of different catchment areas (2 m, 3 m with and without mulch) on yield of Swiss chard.

1.5 Hypotheses

- Infield rainwater harvesting techniques have no positive impact on growth and yield responses of Swiss chard.
- There is no difference in yield responses of Swiss chard under different catchment areas (2 m, 3 m with and without mulch).

CHAPTER 2

LITERATURE REVIEW

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2.1 Early history of rainwater harvesting in the North and South of Africa

2.1.1 Africa north of equator

Rainwater harvesting and irrigation in the history of Africa, this practice is almost inseparable from the discourse on the origins of various types of farming, especially crop cultivation and stock farming. Crop cultivation that proliferated and spread along the Mediterranean fringes of North Africa consisted of largely wheat cereals and barely which were imported originally from Egypt and Western Asia. In and around these areas, rainwater harvesting during various seasons was already evident and was one of the few practices of the ancient civilization. At times cereal crops were irrigated with stored water (Denison and Wotshela, 2009).

2.1.2 Africa South of equator

Historical literature offers another dimension regarding utilization of natural resources and rainfall variables south of the equator. It emphasizes that people in this area remained primarily hunter-gatherers until the introduction of iron about two thousand years. Critically, from its earliest stages, Iron Age gave birth to and consolidated the farming economy. Farming became mixed, emphasizing variety of crops (sorghum, millets, pumpkin, melon and beans) which predominantly relies on rainwater for proper growth. During the first few centuries of their expansions, Bantu Iron Age farmers moved onto regions only thinly populated by small roving bands of Stone Age hunter gatherers in the present South Africa (Denison and Wotshela, 2009).

2.2 Description of rainwater harvesting technology

Rainwater harvesting is an old-age practice used in water scarce rainfed crop production areas (Qadir *et al*., 2007). It was practiced to supplement additional water for crops with insufficient amounts of rainfall for optimum yield production. It involves collecting rainwater from an area which is not in use and directs it to an area used for production, to an area where in most cases a crop is grown (Worku, 2006). Boers and Ben-Asher (1982) reviewed a number of publications on rainwater harvesting and tried to establish a common definition. They defined it as a method to induce, collect, store, and conserve local surface runoff for agriculture in arid and semi-arid regions. According to, Oweis and Hachum (2006) it is the process of concentrating precipitation through runoff and storing it for beneficial use. But, rainwater harvesting was found to be useful in all areas where rainfed agriculture is practiced and where critical water shortage is prevalent during the critical growing stages of crops.

2.2.1 Infield rainwater harvesting

Rainwater harvesting can be done in a number of ways. Alem (1996) described the following water harvesting techniques: Run off and flood farming, ponds, dug wells, roof top, in-situ soil moisture conversation and infield rainwater harvesting. This study was based on infield rainwater harvesting at different catchment areas and using a horticultural crop Swiss chard. The practice is considered a better alternative as compared to other rainwater harvesting techniques as it is cheaper to construct and it reduces runoff water to zero. Recent studies carried out on infield rainwater harvesting in South Africa, showed increased yields for maize, sunflower and sorghum (Hensley *et al*., 2000 and Botha *et al*., 2003). The system also increased crop water productive function and rain water productivity significantly compared to the conventional cultivation practice. Infield rain water harvesting reduces runoff to zero and evaporation from soil surface to some degree. This improves the soil water to be available for transpiration in the semi-arid areas where there is a deficit of rainwater. According to Hensley *et al*. (2000), infield rain water harvesting not only reduces runoff to zero, but also adds twice the total rainfall amount to the basin if infiltration of the runoff strip is assumed zero. In this system, the crop root zone is located in the premises of the basin where runoff is stored in. Therefore, infield rain water harvesting could be used as one of the best practices to improve rain water productivity and boast crop production in semi-arid regions (Worku, 2006).

In a decade the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-ISCW) of South Africa has been developing an infield rainwater harvesting technique for communal farmers with the objective of harnessing rainwater for crop production. It has been shown that the technique resulted in a significant increase in crop yield compared with conventional practices (Hensley *et al*., 2000). Further research conducted mainly in the Free State has shown that, on average, infield rainwater harvesting technology increased crop yields by about a third when compared to the use of conventional tillage techniques. Long-term infield rainwater harvesting production can be improved even more by adding various combinations of mulches on the runoff and basin areas of the field (Botha *et al.,* 2003). Profitability analyses using enterprise budgets show that farmers who adopt even the simplest form of infield rainwater harvesting compared to conventional crop cultivation could increase their income by about R800 per hectare in the case of maize production (WRC, 2000).

Studies have shown that, although shortage of rainfall is an important factor, the most critical problem in semi-arid areas is often the inter and intra seasonal variability (Barron *et al.*, 2003). Thus, poor smallholder producers of crops and livestock in the semi-arid areas of Africa face frequent food shortages and threats to their livelihood caused by droughts or floods. Therefore, the detrimental consequences of both floods and droughts can be exacerbated by poor management of valuable rainwater. The practice is currently spreading in rural South Africa, especially with the financial assistance provided by the Department of Water Affairs (DWA) to resource poor households or an alternative to the capital cost of rainwater storage tanks and related works. It has been proven that infield rainwater harvesting technique will be suitable for application in semi-arid areas of South Africa (Baiphethi *et al.,* 2004 and Kundhlande *et al*., 2004) and contribute to household food security and poverty alleviation.

2.2.2 Characteristics of rainwater harvesting

Rainwater harvesting systems have the following characteristics: they are practiced in arid and semi-arid regions such as regions of South Africa where surface runoff often has an irregular character; it is based on the utilization of runoff and requires a runoff producing area and a runoff receiving area; because of the irregular nature of runoff events, water storage is an integral part of the system and it can be done directly in the soil profile or in small reservoirs, tanks and aquifers (Ibraimo and Munguambe, 2007).

2.2.3 The role and function of the Run-off area

The runoff area has two major functions in the IRWH technique. Firstly, it promotes infield runoff and secondly it acts as a secondary storage medium for water (Kundhlande *et al.,* 2004). Hensley *et al.* (2000) started with preliminary trials to investigate infield runoff. They measured infield runoff from 2 m untilled runoff strips located on the Glen/Bonheim and Glen/Swartland ecotopes for a short period of time. They found infield runoff to be 30% and 35% of the mean annual rainfall, respectively (Joseph *et al*., 2011).

2.2.4 The role and function of the Run-on area (basin)

The runon area has three functions, namely, to (i) stop infield runoff completely, (ii) maximise infiltration and (iii) store harvested water in the soil profile (Kundhlande *et al.,* 2004). The stoppage of runoff from the 2 m runoff area is a very essential characteristic which directly explains the potential yield advantages that could be obtained from the IRWH technique in comparison to conventional tillage (CT). Ex-field runoff from the crop field under CT is one of the major processes responsible for unproductive water losses in crop production (Joseph *et al*., 2011). The basin area of 1 m^2 in the IRWH technique developed by Hensley *et al.* (2000), acts as a surface storage medium where the loss can be converted into gain. The water is temporarily stored in the runon area until the infiltration process is completed. The infiltration rate depends on the soil surface conditions of the basin area as well as internal drainage characteristics of the soil profile (Joseph *et al*., 2011).

2.3 Benefits of water harvesting technology

Better utilization of rainfall through rainwater harvesting can greatly increase agricultural productivity, improve food security and alleviate poverty (Hlanganise, 2010). Fox and Rockstrom (2000) investigated the effect of rainwater for supplementary irrigation of cereal crops to overcome intra-seasonal dry-spells in the Sahel. Their on-farm study demonstrated that supplementary irrigation during dry-spells increased sorghum yield by 14 percent. Reports based on farmer's opinions showed that application of water and soil conservation in the central plateau, Burkina Faso, has rehabilitated degraded land and increased yields of cereals such as sorghum and millet, thus improving food security and household wealth.

Botha *et al.,* 2005 evaluated the agronomic sustainability of the infield rainwater harvesting technique in South Africa. They concluded that infield rainwater harvesting techniques contributed to higher crop yields than normal conventional tillage because it stops runoff and minimizes soil evaporation losses. Pretty *et al*. (2003) examined the extent to which farmers have improved food production with low cost, locally available and environmentally practices. In their study, 208 projects in 52 developing countries selected from Africa, Asia and Latin America showed improvements in water productivity, improvements in soil properties and pest control. Some studies have not found significant benefits resulting from some of the rainwater harvesting practices. Hatibu *et al.* (2002) investigated the effects of modified cropping system for maize, which aimed to reduce drought risk through rainwater harvesting. Macro-catchment rainwater harvesting resulted in more benefits compared to cultivation without rainwater conservation techniques. Besides improving agricultural productivity, rainwater harvesting is associated with other environmental (reduced soil erosion) and social benefits (creation of job opportunities) and it is easy to put into practice (Hatibu *et al*., 2002).

2.4 Mulching

Rainwater harvesting techniques such as IRWH can be incorporated or supplemented by the use of different mulching materials. Mulch is simply a protective layer of a material that is spread on top of the soil. Mulches can either be organic such as grass clippings, straw, bark chips, and similar materials or inorganic such as stones, brick chips, and plastic. Both organic and inorganic mulches have numerous benefits such as protecting the soil from erosion, reducing compaction from the impact of heavy rains, conserving moisture, reducing the need for frequent watering, maintaining a more even soil temperature and preventing weed growth (Li *et al*., 2000). A study conducted by Hensley *et al.* (2000) on Glen Swartland and Glen-Bonheim soils, showed the advantage obtained by applying mulch on infield rain water harvesting system. They showed an increase of maize grain yield of 10 percent and 76 percent during the 1998 and 1999 cropping seasons respectively compared to the non–mulched basin treatment of infield rain water harvesting. Similarly Botha *et al*. (2003) showed that infield rainwater harvesting when combined with different mulch materials improved transpiration and reduced evaporation from the soil surface (Worku, 2006).

2.5 Crop background

Swiss chard, *Beta vulgaris* (L.cicla) also known as spinach beet, is a biennial but it is grown as an annual. It is commonly, but incorrectly, called spinach, and is a very close relative to beetroot. It belongs to the Chenopodiaceae family. Swiss chard thrives in a comparatively cool climate and does best at a temperature range of 7°C to 24°C. Swiss chard can be grown on a wide variety of soil types, provided they are well-drained, free of root knot nematodes, reasonably fertile and amply supplied with water. The main variety of Swiss chard that is available is Fordhook Giant. Fordhook Giant has darker green leaves and broader leaf stems than Lucullus, which is less popular (KZN DAEA, 2001).

2.6 Soil physical properties and crop growth

A productive soil is one which has attributes that promote root growth, accept, hold and supplies water and mineral nutrients, promotes gaseous exchange and biological activity (Mupambwa, 2012). All these attributes are in part, intimately related to soil physical properties (Schoenholtz *et al*., 2000). Optimum plant growth depends as much on a favorable soil physical environment as it does on fertility. Physical properties of a soil control the supply of water, air and nutrients to the plant roots and also modify the environment in which roots grow and function. Furthermore, the physical properties of a soil which have the greatest influence on crop growth are those associated with soil structure (Kutilek, 2004).

2.6.1 Aggregate stability

Aggregate stability is a relative term used to describe the resistance of a soil's structure to destructive forces such as dispersion, raindrop impact and slaking (Le Bissonais, 1996; Six *et al*., 2000). A soil is classified as having a good structure if it is aggregated and stable. Poorly structured soils are characterized by reduced infiltration, increased bulk density and low water retention capacity mainly due to aggregate breakdown upon wetting. Aggregation is a result of the rearrangement, flocculation and cementation of soil particles mediated by SOM (Bronick and Lal, 2005.) A good soil structure is important for maintaining favorable soil physical conditions for plant growth (Krzic, 1997). Unlike other soil physical properties, soil structure is the most dynamic property and is expressed as aggregate stability (Mupambwa, 2012).

2.6.2 Bulk density (ρb)

Soil bulk density (ρb) is defined as a ratio of dry mass to the total volume of soil (solids plus pore space). Bulk density is intimately related to soil porosity, which is the volume of space within a soil filled with air and water (Mupambwa, 2012). Due to its effect on soil aeration, soil water, compaction and temperature, bulk density indirectly influences crop growth. The optimum bulk density for plant growth is different for each soil and crop type. However, generally low ρb leads to poor root-soil contact whilst high ρb reduces aeration and increases compaction (Lampurlanes and Cantero-Martinez, 2003).

2.6.3 Infiltration rate

Infiltration is defined as the movement of water down the soil profile per unit time under gravitational pull (Verhulst *et al*., 2010). The major soil characteristics affecting infiltration are texture, porosity, structural stability and SOM (Bhattacharyya *et al*., 2006; Nyamadzawo *et al*., 2007). Soil structural stability is largely influenced by SOM and fungal mycelia formed during decomposition of organic residues (Lado *et al*., 2008). Therefore, increasing soil organic matter accumulation on the soil surface helps to prevent soil structural degradation like crusting which inhibits infiltration (Nyamadzawo *et al*., 2007). An integration of CA with cover cropping is proposed as a way of increasing SOM, reducing soil disturbance which leads to improved aggregate stability (Six *et al*., 2000). An improved soil structure increases infiltration rate and reduces runoff thereby making more water available for plant growth (Thierfelder and Wall, 2009).

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Description of experimental study sites.

The study was conducted under dryland conditions at two different locations in the Limpopo Province, which are: Capricorn and Sekhukhune districts. In the Capricorn district the study was conducted at the University of Limpopo Experimental Farm (Syferkuil), while for Sekhukhune district it was at Apel (Mphebatho co-operative). Both districts experience summer rainfall.

Syferkuil is located at a longitude of 29°44’15’’E and latitude of 23°53’10’’S (Ramagoshi *et al.,* 2015). It has a mean annual rainfall of 452 mm which reaches its peak during March and daily temperatures of 28°C. Syferkuil is characterized by hot summers (27°C - 30°C) and cool winters (5°C - 17°C).

Apel is located at a longitude of 29°46’26.54’’E and latitude of 24°25’59.25’’S. It is characterized by hot summers with average temperatures of 18°C - 28°C, and cool dry winter with average temperatures of 7°C - 20°C (Greater Sekhukhune District Municipality, 2008). Apel has a mean annual rainfall of about 500 - 600 mm which reaches its peak during March.

The rainfall data from the beginning of the experiment (22 January 2015) until the end of the experiment (23 April 2015) were obtained from an Automatic Weather Station at the University of Limpopo experimental farm, while at Apel, a rain gauge was used to collect the amount of rainfall from the beginning of the experiment (30 January 2015) until the end of the experiment (29 April 2015). Rainfall and temperature recorded are shown in Tables 1 and 2.

Table 1: Mean monthly temperatures, relative evapotranspiration and rainfall at Syferkuil during 2015 growing season

Year	Month	Average maximum temp. °C	Average minimum temp. °C	Total relative evapotranspiration mm	Total rainfall mm
2015	January	33.5	11.4	148.9	43.7
	February	34.2	10.3	140.0	24.1
	March	33.0	8.1	135.0	15.0
	April	29.4	8.3	98.6	81.3
Total				622.3	164.3

Source : University of Limpopo experimental station records.

Table 2: Mean monthly temperatures, relative evapotranspiration and rainfall at Apel during 2015 growing season

Year	Month	Average maximum temp. °C	Average minimum temp. °C	Total relative evapotranspiration mm	Total rainfall mm
2015	January	36.8	10.5	152.9	95.1
	February	32.10	10.4	150.0	26.3
	March	30.5	9.1	138.1	23.8
	April	26.5	7.3	85.6	25.0
Total				526.6	170.2

Source: ARC weather data, Pretoria

3.2 Experimental design, treatments and procedures.

The experiment was laid out in a 576 m^2 total area, the plot size was 2 m x 3 m (for catchment area of 3 m), and 2 m x 2 m for catchment area of 2 m. Around 1 m^2 basin for water storage, the intra-row spacing was 20 cm for infield rainwater harvesting, infield rainwater harvesting with mulch, and infield rainwater harvesting with mulch and irrigation treatments and for 2 m main plot, rainfed and control (both without catchment areas) plots was 50 cm inter-row spacing by 30 cm intra-row spacing. Similarly, for 3 m main plot, rainfed and control plots were 50 cm intrer-row spacing and 30 cm intra-row spacing. There was 2 m spacing between the blocks and 1.5 m between the plots.

The experiment was arranged in 2 x 5 split-plot design arranged using randomised complete block design (RCBD), where the main plot was the two catchment areas (2 m (1 m runoff strip plus 1 m basin)) and (3 m (2 m runoff strip plus 1 m basin)), while the subplots were the five rainwater harvesting techniques (treatments), each treatment was replicated 4 times.

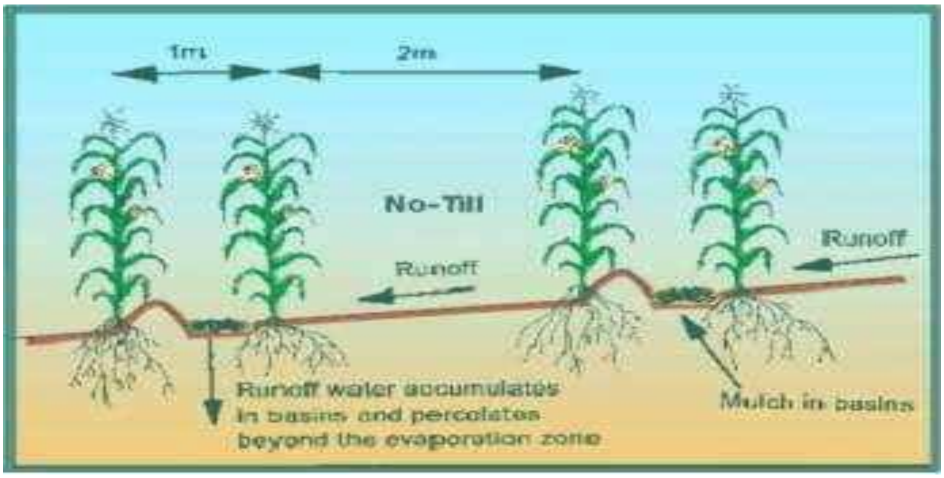

Figure 1: In-field rainwater harvesting basic structure (Hensley *et al*., 2000)

The main plots were:

a) 2 m catchment area
b) 3 m catchment area

The treatments were:

I. Control farmers practice (rainfed and irrigation)
II. Rainfed without catchment area and mulch (flood)
III. Infield rainwater harvesting (with catchment areas)
IV. Infield rainwater harvesting and mulch (with catchment areas)
V. Infield rainwater harvesting, mulch and irrigation (with catchment areas)

Weeds were controlled by hand weeding for all the treatments.

Irrigation

The soil water content up to a depth of 40 cm was frequently checked using the gravimetric method, and when irrigation was required 25 mm was applied which is equivalent to 25 ℓ / m^2 therefore i measured the time it takes to get 25 ℓ of water from the hose pipe. Before each irrigation the flow rate was determined in ℓ / min. This was done by measuring the time it takes to fill 5 x 20 ℓ containers (treatment v).

Flow rate determination

100 ℓ ⟶ 322 s

25 ℓ ⟶ x

$$X = \frac{332 \text{ s}}{4}$$

X= 80.5 s

X= 1' 21'' (at this time irrigation was stopped and 25 ℓ of water has been applied, however this was different depending on the flow rate of water from the hose pipe).

Table 3: Amount of supplementary irrigation (Syferkuil and Apel) during 2015 growing season

Weeks after transplanting	IRWH techniques on catchment area of 2 m and 3 m	Amount of irrigation water (ℓ)
0 and 1 WAT	IRWH + Mulch	400
	IRWH + Mulch + Irrigation	400
	IRWH	400
	Control	400
	Rainfed	400
3 WAT	IRWH + Mulch + Irrigation	200
	Control	200
5 WAT	IRWH + Mulch + Irrigation	200
	Control	200
7 WAT	IRWH + Mulch + Irrigation	200
	Control	200
9 WAT	IRWH + Mulch + Irrigation	200
	Control	200

Mulching

About 0.2 kg of wheat straw mulch (2 cm thickness) was applied inside $1m^2$ basin.

Soil physical properties

Soil bulk density was determined using soil cores at the depth of 0-5 cm and 5-30 cm respectively. The soil was then transferred to plastics bags and then into the beakers at the laboratory, the weight of the beakers was recorded as W_b and then the contents was oven dried at 60°C for 24 hours and the dry weight of the contents was recorded as W_d and divided by the volume of the cores then the bulk density was determined (Bronick and Lal, 2005)..

$$\text{Bulk density (Db)} = \frac{W_d - W_b}{V/\text{core}}$$

Soil moisture was determined prior to transplanting during the trial and at the final harvest per plot. Samples were taken at 3 depths of 0 – 20, 20- 40, and 40- 60 cm using a soil auger. Gravimetric analytical procedure was followed to determine the moisture content of the soil.

Where M_w= Mass of fresh soil

M_d= Mass of dry soil

$$\text{Gravimetric } _{Øg}\ (\%) = \frac{M_w - M_d}{M_d} \times 100$$

Volumetric water analysis was determined from the results obtained from the gravimetric analysis and bulk density for each treatment.

Where (Øg) = Gravimetric(soil moisture content)

Db (g/cm3) = Bulk density

$$\text{Volumetric water} = (Øg) \times Db\ (g/cm^3)$$

Infiltration rate

Infiltrometers were used to determine the infiltration rate per treatment at the beginning and the end of the experiment (Figure 2).

Figure 2: Infiltration rate determination.

Aggregate stability

Initial and final soil samples were taken (in between the plots) using a spade and transferred into plastic bags. At the laboratory, the samples were air dried and giggets clods were fragmented by hand, and then sieved in order to retain the aggregates between 3.15 mm and 5 mm (5 and 3.15 mm) (Figure 3). A minimum of 45 g aggregates was oven dried at 40°C for 24 hours before the test.

Water treatment was recommended for the test, depending on the type of rain each area received (drizzling), according to Le Bissonnais, 1996.

About 6 g of aggregates were weighed in 3 – 5 mm cupels and then the initial weight of aggregates and cupels was noted, before the aggregates were transferred in glass cupels (using three (3) replications per treatment).

<u>Aggregate stability calculation</u>

$$MWD=\frac{(3.5*a)+(1.25*a)+(0.4*a)+(0.09*a)+(0.08*a)}{100}$$

a = means of aggregates as percentage per sieve (using the mean intensive size (mm))

MWD = mean weight diameter

Figure 3: Aggregate stability determination.

Seedling transplanting

Swiss chard (Ford Hook Giant) 3 weeks old seedlings were hardened off and then transplanted at a depth of 3 – 4 cm by hand on the 22 January 2015 at Syferkuil and on the 30 January 2015 at Apel. There was no fertilizer application in the experiment. Weeding was done by means of hoeing three times (two, four and seven weeks after transplanting). Irrigation was done by sprinkler irrigation system during the first week after transplanting for quick crop establishment. From the second week after transplanting up until final harvest, irrigation (quantified) was applied only once a week using a hosepipe and only 25 litres per m^2 of water was applied for Control (rain and irrigation) and IRWH+ Mulch+ Irrigation treatments. About 0.2 kg of wheat straw mulch (2 cm thickness) was applied inside each $1m^2$ basin, for relevant treatments.

3.3 Data collection

Numbers of leaves were counted at 8, 10, and 12 weeks after transplanting, for each data plant. Plant height was measured using a meter ruler at 8, 10 and 12 WAT from two selected data plants. Chlorophyll content was measured using a chlorophyll meter by selecting a fully matured leaf during sunny days from 9h00 to 12h00 pm at 8, 10 and 12 WAT from two selected data plants (Figure 4).

Figure 4: Chlorophyll meter (optic-science CCM) measuring chlorophyll content.

Plant vigour was determined using a green seeker device (handheld optical-plant sensor) the sensor displays the measured value in terms of NDVI (normalised difference vegetation index) reading on its LCD display screen, NDVI value range from 0.00 to 0.99, the higher the reading, the healthier the plant at 8, 10 and 12 WAT. Fresh leaves of data plants were weighed using a weighing balance, and then oven dried at 60°C until they were completely dry and then dry weight was recorded.

Yield: this was determined using the biomass data (fresh leaves weight per plant at 12 WAT and final stand establishment).

3.4 Data analysis

Data collected were subjected to analysis of variance (ANOVA) using General Linear Model (GLM) procedures of Statistics 10.0. Means were separated using LSD at $P \leq 0.05$.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Effect of IRWH techniques on growth of Swiss chard, under different catchment areas.

The IRWH techniques influenced the growth of Swiss chard under different catchment areas. The interactions between the IRWH techniques and catchment areas were found to be significant ($P \leq 0.05$) at both sites (Apel and Syferkuil) with regards to plant height (Tables 4 and 5). The significantly highest mean height value at 12 WAT (28.00 cm) was obtained in IRWH+Mulch+Irrigation treatment under 3 m catchment area, while 27.25 cm was recorded in the same treatment under 3 m catchment area and the least significant values of 15.94 cm and 16.13 cm under 3 m and 2 m catchment area, respectively, were obtained under rainfed treatment at Apel (Table 4). The trend was slightly different for Syferkuil, the significantly highest mean height of Swiss chard at 12 WAT (40.75 cm) was obtained in IRWH+Mulch treatment under 3 m catchment area, 38.63 cm the highest mean height found in the control treatment under 2 m catchment area while the least values were obtained under rainfed treatment 28.50 cm under 2 m catchment area and 29.38 cm under 3 m catchment area (Table 5). Thus, rainfed production of Swiss chard, limits growth of the crop, whereas IRWH with mulch with or without irrigation led to increased height. This agreed with previous findings by Everson *et al.* (2011), who reported that for both cabbage and Chinese cabbage leaf number and plant height were improved by all rainwater harvesting techniques.

Comparing the catchment areas in relation to Swiss chard plant height there were no significant differences (Appendix 1). In terms of the IRWH techniques, significant differences in Swiss chard height were obtained in plant grown under the rainfed treatment which had the lowest average height at 8 and 10 WAT for Apel (Table 6). At Syferkuil however, the trend was slightly different (Table 7). The significantly highest Swiss chard height at 12 WAT for both sites (27.63 cm) and (37.56 cm) for Apel and Syferkuil respectively were obtained in IRWH+mulch+irrigation while the lowest average height values were obtained in the rainfed treatment. This finding is in agreement with Ibraimo (2011) who observed that maize plant height improved under the different in-field rainwater harvesting treatments.

Regarding the number of leaves produced by Swiss chard, similar significant interactions were found between IRWH techniques and catchment areas at both sites

(Tables 8 and 9). The differences obtained in the catchment areas in relation to number of leaves produced by Swiss chard at both sites were not significant (Appendix 2). While comparing the IRWH techniques, the significantly highest average number of leaves at 8 and 10 WAT were obtained in the control (10.94 and 9.81) respectively at Apel, while rainfed treatment had the least values of 6.69 at 10 WAT (Table 10). The trend obtained at Syferkuil was slightly different, even though Swiss chard grown under the rainfed condition had the least significant average number of leaves (9.88) at 8 WAT compared to 14.81 recorded under IRWH+Mulch+Irrigation treatment (Table 11). Hence at Syferkuil, Swiss chard leave production under IRWH+Mulch+Irrigation treatment was better when compared with the rainfed. The results at Syferkuil are in line with the findings of Everson *et al*. (2011), who reported that for both cabbage and Chinese cabbage leaf number and plant height was improved by all rainwater harvesting techniques.

Table 4: Interactive effect of IRWH techniques and catchment areas on plant height (cm) of Swiss chard grown at Apel

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	15.38bc	18.75ab	20.63ab
2	Rainfed	10.38abc	14.38ab	16.13abc
2	IRWH	15.75bc	20.00ab	20.00ab
2	IRWH+mulch	16.50c	20.63a	23.80ab
2	IRWH+mulch+Irrigation	17.75c	22.00a	27.25a
Mean		15.15	19.15	21.56ab
3	Control (farmers practice)	15.75bc	19.25ab	21.88ab
3	Rainfed	13.00abc	15.00ab	15.94abc
3	IRWH	16.63c	21.75a	20.25ab
3	IRWH+mulch	17.38c	22.00a	26.25a
3	IRWH+mulch+Irrigation	15.88bc	20.63ab	28.00a
Mean		15.73	19.73	22.46
CV (%)		16.14	20.11	16.01
SE		1.70	2.76	2.4
Catchment area* IRWH technique		3.66	5.70	5.14

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$.

Table 5: Interactive effect of IRWH techniques and catchment areas on plant height (cm) of Swiss chard grown at Syferkuil

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	26.63a	32.63abc	38.63a
2	Rainfed	20.13b	24.88d	28.50bcd
2	IRWH	23.38ab	28.38bcd	33.63ab
2	IRWH+mulch	23.75ab	27.88cd	33.63ab
2	IRWH+mulch+Irrigation	26.25a	30.75abc	35.25ab
Mean		24.03	28.90	33.93
3	Control (farmers practice)	23.13ab	30.25ab	36.50ab
3	Rainfed	21.75ab	28.13bcd	29.38cd
3	IRWH	20.00b	23.88d	34.38ab
3	IRWH+mulch	26.85a	33.25ab	40.75a
3	IRWH+mulch+Irrigation	24.75ab	35.50a	39.88a
Mean		23.30	30.20	36.18
CV (%)		15.37	12.57	10.63
SE		2.57	2.63	2.64
Catchment area* IRWH technique		5.30	5.42	5.44

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. The homogeneous group format can't be used because of the pattern of significant differences.

Table 6: Effect of IRWH techniques and catchment areas on plant height (cm) of Swiss chard grown at Apel

Treatments	Weeks after transplanting

	8	10	12
Catchment area (m)			
2	15.15a	19.15a	21.58a
3	15.73a	19.73a	22.46a
Mean	15.44	19.44	22.02
CV (%)	37.17	26.27	29.87
SE	1.81	1.61	1.76
IRWH technique			
Control (farmers practice)	15.56a	19.00a	21.25b
Rainfed	11.69b	14.69b	16.03c
IRWH	16.19a	20.88a	20.13b
IRWH+mulch	16.94a	21.31a	25.06a
IRWH+mulch+Irrigation	16.98a	21.31a	27.63a
Mean	15.44	19.44	22.02
CV (%)	16.14	20.11	16.01
SE	1.25	1.95	1.76
IRWH technique	2.57	4.03	3.64

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 7: Effect of IRWH techniques and catchment areas on plant height (cm) of Swiss chard grown at Syferkuil

Treatments	Weeks after transplanting		
	8	10	12

Catchment area (m)			
2	23.30a	28.90a	33.93a
3	24.03a	30.20a	36.18a
Mean	23.67	29.55	35.06
CV (%)	14.46	5.44	11.93
SE	1.08	0.51	1.32
IRWH technique			
Control (farmers practice)	24.88ab	31.44a	37.56a
Rainfed	20.94c	26.50b	31.44b
IRWH	21.69bc	26.13b	31.50b
IRWH+mulch	25.31ab	30.56a	37.17a
IRWH+mulch+Irrigation	25.50a	33.13a	37.56a
Mean	23.66	29.55	35.05
CV (%)	15.37	12.57	10.65
SE	1.82	1.86	1.87
IRWH technique	3.73	3.83	3.85

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 8: Interactive effect of IRWH techniques and catchment areas on number of leaves of Swiss chard grown at Apel

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12

2	Control (farmers practice)	10.00ab	10.00abc	16.00ab
2	Rainfed	9.00ab	7.00cd	11.00ab
2	IRWH	9.00ab	11.00a	13.00ab
2	IRWH+mulch	9.00ab	8.00bcd	14.00ab
2	IRWH+mulch+Irrigation	8.00b	8.00abcd	12.00ab
Mean		9.00	8.80	13.20
3	Control (farmers practice)	11.00a	10.00ab	14.00ab
3	Rainfed	8.00b	7.00d	11.00ab
3	IRWH	8.00b	8.00abcd	9.00b
3	IRWH+mulch	9.00ab	9.00abcd	12.00ab
3	IRWH+mulch+Irrigation	8.00b	10.00ab	16.00a
Mean		9.00	9.00	13.00
CV (%)		22.54	25.36	29.96
SE		1.45	1.54	2.68
Catchment areas x IRWH techniques		2.99	3.00	5.53

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 9: Interactive effect of IRWH techniques and catchment areas on number of leaves of Swiss chard grown at Syferkuil

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	13.00bc	12.00c	15.00ab

2	Rainfed	9.00d	9.00d	9.00b
2	IRWH	11.00cd	14.00bc	9.00b
2	IRWH+mulch	12.00c	13.00bc	13.00ab
2	IRWH+mulch+Irrigation	13.00bc	13.00bc	13.00ab
Mean		12.00	12.00	12.00
3	Control (farmers practice)	16.00ab	16.00ab	14.00ab
3	Rainfed	9.00d	13.00bc	11.00bc
3	IRWH	13.00bc	15.00ab	10.00b
3	IRWH+mulch	13.00bc	15.00ab	13.00ab
3	IRWH+mulch+Irrigation	17.00a	17.00a	18.00a
Mean		14.00	15.00	13.00
CV (%)		16.89	22.02	40.55
SE		1.50	2.17	3.61
Catchment areas x IRWH techniques		3.12	4.47	7.45

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 10: Effect of IRWH techniques and catchment areas on number of leaves of Swiss chard grown at Apel

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	9.20a	8.53a	12.98a

3	9.00a	8.68a	12.35a
Mean	9.00	8.61	12.67
CV (%)	8.75	11.77	34.97
SE	0.25	0.32	1.40
IRWH technique			
Control (farmers practice)	10.94a	9.81a	14.50a
Rainfed	8.31b	6.69b	11.19a
IRWH	8.38b	9.00a	10.61a
IRWH+mulch	9.19ab	8.19ab	12.94a
IRWH+mulch+Irrigation	8.69b	9.31a	14.00a
Mean	9.22	8.60	12.65
CV (%)	22.54	25.36	29.96
SE	1.03	1.09	1.89
IRWH technique	2.12	2.25	NS

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$.

Table 11: Effect of IRWH techniques and catchment areas on number of leaves of Swiss chard grown at Syferkuil

Treatments	Weeks after transplanting		
	8	10	12
Catchment area			
2	12.45a	12.35a	11.88a
3	13.65a	15.50a	13.30a

Mean	13.05	13.93	12.59
CV (%)	14.31	28.20	31.65
SE	0.57	1.24	1.26
IRWH technique			
Control (farmers practice)	14.06ab	14.75a	11.65a
Rainfed	9.88c	14.13a	10.50a
IRWH	11.94bc	13.31a	12.50a
IRWH+mulch	12.31b	13.56a	13.69a
IRWH+mulch+Irrigation	14.81a	13.88a	14.63a
Mean	12.60	13.93	12.59
CV (%)	16.89	22.02	40.55
SE	1.06	1.53	2.55
IRWH technique	2.20	NS	NS

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Similar significant interactions between IRWH techniques and catchment areas were found for Swiss chard chlorophyll contents at both sites. At Apel, the significantly highest average chlorophyll contents of Swiss chard (46.80 CCI) at 8 WAT was obtained in the rainfed treatment under 2 m catchment area, while the least significant value (27.06 CCI) at 8 WAT was obtained under the same catchment area (2 m) under the IRWH treatment. At 12 WAT, the significantly highest average chlorophyll content was obtained in Swiss chard grown under the rainfed condition (47.60 CCI) under 3 m catchment area, while the least value (26.08 CCI) was obtained in IRWH + mulch + irrigation treatment under 2 m catchment area (Table 12). At Syferkuil however, although Swiss chard grown under the rainfed condition and 2 m catchment area had significantly highest chlorophyll contents (34.94 CCI) the least value (22.38 CCI) was obtained at 3 m catchment area and IRWH treatment combination (Table 13). At 12 WAT however, the highest average Swiss chard chlorophyll contents (31.12 CCI) was obtained under 2 m catchment area and IRWH treatment combination and least significant value (19.41 CCI) was found under 3 m catchment area and rainfed treatment combinations.

Comparing the catchment areas, the differences obtained in chlorophyll contents of Swiss chard under different catchment areas and Swiss chard at both sites were not significant (Appendix 3). At Apel, Swiss chard grown under rainfed condition had consistently significantly highest average chlorophyll content at 8 WAT to 10 WAT, while the least values were found in IRWH treatment from (8 to 10 WAT) (Table 14). The trend observed at Syferkuil was not specific, at 12 WAT however, the lowest significant average chlorophyll content of Swiss chard (23.64 CCI) was found in the rainfed and control treatments, while the highest average value (28.03 CCI) was found in IRWH+mulch+irrigation treatments (Table 15).

Table 12: Interactive effect of IRWH techniques and catchment areas on chlorophyll content (CCI) of Swiss chard grown at Apel.

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	31.46b	35.60b	36.78abc
2	Rainfed	46.80a	52.91a	43.30ab
2	IRWH	27.06b	35.54b	29.06c
2	IRWH+mulch	28.61b	54.74a	31.49bc
2	IRWH+mulch+Irrigation	35.04ab	35.00b	26.08c

Mean		33.79	42.36	33.34
3	Control (farmers practice)	29.66b	37.08ab	36.95abc
3	Rainfed	38.53ab	51.71a	47.60a
3	IRWH	29.11b	35.34b	34.26bc
3	IRWH+mulch	39.10ab	45.16ab	36.39abc
3	IRWH+mulch+Irrigation	36.26ab	41.35ab	34.18bc
Mean		34.53	42.13	37.88
CV (%)		30.15	31.56	25.64
SE		7.29	9.42	6.46
Catchment areas x IRWH techniques		15.03	14.23	13.33

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 13: Interactive effect of IRWH techniques and catchment areas on chlorophyll content (CCI) of Swiss chard grown at Syferkuil

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	27.80ab	28.68a	27.15ab
2	Rainfed	34.95a	21.46ab	22.53bc
2	IRWH	27.80ab	16.95b	31.12a
2	IRWH+mulch	33.73a	25.71ab	29.53ab
2	IRWH+mulch+Irrigation	28.49ab	23.49ab	30.13a
Mean		30.43	23.26	28.09

3	Control (farmers practice)	27.20ab	23.49ab	25.66ab
3	Rainfed	23.63bc	24.23ab	19.41c
3	IRWH	22.38bc	23.79ab	24.93bc
3	IRWH+mulch	25.07ab	19.54ab	23.80bc
3	IRWH+mulch+Irrigation	22.59bc	24.56ab	25.11ab
Mean		24.17	23.12	23.78
CV (%)		27.44	33.60	22.97
SE		6.50	4.40	4.10
Catchment areas x IRWH techniques		7.41	9.09	8.47

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 14: Effect of IRWH techniques and catchment areas on chlorophyll content (CCI) of Swiss chard grown at Apel

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	33.79a	42.36a	33.34a
3	34.53a	42.13a	37.88a
Mean	34.16	42.24	35.61
CV (%)	29.56	18.25	20.39
SE	3.19	2.22	2.29
IRWH technique			

Control (farmers practice)	30.56b	36.34b	36.86ab
Rainfed	42.66a	52.31a	35.45a
IRWH	28.09b	35.44b	31.66b
IRWH+mulch	33.86ab	48.95b	33.94b
IRWH+mulch+Irrigation	35.65ab	38.18b	30.13b
Mean	34.16	42.24	33.61
CV	30.15	31.56	25.64
SE	5.15	9.42	6.46
IRWH technique	10.63	13.76	9.42

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$.

Table 15: Effect of IRWH techniques and catchment areas on chlorophyll content (CCI) of Swiss chard grown at Syferkuil

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	26.71a	23.26a	26.75a
3	29.99a	22.14a	23.79a
Mean	27.35	22.70	25.27
CV (%)	16.55	39.50	55.78
SE	1.43	2.81	4.45
IRWH technique			

Control (farmers practice)	25.08a	26.08a	23.64ab
Rainfed	24.09b	22.63ab	23.64ab
IRWH	25.54a	23.64ab	27.30a
IRWH+mulch	25.64a	22.84ab	26.41ab
IRWH+mulch+Irrigation	26.64a	18.30a	28.03a
Mean	25.40	22.70	25.27
CV	33.60	27.44	22.97
SE	4.59	3.11	2.90
IRWH technique	9.48	6.43	5.99

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

There were significant (P ≤ 0.05.) interactions between IRWH techniques and catchment areas in relation to Swiss chard plant vigour at both sites. The significantly highest value of 0.65 NDVI and 0.79 NDVI were obtained in the control (farmers practice) and 3 m catchment treatment combination at 10 and 12 WAT respectively while the least significant values (0.50 NDVI) at 10 WAT and (0.55 NDVI) at 12 WAT were obtained in IRWH+mulch and rainfed respectively at Apel (Table 16). At syferkuil however, the trend was slightly different, the significantly highest average plant vigour (0.79 NDVI) at 10 WAT was obtained in IRWH and 2 m catchment area, while the least significant average plant vigour (0.59 NDVI) at 10 WAT was recorded in the same IRWH technique but under 3 m catchment area (Table 17). Plant vigour is a parameter to measure the healthiness of the plant. According to Ibraimo (2011) the effectiveness of IRWH techniques can be influenced by soil type and structure which contribute greatly to crop growth.

As reported earlier the differences between the catchment areas were not significant even in relation to Swiss chard plant vigour at both sites (Appendix 4). However, Swiss chard plant vigour varied with the IRWH techniques. Similar trend was observed at 12 WAT only that the lowest significant value (0.57 NDVI) was recorded under the rainfed treatment (Table 18). The trend recorded for plant vigour and IRWH techniques at Syferkuil was not significant, even though the highest average plant vigour was recorded in the IRWH treatment with mulch, with or without irrigation that is, 0.69 NDVI at 8 WAT and 0.76 NDVI at 12 WAT (Table 19).

Table 16: Interactive effect of IRWH techniques and catchment areas on plant vigour (NDVI) of Swiss chard grown at Apel

Catchment area	IRWH technique	Weeks after transplanting		
(m)		8	10	12
2	Control (farmers practice)	0.60ab	0.60ab	0.70ab
2	Rainfed	0.61ab	0.54bc	0.60bc
2	IRWH	0.57bc	0.53bc	0.69ab
2	IRWH+mulch	0.55bc	0.57abc	0.63abc
2	IRWH+mulch+Irrigation	0.56bc	0.60ab	0.64abc
Mean		0.58	0.57	0.65
3	Control (farmers practice)	0.67a	0.65a	0.79a
3	Rainfed	0.59abc	0.60ab	0.55c
3	IRWH	0.50c	0.60ab	0.68ab
3	IRWH+mulch	0.54bc	0.50c	0.68ab
3	IRWH+mulch+Irrigation	0.59abc	0.62ab	0.69ab

Mean		0.58	0.59	0.68
CV		11.71	11.64	10.65
SE		0.05	0.05	0.05
Catchment areas x IRWH techniques		0.09	0.10	0.10

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 17: Interactive effect of IRWH techniques and catchment areas on plant vigour (NDVI) of Swiss chard grown at Syferkuil

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	0.60b	0.72ab	0.72a
2	Rainfed	0.66a	0.70ab	0.60ab
2	IRWH	0.64ab	0.79a	0.77a
2	IRWH+mulch	0.67a	0.73a	0.76a
2	IRWH+mulch+Irrigation	0.71a	0.74ab	0.73a
Mean		0.66	0.73	0.73
3	Control (farmers practice)	0.69a	0.72ab	0.69a
3	Rainfed	0.68a	0.69ab	0.65ab
3	IRWH	0.61b	0.59b	0.68a
3	IRWH+mulch	0.71a	0.74b	0.73a
3	IRWH+mulch+Irrigation	0.66a	0.73ab	0.78a
Mean		0.67	0.69	0.68

CV	10.70	10.05	6.76
SE	0.05	0.04	0.04
Catchment areas x IRWH techniques	0.09	0.10	0.07

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 18: Effect of IRWH techniques and catchment areas on plant vigour (NDVI) of Swiss chard grown at Apel

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	0.58a	0.57a	0.65a
3	0.58a	0.59ab	0.67b
Mean	0.58	0.58	0.66
CV (%)	6.98	6.36	10.62
SE	0.01	0.01	0.04
IRWH technique			
Control (farmers practice)	0.64a	0.63a	0.72a
Rainfed	0.60ab	0.57ab	0.57b
IRWH	0.53b	0.56ab	0.69a

IRWH+mulch	0.55b	0.54b	0.65a
IRWH+mulch+Irrigation	0.57ab	0.61a	0.33ab
Mean	0.58	0.58	0.59
CV (%)	11.71	11.64	10.65
SE	0.03	0.03	0.03
IRWH technique	0.07	0.07	0.07

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

Table 19: Effect of IRWH techniques and catchment areas on plant vigour (NDVI) of Swiss chard grown at Syferkuil

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	0.66a	0.72a	0.75a
3	0.68a	0.68a	0.73a
Mean	0.67	0.70	0.73
CV (%)	8.23	10.45	10.17
SE	0.02	0.02	0.02
IRWH technique			
Control (farmers practice)	0.65a	0.72a	0.75a
Rainfed	0.67a	0.67a	0.71a
IRWH	0.65a	0.70a	0.72a

IRWH+mulch	0.69a	0.70a	0.76a
IRWH+mulch+Irrigation	0.69a	0.73a	0.76a
Mean	0.62	0.70	0.75
CV (%)	10.70	10.05	6.76
SE	0.04	0.04	0.03
IRWH technique	NS	NS	NS

Means followed by the same letter in a column are not significantly different at P ≤ 0.05.

4.2 Effect of IRWH techniques on biomass production and yield of Swiss chard under different catchment areas.

The biomass production and yield of Swiss chard varied with IRWH technique. The interactions between IRWH technique and catchment areas were significant in relation to Swiss chard biomass production at both sites. At apel, the significantly highest average fresh shoot mass (488.50 g) at 10 WAT was obtained in IRWH+mulch+irrigation and 3 m catchment area treatment combination, while the least value at 10 WAT (163.40 g) was obtained under IRWH and also 3 m catchment area treatment combination. Similar pattern was recorded at 12 WAT (Table 20). At Syferkuil the results obtained was similar to that of at Apel. Nevertheless, the highest significant fresh shoot mass at 12 WAT (854.15 g) was found in the 3 m catchment and IRWH+mulch treatment combination, while the lowest value at 8 WAT (138.15 g) was found in 2 m catchment and rainfed treatment combination (Table 21). The results indicated that better biomass production was recorded in IRWH treatment in combination with mulch compared to treatments without mulch under 3 m catchment area. This was supported by the findings of Botha *et al*. (2003) that infield rainwater harvesting when combined with different mulch materials improved transpiration and reduced evaporation from the soil surface therefore crop growth is improved.

There was no significant difference among the catchment areas in relation to Swiss chard biomass production (Appendix 5), just like other parameters. At Apel, the significantly highest average fresh shoot mass (431.05 g) at 10 WAT and 360.23 g at 12 WAT were obtained in IRWH+mulch+irrigation and control respectively. While the least significant values 254.31 g at 10 WAT and 250.93 g at 12 WAT were found in IRWH treatment (Table 22). The trend observed at Syferkuil was different, the significantly highest values 402.34 g at 10 WAT and 642.13 g at 12 WAT were obtained in control and IRWH treatments respectively and least significant values 218.79 g (10 WAT) and 391.44 g (12 WAT) were found in IRWH+mulch and rainfed treatments respectively (Table 23). The variation in trend of Swiss chard biomass production obtained at Apel and Syferkuil (with different soil types) agreed with the findings of Ibraimo, 2011, who indicated that soil type and structure contributed greatly to crop growth.

Table 20: Interactive effect of IRWH techniques and catchment areas on harvested fresh shoot mass per plant (g) of Swiss chard grown at Apel

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	150.31a	444.14ab	356.58ab
2	Rainfed	165.10a	279.90bcd	286.24ab
2	IRWH	141.69a	345.19abc	297.00ab
2	IRWH+Mulch	123.99a	259.24cd	230.10ab
2	IRWH + Mulch + Irrigation	213.46ab	373.56abc	249.55ab
Mean		158.91	340.40	283.90
3	Control (farmers practice)	220.50ab	327.41abcd	363.87a
3	Rainfed	149.71a	303.83bcd	299.58ab

3	IRWH	132.49a	163.4d	204.85b
3	IRWH+Mulch	159.46a	332.50abc	330.19ab
3	IRWH+Mulch+Irrigation	209.46ab	488.54a	407.65a
Mean		174.32	323.14	321.23
CV (%)		164.19	168.88	135.14
SE		79.55	81.83	5.48
Catchment area* IRWH technique		45.90	98.2	102.20

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. NS stands for non- significant at P ≤ 0.05.

Table 21: Interactive effect of IRWH techniques and catchment areas on fresh shoot mass per plant (g) of Swiss chard grown at Syferkuil

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	241.35bcd	263.55bc	591.35ab
2	Rainfed	138.15d	375.05ab	380.25bc
2	IRWH	294.63bc	408.03ab	529.32bc
2	IRWH+Mulch	297.93bc	263.50bc	398.30bcd
2	IRWH+Mulch+Irrigation	231.47bcd	242.98bc	667.45ab
Mean		240.71	356.27	513.34
3	Control (farmers practice)	283.67bcd	312.92bcd	601.98ab
3	Rainfed	180.18cd	260.55bc	402.63bcd

3	IRWH	495.17a	185.18d	754.93abc
3	IRWH+Mulch	336.65b	174.02d	854.15abc
3	IRWH+Mulch+Irrigation	256.60bcd	223.58bc	332.75bcd
Mean		310.47	231.25	589.28
CV (%)		123.96	200.28	176.14
SE		60.06	97.04	85.34
Catchment area* IRWH technique		47.7	95.60	151.00

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. NS stands for non- significant at P ≤ 0.05.

Table 22: Effect of IRWH techniques and catchment areas on harvested fresh shoot mass per plant (g) of Swiss chard grown at Apel

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	158.90a	340.40a	283.90a
3	174.32a	323.14a	321.23a
Mean	166.62	331.77	302.57
CV (%)	192.71	95.97	165.70
SE	60.56	30.16	52.07
IRWH technique			
Control (farmers practice)	185.41a	385.78ab	360.23a

Rainfed	157.41a	291.86bc	292.91ab
IRWH	137.09a	254.31c	250.93b
IRWH+mulch	141.73a	295.87bc	280.16ab
IRWH+ Mulch+Irrigation	211.46a	431.05a	328.60ab
Mean	166.62	331.77	302.57
CV (%)	116.10	119.42	95.56
SE	56.25	57.86	46.30
IRWH technique	15.5	20.23	23.3

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$. NS stands for non- significant at $P \leq 0.05$.

Table 23: Effect of IRWH techniques and catchment areas on fresh shoot mass per plant (g) of Swiss chard grown at Syferkuil

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	240.71a	356.27a	513.34a
3	310.47a	231.25a	589.28a
Mean	275.59	293.76	551.31
CV (%)	116.86	157.69	240.87
SE	36.72	49.55	75.69
IRWH techniques			
Control (farmers practice)	262.51bc	402.34a	596.66a

Rainfed	205.82c	317.80ab	391.44b
IRWH	394.90a	296.60ab	642.13a
IRWH+mulch	317.29ab	218.79b	626.22a
IRWH Mulch+Irrigation	197.40c	233.28b	500.10ab
Mean	275.59	293.76	551.31
CV (%)	87.65	141.62	124.55
SE	42.47	68.62	60.35
IRWH technique	84.25	90.87	101.12

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$. NS stands for non- significant at $P \leq 0.05$.

Similar significant ($P \leq 0.05$) interactions between IRWH techniques and catchment areas were found for dry shoot mass of Swiss chard. At Apel, the highest significant average dry shoot mass per plant at 10 WAT (36.97 g) was found in 2 m catchment and control treatment combination and 36.46 g in 2 m and IRWH+mulch+irrigation, while the lowest value at 10 WAT (17.38 g) was found in 3 m catchment and IRWH treatment combination. Similar trend was obtained at 12 WAT except that the highest value of 34.01 g was found in 3 m catchment and IRWH+mulch+irrigation treatment combination, compared to 17.13 g in IRWH and 3 m catchment area treatment combination (Table 24). The results obtained at Syferkuil was similar to that of Apel, with the highest average dry shoot mass of 43.43 g at 10 WAT obtained in 2 m catchment and control treatment combination and 17.53 g at 10 WAT obtained in 3 m catchment and IRWH+mulch treatment combination and rainfed treatment. The significantly highest average dry shoot mass at 12 WAT (87.07) was obtained in IRWH+mulch+irrigation at 2 m catchment area, followed by 86.98 g in IRWH+Mulch treatment combination (Table 25). Thus, there were varied responses across location with regard to IRWH techniques with or without mulch and irrigation. The results thus contradict the findings of Ibraimo, 2011, which stated that under in-field rainwater harvesting in combination with mulch, maize experienced fast biomass accumulation, flowering and grain filling, which required a lot of water from the soil.

Furthermore, insignificant differences between catchment areas were obtained for dry shoot mass of Swiss chard (Appendix 6). The significantly highest dry shoot mass (32.09 g) was found IRWH+mulch+irrigation at 10 WAT while the least significant value (21.53 g) was recorded in IRWH+mulch treatment for Swiss chard grown at Apel (Table 26). At Syferkuil however, the significant highest shoot mass (68.46 g) at 12 WAT was obtained in IRWH treatment, and the lowest significant value (45.05 g) at 12 WAT recorded in rainfed treatment (Table 27). The results thus indicated varied response in Swiss chard dry biomass production in relation to IRWH and ecological location.

Table 24: Interactive effect of IRWH techniques and catchment areas on harvested dry shoot mass per plant (g) of Swiss chard grown at Apel

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	13.49ab	36.87a	30.83b
2	Rainfed	15.05ab	23.80ab	23.54ab
2	IRWH	13.58ab	25.68ab	25.43ab
2	IRWH+Mulch	11.96ab	21.29ab	18.14ab
2	IRWH+Mulch+Irrigation	18.90a	27.73ab	20.15ab
Mean		14.59	27.00	23.62
3	Control (farmers practice)	24.61a	26.75ab	26.53ab
3	Rainfed	15.29ab	26.43ab	24.31ab
3	IRWH	11.78ab	17.38b	17.13ab

3	IRWH+Mulch	13.35ab	23.80ab	23.28ab
3	IRWH+Mulch+Irrigation	18.08a	36.46a	34.01b
Mean		16.62	26.16	25.05
CV (%)		15.9	12.56	8.28
SE		7.69	6.09	4.01
Catchment area* IRWH technique		9.17	10.14	10.21

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. NS stands for non- significant at P ≤ 0.05.

Table 25: Interactive effect of IRWH techniques and catchment areas on dry shoot mass per plant (g) of Swiss chard grown at Syferkuil

Catchment area (m)	IRWH technique	Weeks after transplanting		
		8	10	12
2	Control (farmers practice)	23.48abcd	48.43a	58.85bc
2	Rainfed	15.58d	32.15ab	46.40bc
2	RWH	25.08abcd	35.63ab	51.60bc
2	IRWH+Mulch	27.98abcd	22.85b	43.83bc
2	IRWH+Mulch+Irrigation	22.85bcd	18.13b	87.05a
Mean		22.99	31.44	57.35
3	Control (farmers practice)	25.20abcd	29.03ab	43.70bc
3	Rainfed	18.53cd	17.53b	86.98a
3	IRWH	34.33a	21.70b	85.33a

3	IRWH+Mulch	32.40a	17.53b	86.98a
3	IRWH+Mulch+Irrigation	25.50abcd	19.93b	33.3 c
Mean		27.19	23.55	62.48
CV (%)		9.86	18.02	65.84
SE		4.78	8.73	20.69
Catchment area* IRWH technique		19.80	18.70	33.67

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. NS stands for non- significant at P ≤ 0.05.

Table 26: Effect of IRWH techniques and catchment areas on harvested dry shoot mass per plant (g) of Swiss chard grown at Apel

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	14.59a	27.00a	23.62a
3	16.62a	26.16a	25.05a
Mean	15.61	26.58	24.34
CV (%)	17.12	12.05	10.50
SE	5.38	3.79	3.30
IRWH techniques			
Control (farmers practice)	19.05a	31.81a	28.68a
Rainfed	15.17a	24.93ab	23.93abc

IRWH	12.68a	21.53b	21.28bc
IRWH+mulch	12.66a	22.54b	20.71c
IRWH+Mulch+Irrigation	18.49a	32.09aB	27.08ab
Mean	15.61	26.58	24.34
CV (%)	11.22	8.88	5.86
SE	5.44	4.30	2.84
IRWH technique	NS	8.70	6.50

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. NS stands for non- significant at P ≤ 0.05.

Table 27: Effect of IRWH techniques and catchment areas on dry shoot mass per plant (g) of Swiss chard grown at Syferkuil

Treatments	Weeks after transplanting		
	8	10	12
Catchment area (m)			
2	22.99a	31.44a	57.35a
3	27.19a	23.55a	62.48a
Mean	25.09	27.50	59.92
CV (%)	7.26	14.61	18.41
SE	2.28	4.59	5.78
IRWH techniques			
Control (farmers practice)	24.34a	38.99a	60.98a
Rainfed	17.05b	30.60ab	45.05b

IRWH	29.70a	28.66ab	68.46a
IRWH+mulch	30.19a	20.19b	64.90a
IRWH+Mulch+Irrigation	24.18a	19.03b	60.18a
Mean	25.09	27.50	59.92
CV (%)	6.97	12.74	13.14
SE	3.38	6.17	6.37
IRWH technique	5.5	10.4	9.50

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. NS stands for non- significant at P ≤ 0.05.

The yield of Swiss chard varied with IRWH techniques. The interactions between the IRWH techniques and catchment areas in relation to the yield of Swiss chard grown at both sites were significant. According to Figures 5 and 6, the lowest Swiss chard yields were obtained under IRWH and rainfed treatments. Furthermore at Apel, significantly higher average yield at 12 WAT (89.58 t/ha^{-1}) was obtained in IRWH+Mulch+irrigation and 2 m catchment area treatment combinations, while the lowest value at 12 WAT (15.96 t/ha^{-1}) was found in the 3 m catchment and rainfed treatment combinations (Table 28). A similar trend was obtained at Syferkuil, nevertheless the significantly highest average yield (84.86 t/ha^{-1}) at 12 WAT was obtained in the IRWH+Mulch+irrigation and 3 m catchment area treatment combination, while the least value (20.66 t/ha^{-1}) was found in the 3 m catchment and rainfed treatment combination (Table 28). The yield of Swiss chard under IRWH+Mulch+irrigation compared to other treatments can be attributed by the mulching and irrigation. The mulch conserved soil moisture, reducing evaporation thus, water loss was minimal. During the short rainy season, the limited amount of rainfall received did not meet the crop water requirements, hence need for supplementary irrigation to mitigate dry spells. The findings of this study were in agreement with Mzirai and Tumbo (2010), who stated that yield of crops that received extra water from external catchments (macro RWH), increased by more than 120% as compared to fields that received rainfall only (rainfed).

Comparing the catchment areas, the differences obtained in yield of Swiss chard under different catchment areas and Swiss chard yield at both sites were not significant (Appendix 7). At Apel, the highest significant average yield (75.45 ton ha^{-1}) at 12 WAT was obtained under the control treatment, although this was not significantly different from those grown under infield rainwater harvesting techniques with or without mulch and irrigation. The lowest average yield (16.43 t/ha^{-1}) was recorded in the rainfed treatment (Table 29). At Syferkuil, the significantly highest average Swiss chard yield (95.54 t/ha^{-1}) was found in IRWH+Mulch+ irrigation at 12 WAT, while the least significant value (30.82 t/ha^{-1}) was recorded in the rainfed treatment. These results at Syferkuil further agreed with the findings of Botha *et al.* (2003) and Botha, (2007) who got an increase of 25% and 50% on maize yield under in-field rainwater harvesting.

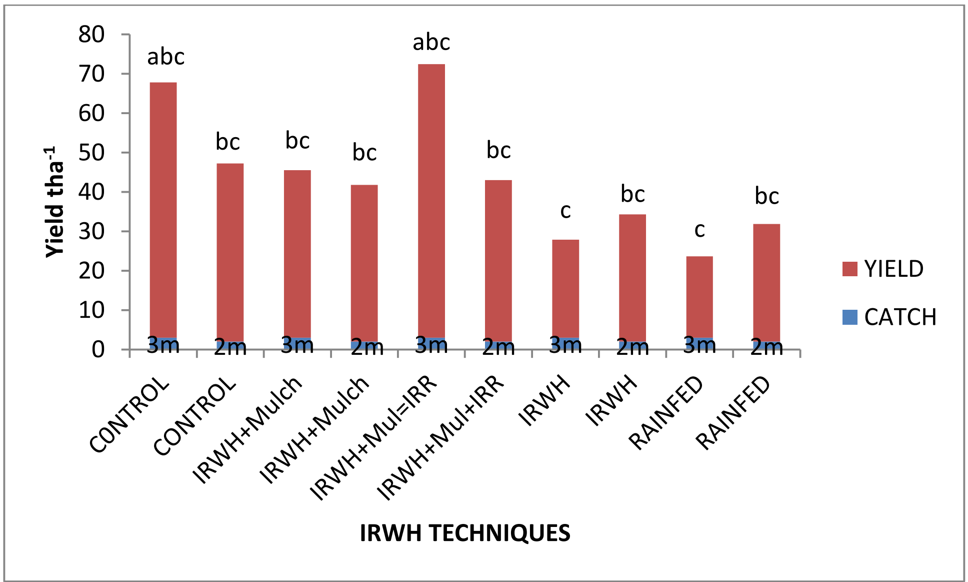

Figure 5: Effect of rainwater harvesting techniques and catchment areas on yield of Swiss chard at Apel at 12 WAT.

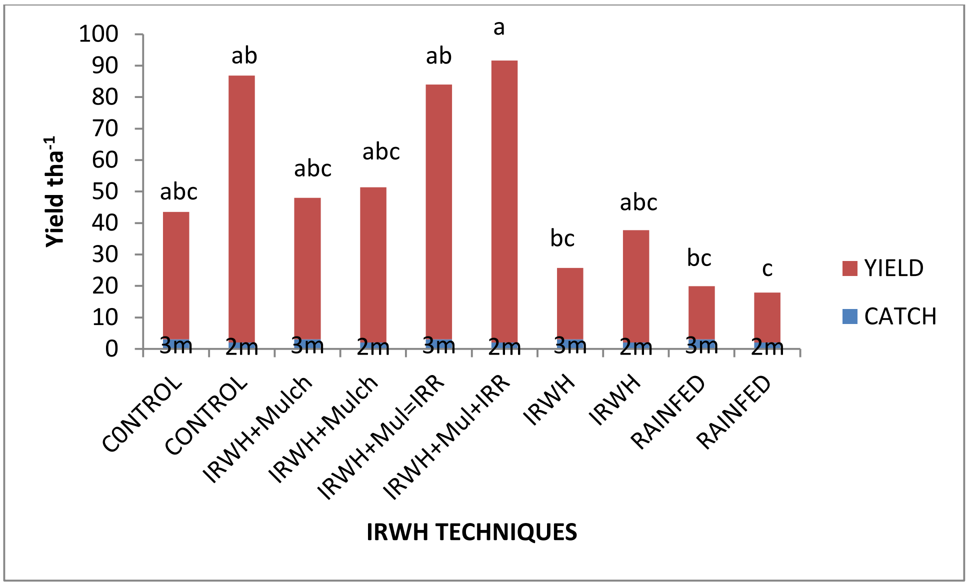

Figure 6: Effect of rainwater harvesting techniques and catchment areas on yield of Swiss chard at Syferkuil at 12 WAT.

Table 28: Interactive effect of IRWH techniques and catchment areas on fresh leaf yield (t /ha^{-1}) of Swiss chard grown at Apel and Syferkuil at 12 WAT

Catchment area (m)	IRWH techniques	Apel	Syferkuil
2	Control (farmers practice)	84.88ab	40.99bc
2	Rainfed	15.92c	29.90c
2	IRWH	35.71abc	24.88c
2	IRWH+Mulch	49.30abc	42.52bc
2	IRWH+Mulch+Irrigation	89.58ab	84.83ab
Mean		55.08	44.62
3	Control (farmers practice)	40.50abc	69.50abc
3	Rainfed	16.92bc	20.66c
3	IRWH	22.67bc	24.88c

3	IRWH+Mulch	45.04abc	42.52bc
3	IRWH+Mulch+Irrigation	81.01abc	84.86ab
Mean		41.23	48.48
CV (%)		50.40	75.14
SE		35.57	24.73
Catchment area* IRWH technique		73.40	51.05

Means followed by the same letter in a column are not significantly different at P ≤ 0.05. NS stands for non- significant at P ≤ 0.05.

Table 29: Effect of IRWH techniques and catchment areas on fresh leaf yield (t/ha^{-1}) of Swiss chard grown at Apel and Syferkuil at 12 WAT.

Treatments	Apel	Syferkuil
Catchment area (m)		
2	59.28a	49.85a
3	41.23a	48.48a
Mean	50.25	49.17
CV (%)	74.21	84.74
SE	11.79	13.17
IRWH techniques		
Control (farmers practice)	75.45a	49.70b

Rainfed	16.43b	30.82b
IRWH	35.99ab	32.34b
IRWH+mulch	58.36ab	37.41b
IRWH+Mulch+Irrigation	65.04ab	95.54a
Mean	50.25	49.16
CV (%)	100.08	71.14
SE	25.15	17.49
IRWH technique	51.90	36.09

Means followed by the same letter in a column are not significantly different at $P \leq 0.05$. NS stands for non- significant at $P \leq 0.05$.

4.3 Treatment effect on selected soil properties

4.3.1 Pre-planting soil chemical properties at Apel and Syferkuil.

The analytical results for Apel and Syferkuil before crop establishment, shows that pH was slightly alkaline (7.58), while Syferkuil was moderately acidic (5.60). At Apel the soil was low in P (1.50 mg/L), while this was moderately high (14.25 mg/L) at Syferkuil. The textural classes of the soil at Apel was clay, while it was sandy loam at Syferkuil (Table 30).

Table 30: Soil analytical results for Apel and Syferkuil before crop establishment

Property	Apel	Syferkuil
P (mg/L)	1.50	14.25
K (mg/L)	142.75	130.75
Ca (mg/L)	3348.00	734.75

Mg (mg/L)	1316.00	442.25
Exc. Acidity (cmol/L)	0.09	0.10
Total cations (cmol/L)	27.06	7.69
Acid sat. (%)	0.00	0.50
pH (KCl)	7.58	5.60
Zn (mg/L)	0.43	0.78
Mn (mg/L)	1.00	1.75
Cu (mg/L)	2.18	2.98
Organic C (%)	0.58	0.78
N (%)	0.15	0.08
Clay (%)	39.25	29.25
Textural classes	Clay	Sandy loam

4.3.2 The effect of IRWH techniques and catchment area on soil bulk density and soil moisture at Apel and Syferkuil.

The results indicated that prior planting the soil were low in soil moisture at both sites due to low rainfall experienced during the 2015 season. At Syferkuil, however, the results also indicated that treatments with mulch had an increased soil moisture content at 12 WAT compared to initial value before crop establishment. This may be attributed to reduced moisture evaporation from the soil due to mulch layer (Table 31). A similar trend was obtained at Apel, with highest average moisture content (20.96 %) obtained under IRWH+Mulch+Irrigation treatment combination with 3 m catchment area, while the lowest (9.89 %) was obtained under rainfed treatment (Table 32).

Table 31: The effect of IRWH techniques and catchment area on soil bulk density and soil moisture at a depth of 5 to 30 cm at Apel

	Bulk density g/cm^3		Soil moisture %		Bulk density g/cm^3		Soil moisture %	
	3 m	2 m	3 m	2 m	3 m	2 m	3 m	2 m
IRWH techiques								
Control	1.03	0.81	14.96	19.47	1.06	0.84	10.86	20.13
IRWH+Mulch	0.91	1.12	17.95	18.46	0.86	0.82	17.81	19.63
IRWH+Mulch+Irrigation	1.13	0.89	19.21	22.44	1.13	0.72	20.96	22.18
IRWH	0.85	1.12	13.94	19.48	1.14	0.95	9.95	19.00
Rainfed	0.76	1.01	14.98	16.82	0.71	0.71	9.89	16.78

Table 32: The effect of IRWH techniques and catchment area on soil bulk density and soil moisture at a depth of 5 to 30 cm at Syferkuil

	Bulk density g/cm^3	Soil moisture %	Bulk density g/cm^3	Soil moisture %

	3 m	2 m	3 m	2 m	3 m	2 m	3 m	2 m
IRWH techiques								
Control	1.43	1.44	4.49	5.77	1.44	1.43	4.43	6.88
IRWH+Mulch	1.52	1.72	3.92	6.47	1.52	1.72	5.16	6.96
IRWH+Mulch+Irrigation	1.47	1.29	4.76	6.24	1.47	1.25	5.39	7.18
IRWH	1.34	1.53	4.49	5.77	1.34	1.51	4.55	6.67
Rainfed	1.23	1.40	3.63	4.61	1.23	1.40	4.11	6.37

4.3.3 Soil physical properties in relation to IRWH technique and catchment area at Apel and Syferkuil.

The results of soil physical properties showed that soils under IRWH treatment at both sites had the highest aggregate stability and lowest infiltration rate under the 3 m catchment area (Tables 33 and 34). For instance the highest average 0.81 aggregate stability was obtained under IRWH treatment while the lowest average 19.00 infiltration rate was obtained under the same treatment and 3 m catchment treatment combinations at Syferkuil. A similar trend was obtained at Apel. The results were contrary to the findings of Thierfelder and Wall (2009), who stated that an improved soil agreggates increases infiltration rate and reduce runoff there by making more water available for crops growth.

Table 33: The effect of IRWH technique on soil physical properties under different catchment areas at Apel at 8,10 to 12 WAT

IRWH techniques	Aggregate stability		Bulk density g/cm^3				Soil moisture content (%)				Volumetric water analysis (%)				Infiltration rate steady state	
			0 – 5 cm		5 – 30 cm		0- 15 cm		15 – 30 cm		0- 15 cm		15 – 30 cm			
	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m
Control	0.40	0.24	1.05	1.01	1.01	1.12	14.70	18.33	24.31	24.10	14.06	18.51	25.53	24.43	25.00	35.00
IRWH+Mulch	0.35	0.29	1.24	1.15	0.63	0.77	16.50	17.93	25.67	23.30	20.46	20.62	16.17	17.94	25.00	30.00
IRWH+Mulch+Irrigation	0.20	0.12	1.63	1.56	1.31	1.20	23.44	17.98	29.14	30.12	38.20	28.04	38.17	36.14	35.00	45.00
IRWH	0.87	0.33	0.97	1.60	0.95	1.02	19.77	18.99	20.10	22.10	19.18	30.38	19.10	22.54	16.00	25.00
Rainfed	0.70	0.28	0.87	0.97	1.00	0.84	16.48	17.62	19.30	18.77	14.33	17.09	19.30	14.36	17.00	20.00

Table 34: The effect of IRWH technique on soil physical properties under different catchment areas at Syferkuil at 8,10 to 12 WAT.

IRWH techniques	Aggregate stability		Bulk density g/cm^3				Soil moisture content (%)				Volumetric water analysis (%)				Infiltration rate steady state	
			0 – 5 cm		5 – 30 cm		0- 15 cm		15 – 30 cm		0- 15 cm		15 – 30 cm			
	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m	3m	2m
Control	0.43	0.21	1.40	1.33	0.61	1.30	16.30	18.34	23.31	25.10	22.82	24.39	15.31	32.63	20.00	35.00
IRWH+Mulch	0.75	0.28	1.14	1.02	0.74	0.81	18.40	21.92	26.60	30.30	20.98	22.35	19.68	24.54	24.00	35.00
IRWH+Mulch+Irrigation	0.23	0.21	1.61	1.11	1.10	1.20	20.24	19.18	32.24	38.12	32.59	25.28	35.46	45.74	30.00	30.00
IRWH	0.81	0.81	1.32	1.20	0.87	0.92	16.77	20.19	23.12	27.1	22.14	24.23	20.11	24.93	19.00	22.00
Rainfed	0.50	0.35	0.57	0.87	0.67	0.74	15.48	16.65	20.30	17.77	8.82	14.48	13.60	13.14	20.00	20.00

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Water scarcity affects rainfed crop production. This study was conducted to assess the effect of IRWH as soil moisture conservation technique for improved vegetable crops production in Limpopo Province. The results indicated that the growth of Swiss chard in terms of plant height, number of leaves, chlorophyll contents and plant vigour improved with IRWH techniques compared to rainfed. At final harvest the tallest Swiss chard plant at both Apel and Syferkuil were obtained in crops grown under IRWH+Mulch+Irrigation while the shortest plants were obtained in the rainfed. The trend recorded with regard to IRWH technique and Swiss chard growth at Apel varied, while at Syferkuil, Swiss chard with the highest leaf production and chlorophyll contents were found in IRWH treatment combination, while rainfed crops had limited leaf production and chlorophyll content.

The IRWH technique had beneficial effect on fresh shoot mass production of Swiss chard at both sites. Hence greatest fresh shoot biomass was obtained in IRWH+Mulch+Irrigation treatment combination at Apel, at Syferkuil, the greatest fresh shoot biomass was found in IRWH+Mulch treatment combination. In terms of dry biomass production, supplementary irrigation appeared to be paramount importance at both sites. The highest dry shoot mass and yield of Swiss chard were found in the control (rainfed+irrigation) at Apel, while at Syferkuil the highest dry shoot mass and yield of Swiss chard were found in the control and IRWH+Mulch+Irrigation treatment combination respectively.The size of catchment area did not affect both biomass production and yield of Swiss chard at both sites.

It can therefore be concluded that at Apel, although the use of IRWH technique could be beneficial for improved Swiss chard production, supplementary irrigation is of vital importance. At Syferkuil however, IRWH+Mulch+Irrigation is more, beneficial for Swiss chard yields, plant height, leave production were greatly improved. Further research should be conducted to ascertain the beneficial effect of IRWH techniques on improved vegetable crops production under different ecological zones and soil types in Limpopo province.

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APPENDICES

Appendix1: Analysis of variance (ANOVA) effect of IRWH techniques and catchment areas on plant height (cm) of Swiss chard grown at Apel and Syferkuil.

		Apel						Syferkuil					
		Weeks after transplanting											
		8		10		12		8		10		12	
Source	DF	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value
Rep	3	29.92		130.87		72.42		40.92		24.05		79.40	
Main	1	3.31	0.77	3.31	0.74	7.88	0.70	5.26	0.55	16.90	0.19	50.63	0.19
Error Rep*Main	3	98.77		78.22		129.80		35.12		7.75		52.47	
Sub	4	150.25	0.01**	254.81	0.01**	645.78	0.00**	151.16	0.05	307.21	0.00**	342.78	0.00**
Main*Sub	4	20.85	0.51	11.66	0.94	7.85	0.96	71.34	0.28	158.91	0.02	207.87	0.02
Error Rep*Main*Sub	24	149.00		366.73		298.07		317.40		331.08		334.25	
Total	39	452.08		845.59		1161.80		621.19		849.90		1067.0	

Appendix 2: Analysis of variance (ANOVA) effect of IRWH techniques and catchment areas on number of leaves of Swiss chard grown at Apel and Syferkuil.

		Apel						Syferkuil					
		Weeks after transplanting											
		8		10		12		8		10		12	
Source	DF	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value
Rep	3	42.10		9.10		8.47		21.15		75.68		13.72	
Main	1	0.40	0.45	0.23	0.67	3.91	0.69	52.90	0.27	99.23	0.09	20.31	0.34
Error Rep*Main	3	1.90		3.08		58.82		9.75		46.28		47.62	
Sub	4	37,60	0.05	47.73	0.05	90.54	0.21	119.85	0.00**	9.84	0.89	85.23	0.53
Main*Sub	4	14.60	0.05	30.28	0.21	66.31	0.36	21.73	0.34	56.09	0.24	148.85	0.26
Error Rep*Main*Sub	24	101.60		114.20		345.15		108.73		225.68		625.23	
Total	39	197.60		204.60		573.19		334.10		512.78		940.94	

Appendix 3: Analysis of variance (ANOVA) effect of IRWH techniques and catchment areas on chlorophyll content of Swiss chard grown at Apel and Syferkuil.

		Apel						Syefrkuil					
		Weeks after transplanting											
		8		10		12		8		10		12	
Source	DF	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value
Rep	3	529.00		341.65		96.10		304.38		253.39		12.26	
Main	1	5.45	0.83	0.54	0.93	205.75	0.14	16.38	0.44	12.54	0.72	87.17	0.52
Error Rep*Main	3	305.99		178.29		158.17		61.43		236.92		596.01	
Sub	4	995.62	0.08	1952.53	0.05	1175.03	0.02	493.06	0.25	253.58	0.20	273.18	0.05
Main*Sub	4	369.40	0.50	202.34	0.89	62.71	0.93	156.53	0.76	147.56	0.45	52.13	0.07
Error Rep*Main*Sub	24	2545.88		4266.67		2000.95		2025.9		931.09		808.69	
Total	39	4749.35		6942.02		3700.72		3057.71		1835.90		1829.50	

Appendix 4: Analysis of variance (ANOVA) effect of IRWH techniques and catchment areas on plant vigour of Swiss chard grown at Apel and Syferkuil.

		Apel						Syferkuil					
		Weeks after transplanting											
		8		10		12		8		10		12	
Source	DF	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value
Rep	3	0.01		0.70		0.03		0.01		0.70		0.03	
Main	1	0.00	0.31	0.02	0.14	0.00	0.58	0.00	0.31	0.02	0.14	0.00	0.58
Error Rep*Main	3	0.01		0.02		0.02		0.01		0.02		0.02	
Sub	4	0.01	0.73	0.02	0.54	0.01	0.31	0.01	0.73	0.02	0.54	0.01	0.31
Main*Sub	4	0.01	0.49	0.02	0.34	0.02	0.13	0.01	0.49	0.02	0.34	0.02	0.13
Error Rep*Main*Sub	24	0.12		0.12		0.06		0.12		0.12		0.06	
Total	39	0.17		0.27		0.14		0.17		0.27		0.14	

Appendix 5: Analysis of variance (ANOVA) effect of IRWH techniques and catchment areas on fresh shoot mass (g) of Swiss chard grown at Apel and Syferkuil.

		Apel						Syferkuil					
		Weeks after transplanting											
		8		10		12		8		10		12	
Source	DF	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value
Rep	3	25190.00		34365.00		7556.00		360.47		17085.00		18762.00	
Main	1	1178.00	0.61	1586.00	0.52	10670.00	0.21	41.01	0.73	48665.00	0.15	2267.00	0.30
Error Rep*Main	3	10718.00		8820.00		12429.00		868.14		40453.00		1172.14	
Sub	4	21432.00	0.13	109586.0	0.04	13655.20	0.48	301.18	0.64	21730.00	0.00**	956.00	0.02*
Main*Sub	4	5619.00	0.72	11325.00	0.81	60634.00	0.81	218.83	0.76	71706.00	0.81	8112.30	0.04
Error Rep*Main*Sub	24	65125.00		221438.0		916548.00		2836.71		173152.0		9231.00	
Total	39	129263.00		387120.0		121248.00		4625.83		568065.0		572173.0	

Appendix 6: Analysis of variance (ANOVA) effect of IRWH techniques and catchment areas on dry shoot mass (g) of Swiss chard grown at Apel and Syferkuil.

		Apel						Syferkuil					
		Weeks after transplanting											
		8		10		12		8		10		12	
Source	DF	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value	SS	P value
Rep	3	595.94		544.50		1505.45		83.80		254.48		105.61	
Main	1	45.26	0.63	137.27	0.22	105.14	0.30	176.40	0.16	352.67	0.15	350.00	0.47
Error Rep*Main	3	504.91		170.91		204.12		156.23		876.24		727.00	
Sub	4	284.92	0.78	1194.71	0.02	816.06	0.41	906.23	0.00**	1120.00	0.05	891.00	0.06
Main*Sub	4	629.41	0.41	222.15	0.62	1025.74	0.30	71.29	0.81	556.70	0.92	421.00	0.18
Error Rep*Main*Sub	24	3649.07		1992.28		4753.93		1095.43		3121.00		1568.00	
Total	39	5709.52		4261.90		841044.00		2489.40		4567.80		2930.50	

Appendix 7: Analysis of variance (ANOVA) effect of IRWH techniques and catchment areas on yield (ton/ha) of Swiss chard grown at Apel and Syferkuil.

	Apel			Syferkuil	
		Weeks after transplanting			
		12			
Source	DF	SS	P value	SS	P value
Rep	3	18906.00		5165.60	
Main	1	3257.00	0.22	18.90	0.92
Error Rep*Main	3	4173.00		5206.80	
Sub	4	18140.00	0.01**	23271.70	0.05
Main*Sub	4	14486.00	0.05	5518.70	0.05
Error Rep*Main*Sub	24	60715.00		29361.70	
Total	39	119678.00		68543.50	