CLIMATE CHANGE AND AVOCADO PRODUCTION: A CASE STUDY OF THE LIMPOPO PROVINCE OF SOUTH AFRICA

By

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DECLARATION OF ORIGINALITY

I hereby declare that this dissertation which I submit for the degree of MAgric (Agricultural Economics) at the University of Pretoria is my own work and it has not been previously submitted by me for a degree at this or any other institution of higher learning.

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Date ------------------------

DEDICATION

To:

My late father; Ramudzuli Petrus Mphephu, whose passion and love for agriculture impacted my academic life enormously

My beloved grandmother; Helen Maluga, for her advice, her patience and her faith.

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ABSTRACT

Climate change is a major concern worldwide, given its projected impact on agricultural production, especially in semi-arid environments. The production of subtropical fruits, including avocado, in South Africa is also expected to be highly vulnerable to climate variability and change. The country is experiencing unseasonal intense summer rain and drought, with drought having the worst record for the past 30 years in the 2015/16 production seasons. The avocado industry in South Africa contributes immensely to the economy as an enabler food security through job creation for the majority of individuals who are living in rural areas. The industry contributes about 10% of employment opportunities in the country's formal sector. It employs a permanent farm labour force of around 6000 and another 2000 casual labourers during peak times. Amongst the challenges that the avocado industry is facing is the decrease in production in recent times. In response, this study is designed to assess the impacts of climate variability and change on the production of avocados in the Limpopo province. It also assesses the adaptation strategies for farmers that might boost their economic returns.

The study used both primary and secondary data. Primary data was collected in the avocado producing districts of Limpopo province. A sample comprised 46 respondents who were interviewed, using structured survey questionnaires that contained both open- and closed-ended questions. These questionnaires aimed at gaining more details on the farmer's perspective on how climate change is influencing the sustainability of avocado production. The data was then analysed using descriptive statistics. The secondary data, which is the climatic data, was obtained from the ARC-ISCW; from their 94 weather stations around Limpopo province, four stations around the subtropical areas were randomly chosen. Avocado production data over the years was obtained from the South African Subtropical Growers Association.

Eighty-seven percent (87%) of the respondents acknowledged that the pattern of weather has been changing over the past years and that these changes are having a negative impact on avocado production. The analysis of climate variables during the agricultural season showed a slight positive trend for temperature, with a decrease in precipitation. The results also showed that temperature variability over the years has had a negative and significant impact on avocado yields. There was no correlation between rainfall and avocado yields, mainly because 90% of the respondents were commercial farmers who are producing under irrigation.

In conclusion, avocado production is generally more sensitive to changes in temperature than rainfall in the Limpopo province. This study thus recommends that adaptation measures that are aimed at reducing the impacts of climate change on avocado production are essential for coping with climate variability. Some of the adaptation measures are: the need for the installation of water harvesting and storage structures for the small-scale farmers who are producing on dry land; the application of careful management techniques when faced with high summer temperatures; the use of mulch and growth regulators to improve fruit size; the use of windbreaks to reduce tree and fruit damage; and the implementation of a canopy management system to improve productivity. To avoid loss, farmers may also insure their fruits.

Key words: Climate change, Avocado production, Limpopo province and Adaptation strategies

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LIST OF ACRONYMS

DAFF -	Department of agriculture, fisheries and forestry
DBSA -	Development Bank of southern Africa
FAO -	Food and Agriculture Organisations
GDP -	Gross domestic product
GHGs -	Greenhouse gases
GVP -	Gross Value of Production
GGP -	Gross Geographic Product
IPCC -	Intergovernmental Panel on Climate Change
IDW -	Inverse Distance Weighting
KZN -	KwaZulu-Natal
LDA -	Limpopo Department of Agriculture
LDCs -	Least developed countries
UNFCCC -	The United Nations Framework Convention on Climate Change
UNICEF -	The United Nations Children's Fund
UN -	United Nations
USA -	United State of America
RSA -	Republic of South Africa
SAAGA -	South African avocado growers' association
STATA -	Statistics and Data
SEDA -	Small Enterprise Development Agency

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

Agricultural production is facing considerable challenges that result in lower productivity, which is affecting the societal requirements of the increasing global population. Many countries are already concerned about the risks that climate change poses for sustainable development (Warner, 2013). The impacts of climate change have been a major concern worldwide in terms of uncertainty in agricultural production, with climate change being projected to disrupt the ability of land resources to support different types of vegetation and so alter production possibilities (IPCC, 1996). Some attempts, globally, have been made to assess climate change impacts on agriculture (Mendelsohn & Tiwari, 2000; Benhin, 2006; Ayinde et al., 2011; Calzadilla et al., 2013).

The rising debate is that the emissions of greenhouse gasses caused by human activities will, in the long run, cause higher temperatures and decreased rainfall in some regions (Christensen et al. 2007). Simultaneously, another debate currently underway is whether the rise in temperature will benefit or negatively affect agricultural production in temperate, semi-arid and sub-tropical climates (Mendelsohn et al. 1994; Kelly et al. 2005; Schenker et al. 2005; Ashenfelter & Storchmann 2006; Dêschenes & Greenstone, 2007). The general scientific agreement is that changes in temperature and rainfall changes will affect agricultural productivity negatively (IPCC, 1997). Not only will these climate changes affect agricultural productivity, they will also impact on the economic well-being of each country (Abidoye & Odusola, 2015).

Various impact studies that have been done focused on the agricultural sector for many reasons, one being that temperature and rainfall are direct inputs of agricultural production and any changes in these will automatically affect the production (Wolfram, 2010). Developing countries appear to be more especially vulnerable to climate change in terms of agriculture than already developed countries are due to their dependence on rain-fed agriculture (Parry et al. 2007). A study done by Gbetibouo and Hassan (2005) analysed the economic impacts of climate change on a few major crops in South Africa and concluded that most crops are more highly sensitive to temperature change than they are to rainfall changes.

Agricultural production in poor developing economies still comprises large share of income. For example, FAO (2011) shows that the agriculture industry accounts for around 60 percent of gross domestic product (GDP) in those countries. Agriculture is the pillar of developing countries, which suggests that it would not be possible to develop their economies without considering the improvement of the agriculture sector.

The Limpopo province of South Africa produces agricultural products that range from tropical fruits, to cereals, and to vegetables. This province is the main avocado-growing area in South Africa, with 61% of the national production (DAFF, 2015). South African avocado fruit is one of the subtropical fruits that are becoming more important as a food item and earner of foreign exchange (SAAGA, 2005). The avocado industry plays a major role in Limpopo’s economy in terms of creating jobs for rural dwellers, with agriculture contributing about 10% of employment opportunities in the country’s formal sector. Although South Africa is geographically remote from major world markets, its fresh fruit industry is dependent on exporting the produce to far-off markets (O’Brien, 2000). The industry has been reported to be unstable in production for the past few years (DAFF, 2015). The importance of the agricultural sector in the country’s economy, together with its sensitivity to climatic conditions, thus renders investigating the impacts of climate change on important crops in South Africa like avocado of importance.

There is a need to increase knowledge of the biophysical and economic factors that contribute tremendously in the productivity of crops; therefore, knowledge of these factors is essential to policy makers and farmers in taking necessary steps. In this study, we assess the possible impacts of climate and the agro-economic indices associated with the production of avocados in the Limpopo province of South Africa.

1.2 PROBLEM STATEMENT AND JUSTIFICATION

The agricultural sector of South Africa contributes tremendously in the country’s economy, providing more or less 4% of the GDP (SEDA, 2012). The avocado industry of South Africa also plays a major role in terms of creating jobs for rural dwellers, with agriculture providing about 10% of the employment opportunities in the country’s formal sector. The avocado industry employs a permanent farm labour force of around

6000 and another 2000 casual labourers during peak periods (DAFF, 2015).The fruit industry in South Africa is a multibillion-rand industry, which contributes significantly to the well-being of the South African population, directly and indirectly through its forward and backward economic linkages (SEDA, 2012).The decrease in production in recent times is amongst the other challenges that the avocado industry is facing (SAAGA, 2010). In previous years, avocado production has been stable, but from the 2003/04 to 2009/10 agricultural seasons, the industry reported a great decline in production (SAAGA, 2010). In the 2008/09 agricultural year, avocado production was estimated at 95 857 tons, decreasing by 33% in production year of 2009/10 (DAFF, 2015).

The problem investigated in the study is that there is an observable trend in the decrease of production yield of avocados over a period, this could be ascribed to climate change and its variability coupled with lack of mitigation strategies. Estimating the impacts that climate change has on avocado production is important for providing empirical evidence that can be used in the implementation of appropriate measures for adaptation to climate change. The findings obtained can be most useful in decision making, to both farmers and policy makers, for working together in implementing the correct strategies that would be beneficial to the avocado industry and the province's economy.

1.3 OBJECTIVES

1.3.1 The overall objective

General: To assess the impact of climate variability/change and the agro-economic factors impacting on the production of avocados in the Limpopo province.

1.3.2 The specific objectives of the study are:

Specific objectives

- **(a)** To investigate possible agro-economic factors that affect the production of avocados
- **(b)** To determine the impact of climate change (temperature and rainfall) on the production of avocados
- **(c)** To suggest adaptation measures to climate change.

1.4 RESEARCH QUESTIONS

This study aim to answer the following questions:

(a) What are the possible agro-economic factors that affect avocado production?

(b) How is climate variability affecting the production of avocados in the Limpopo province?

(c) What are the constraints facing avocado farmers in the Limpopo province?

1.5 SIGNIFICANCE OF THE STUDY

This study contributes to the already existing body of knowledge on the interaction and effects of agro-economic factors and climate variability/change on agricultural production. It assesses the impacts of climate variability on avocado production. The results of this research will help farmers invest in climate change adaptation in the region. The study will further assist policy makers when taking decisions.

1.6 LAYOUT OF THE THESIS

This thesis is composed of five chapters. The first chapter gives a general perspective, the definition and problem statement of climate change and avocado production, and formulates the objective guiding the study. Chapter Two presents a theoretical and empirical literature review on climate change and avocado production. This chapter highlights an overview of the South African avocado industry, and gives projections of future changes in climate. Chapter Three outlines the methodology applied for the analysis in this study. Chapter Four gives the finding and Chapter Five gives conclusions and recommendations.

CHAPTER TWO

THEORETICAL AND EMPIRICAL LITERATURE

2.1 INTRODUCTION

Climate change is one of the main factors that this study aims to explore, and as such, its influence on the growth and subsequent marketing of the avocado fruit will be discussed in this chapter.

This chapter presents the theoretical and empirical literature of the study. it is organised into the following sections: section 2.2 presents theoretical literature, and subsection 2.2.1 presents literature on climate change and projections of future changes in climate; 2.2.2 presents an overview of an avocado industry; 2.2.3 presents information on the industry performance and available markets; 2.2.4 presents the impacts of climate change on avocado production; 2.2.5 presents the importance of weather on production of avocado; and lastly, subsection 2.2.6 presents the annual avocado growth stages in response to climatic conditions. Section 2.3 presents the empirical literature, with subsection 2.3.1 looking into empirical comparative studies.

2.2 THEORETICAL LITERATURE

2.2.1 Climate change and projections of future changes in climate

Climate change can be described as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (UNFCCC, 2007b). According to IPPC (2007), climate change is attributed to a statistically significant deviation of the mean state or variability of climate over a lengthy period (IPCC, 2007). Additionally, the change in occurrence and intensity of extreme weather events, such as heat waves, floods, droughts and bushfires, could also be linked to climate change (IPCC, 2012a). However, there are also some advantageous effects that could be expected to result from changes in climate, particularly in some temperate regions (Mendelsohn et al. 1999).

This phenomenon is a global issue that affects everyone, and in agriculture it is more often related to its potential impacts on productivity (O’Reilly et al. 2003; Lobell and Field, 2007; Lobell et al. 2011; Gourdji et al. 2013). Africa is recognised to be more highly exposed to climate change than other regions in the world are, and susceptible areas are expected to experience losses in agricultural productivity (Rosenzweig et al. 2002). Reduction in yields could lead to large losses in revenue, which in return will impact negatively on food security (Butt et al. 2005). Negative economic impacts of climate change are felt by the poorest members of society who depend greatly on agriculture for jobs, food and income (FAO, 2011). Therefore, the expected impacts of climate change have really stirred serious worries over the enormousness of future global food production in agricultural sectors (Bindi & Olesen, 2002).

Future temperature changes

Climate models project an increase in temperature in Africa over the next 10 to 90 years (IPCC, 2007). Changes in average temperatures are estimated to rise by 1.5 to 3°C over the continent by 2050, and will carry on to increase further over the years (IPCC, 2007). Heatwave occurrences in all seasons are very likely to be above normal due to projected increases in global annual mean temperature throughout the region. The annual rainfall is expected to decrease greatly in Mediterranean Africa and the northern part of Sub-Saharan Africa (IPCC, 2007). Drought is also predicted to increase by the year 2080 by up to 8% for the arid and semi-arid regions, under a variety of climate scenarios. This will result in the overall cost of adaptation becoming no less than 5 to 10% of the Gross Domestic Product (GDP) of most African countries. The key global predictions are set out in Table 2.1 below.

Table 2.1: Key global predictions

• Total increases in average global temperatures are estimated to be within the range of -17.5°C to -13°C by 2100, and are likely to increase by at least -16.3°C for all scenarios, apart from the one representing the most aggressive mitigation of greenhouse gas emissions. • The average global temperature is projected to warm by at least twice as much in the next 100 years to come as it has done during the last 100 years. • Ground-level air temperatures are anticipated to carry on warming faster over land than in oceans • Some parts of the world are expected to see higher temperature increases than the global average

Source: IPCC (2007)

2.2.2 Overview of South African avocado industry

South Africa is not the only country growing avocados, research shows that avocado is grown around the world in the sub-tropic and temperate climate regions (Witney, 2002). The areas in which avocados are grown include Central and South America, Spain, Kenya and South Africa (Bill, 2014). According to de Graaf (2011), the most recent estimates suggest that the world produces about 3.5 million metric tons of avocado per year, with most of this (32%) being produced in Mexico. In South Africa, the fruit is grown in the regions that fall in the north-eastern areas (Limpopo and Mpumalanga) and some areas of Kwa-Zulu Natal (Donkin, 2007) (Figure 2.1). These areas are characterised by relatively high summer rainfall and are made up of highly weathered and freely drained soils with low pH levels (Witney, 2002).

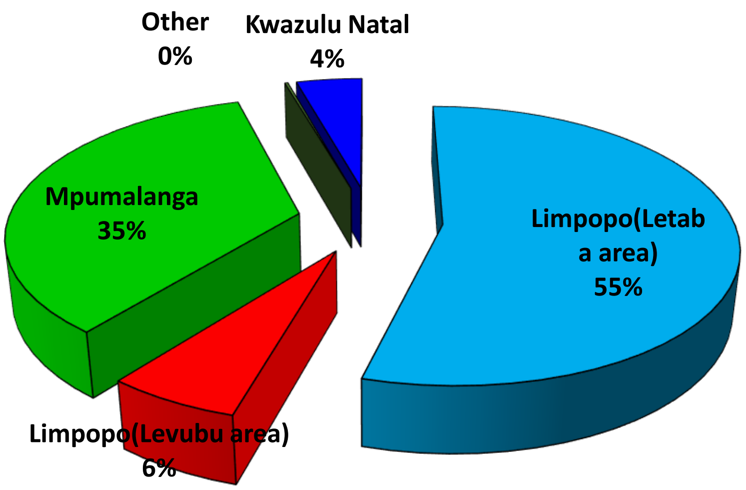

Figure 2.1: South African avocado commercial production regions; percentage production by province

Source: Subtrop (2013)

The Limpopo province represents the highest percentage of national avocado production (61%), with 9 401 ha under avocado cultivation in 2012 (DAFF, 2012). The Letaba and Soutpansberg districts of Limpopo province are the areas where most of the avocado plantings are found (DAFF, 2015). KwaZulu-Natal and Mpumalanga provinces follow with 30% (4 554 ha) and 8% (1 319 ha), respectively.

2.2.3 Industry performance and available markets

Subtropical fruits in South Africa (particularly avocado and banana) represent the strongest contributors to the gross value of horticultural products (Scheepers et al. 2007).

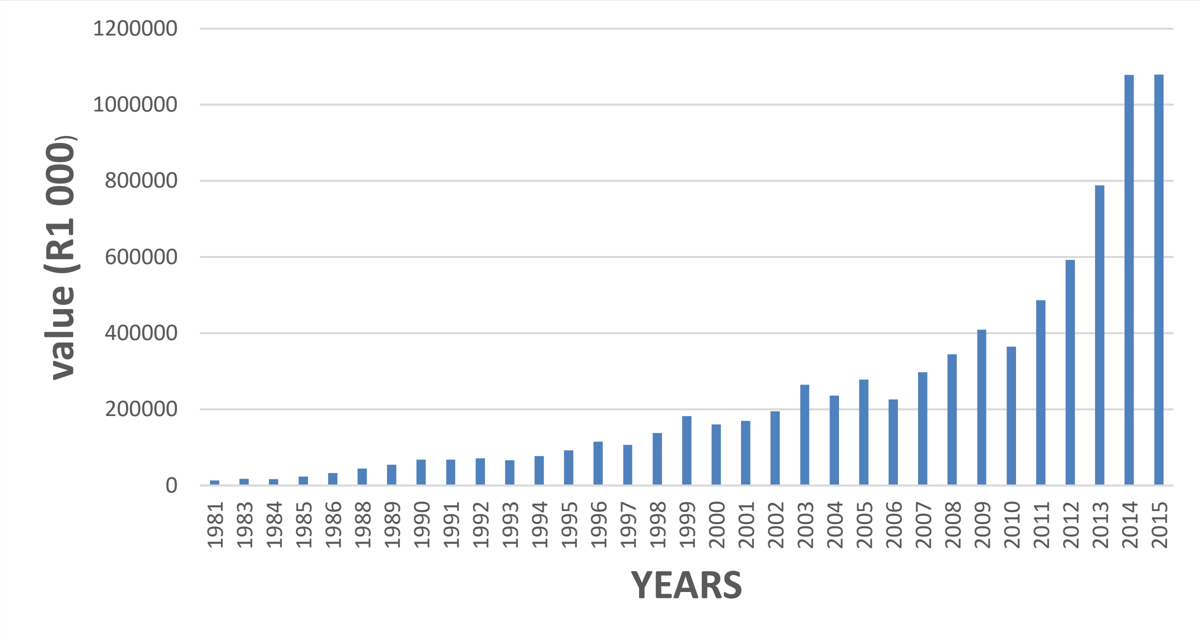

Figure 2.2: Gross value of production for avocados in South Africa, 1981–2015

Source: Quantec Easydata (2015)

As illustrated in Figure 2.2 above, there has been an exponential growth in the gross value of production (GVP) for avocados from 1981/82 to 2014/15. This observation can be attributed to the fact that the avocado industry is mainly export based (Donkin, 2007 & Scheepers et al. 2007). The gross value of production is greatly dependent on international avocado prices and fluctuations in the value of the South African currency relative to the currencies of South Africa's trading partners. However, fluctuations in the total value of production for avocados cannot certainly be fully explained by fluctuations in the quantity of avocados produced in a given production season. The gross value of production increased by 40% between the 2012/13 and 2014/15 production seasons. The gross value was, however, 98% higher during 2014/15, as compared with the previous decade.

Linden (2013) has stated that South Africa exports 60% of its production because South African per capita consumption falls below 1 kg per annum. Ntombela et al. (2013) and Mt. Kenya Fresh Avocados (2016) put South Africa at the top of the avocado exporters in Africa and at number 4 in the world (Figure 2.3 below). It has been stated by Bill et al. (2014) that the two major markets for world avocado trade are the United States and the European Union, which account for imports of 150–160 000 tons per year, and 140 000 tons per year, respectively. Additionally, according to DAFF (2015), the European Union has been the major importer of South African avocados for the past 5 seasons, as can be seen in Figure 2.4 below. Cordes (2016b) also states that South Africa will be alongside Peru and Brazil in the promotion of avocado in Europe in 2017, under the banner of the newly formed World Avocado Organization.

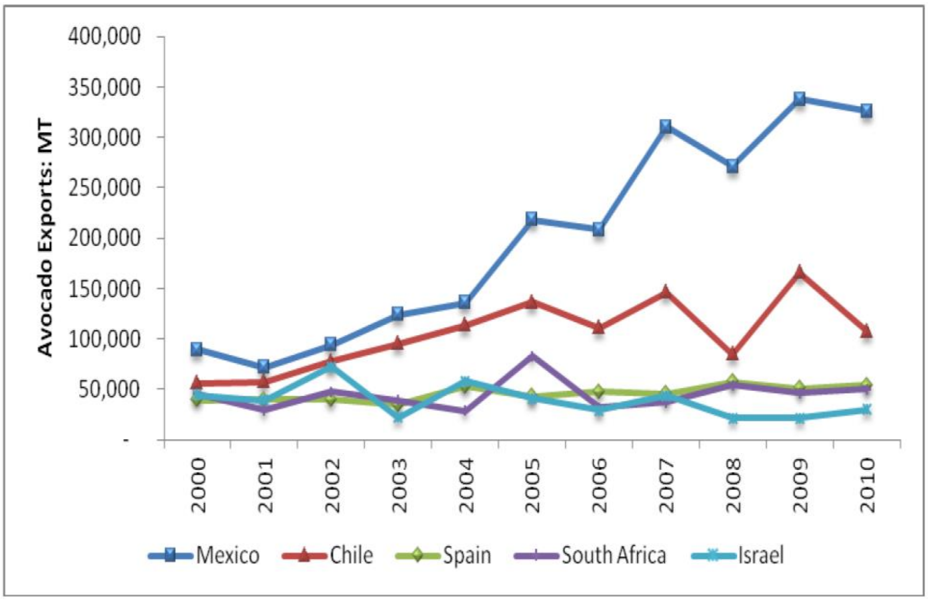

Figure 2.3: The top five avocado exporters in the world

Source: Ntombela et al (2013)

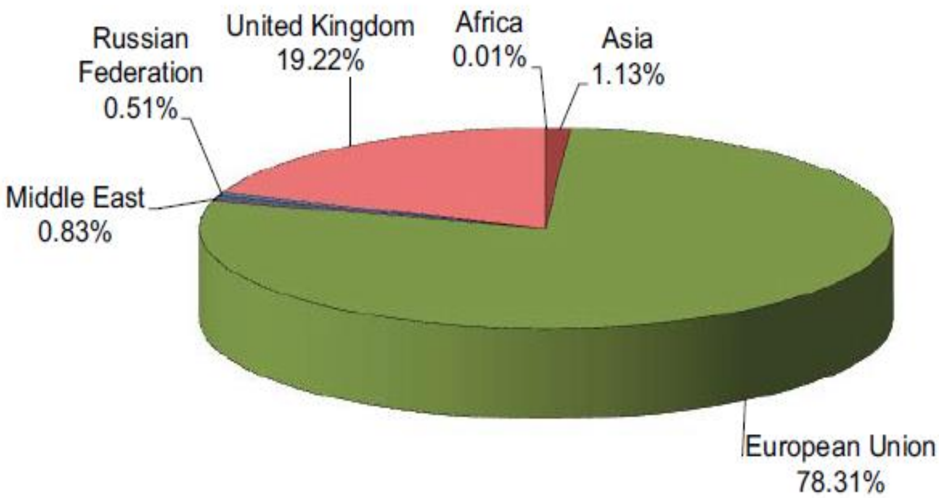

Figure 2.4: Major importers of South African Avocados for the past five seasons

Source: DAFF (2015)

According to Donkin (2007) and SAAGA (2012), the South African avocado industry saw a growth in the area planted from 2000 ha to 12 000 ha from 1970 to 2003. This correlates fairly well with the findings of Voster (2001) who noted that South African export volumes grew linearly from 1981 to 2000. The avocado export market has been unstable in the past few years (Figure 2.5 below), mostly because of the weakening and strengthening of the Rand against the Euro, together with the British pound and the dollar (USA). In the years 2007 and 2010, the export volumes were at their lowest due to fruit quality problems caused by unfavourable weather conditions (DAFF, 2015). Moreover, it has been reported that export prices have mainly been reactive to avocado quantities being sold, and the prices are typically lower in the domestic market as compared with export markets (DAFF, 2015).

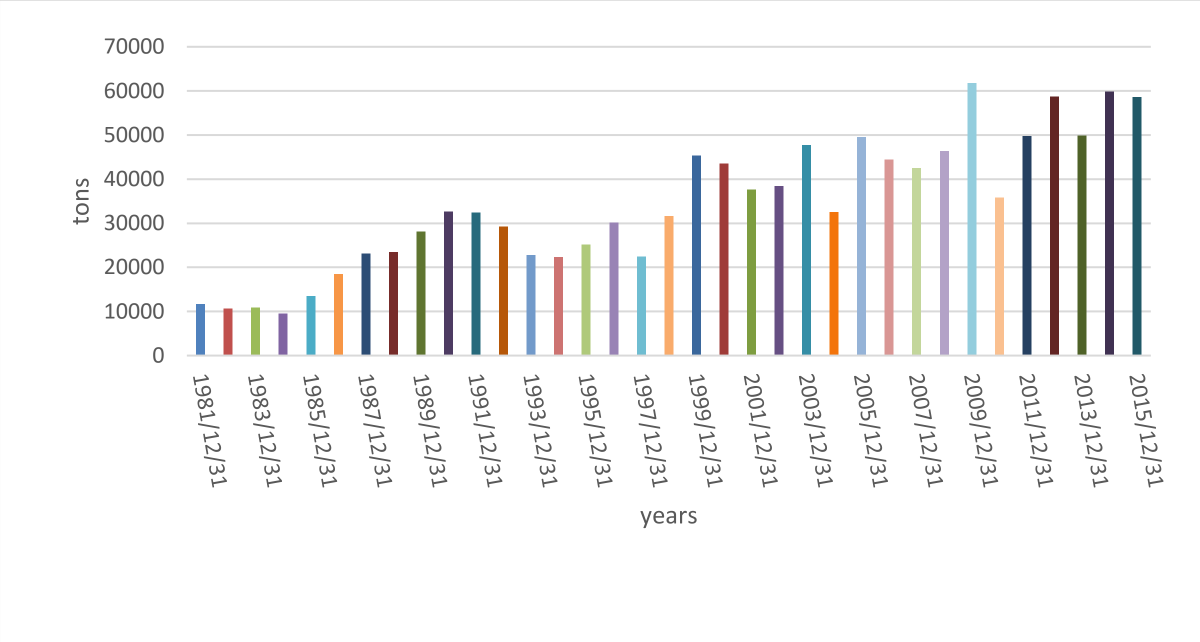

Figure 2.5: South African avocado export volumes from 1981 to 2015

Source: Quantec Easydata (2015)

As emphasised above, the avocado industry in South Africa is export orientated, with roughly 3.0% of the international market share during the year 2014. During the 2014 agricultural season, South Africa exported 60 000 tons of avocados with a total value of R978 million (DAFF, 2015). The quantity exported during 2014 was higher than the quantity exported in 2013.

Table 2.2: Share of provincial avocado exports to the total RSA avocado exports (%)

Years provinces	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Western cape	0.6	3.4	7.4	0.9	0.2	0.2	0.4	0.7	0.3	1.2
Eastern cape	0	0	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0
KZN	6.0	1.1	2.9	1.6	0.9	1.4	2.0	1.7	0.3	0.1
Gauteng	17.3	19.5	12.9	9.8	13.0	14.8	25.4	13.5	11.5	12.2
Mpumalanga	8.9	10.8	21.2	15.1	17.7	18.9	28.0	14.1	13.4	13.9
Limpopo	67.2	65.2	54.8	72.4	68.1	64.8	44.3	70.0	74.5	72.6

Source: DAFF (2015)

Table 2.2 illustrates the provincial shares contributed to national avocado exports, of which Limpopo commanded the greatest share of avocado exports, with an average of 65% of the total exports for the past ten years, followed by Mpumalanga (16%) and Gauteng (15%). These three leading provinces together accounted for 98.7% of total value of South African exports of avocados in 2014.

Donkin (2011) states that 13 250 ha of land are used to produce an annual amount of 10 000 tons of avocado in South Africa. Despite the fact that the South African avocado industry is export based, the local markets still take up a substantial amount of the sales of avocado. For example, Ntombela et al. (2013) assert that the local market takes up 40% of the produce, with 25% going to the formal markets and the remaining 15% being taken by the informal *"bakkie sales"* market. According to Linden (2013), who refers to them as "*walker markets"* because they take the fruit directly to the streets, these informal markets are unique to South Africa and are rapidly growing all over the country. Some of the avocado that is produced in South Africa is processed into oil and guacamole (Donkin, 2011; Ntombela et al. 2013).

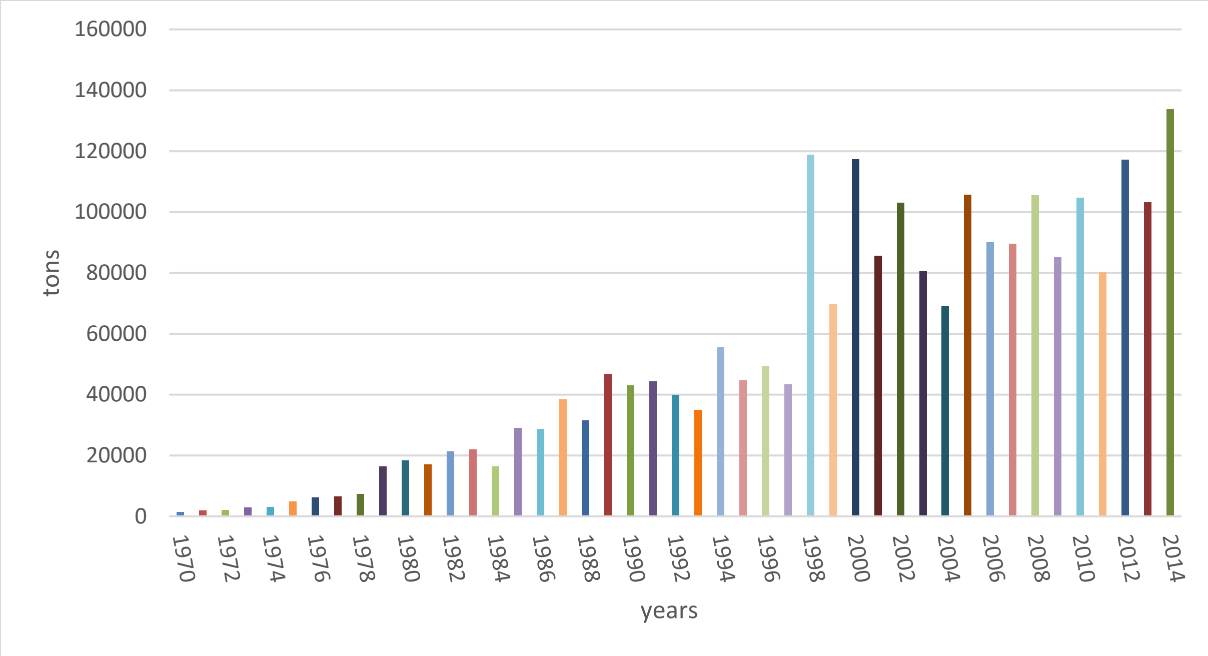

Figure 2.6: Total South African avocado production 1970–2014

Source: Statistics and Economic Analysis, DAFF; SAAGA, (2014)

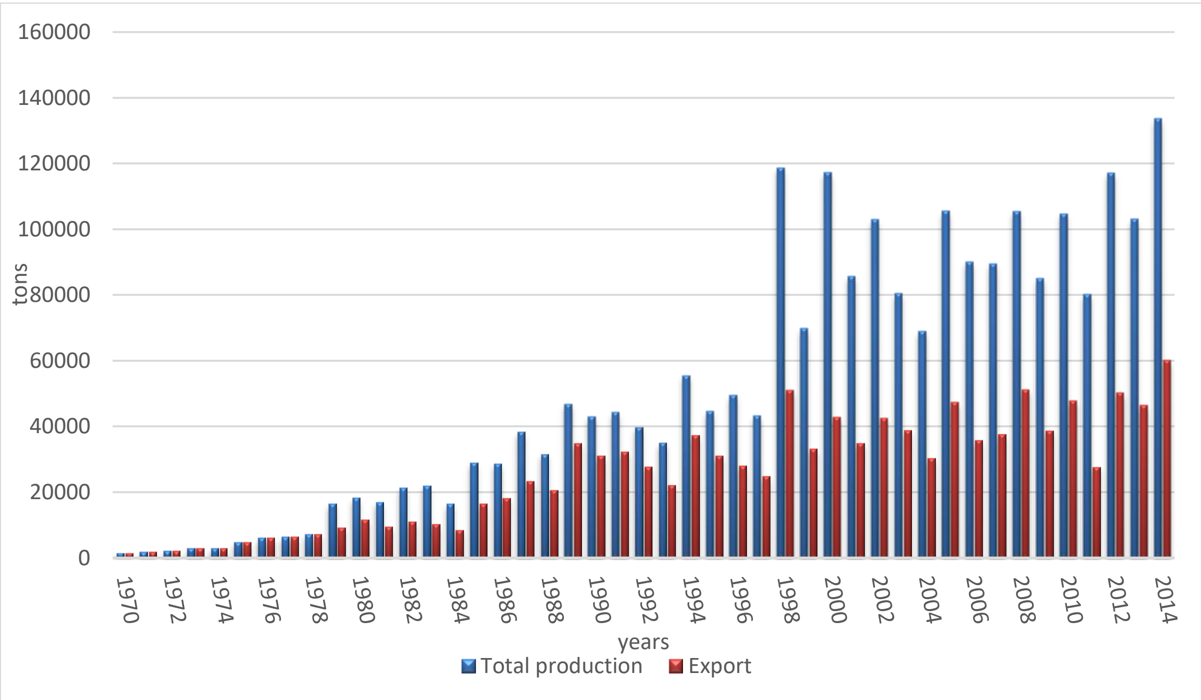

Figure 2.7: South African avocado and exports from 1970 to 2014

The South African avocado industry has made considerable progress in improving the quality of avocados marketed in Europe. Over the past decade, avocado exports have been growing, and there is correlation between avocado yield and the quantity exported (Figure 2.7 above). As avocado production increases, the quantity of avocados exported also increases proportionally. The main challenges that the avocado industry is facing comprise strict market place requirements. There are high demands placed on fruit quality and size. In addition, overseas markets prefer one cultivar, the Hass cultivar (Cutting et al. 1993), which bears a large percentage of undersized (<200g) fruit. Quality defects cause sales to be difficult in the market because the market has become increasingly competitive.

A huge quality defect that continues to cause difficulties in the market is lentigo damage experienced with the Hass cultivar, which is mainly caused either by the rough handling of fruit or too low cold storage temperatures (Milne, 1994). In the experiments done by Fitzell and Muirhead (1983), temperature during ripening of avocado fruit was found to have an important effect on the development of post-harvest diseases. A high percentage of South African avocados was noted to have displayed packing and picking injuries during the year 2009 (SAAGA, 2014), and these quality defects are mainly associated with fruits having been more disposed to physical injuries because of unfavourable weather conditions.

South Africa is also at a disadvantage compared with some of its competitors. The imports tariffs charged by some Asian countries are very high; for example, avocados exported from South Africa to China bears tariffs of 25%.The following Table (2.3) illustrates the strength, weaknesses, opportunities and threats experienced by the South African avocado industry.

Table 2.3: South African Avocado SWOT Analysis

Strength	Weaknesses
•Promotion of S.A. avocado has been successful, especially in the European markets •Well-established export operations. •South Africa avocado industry has a strong international market reputation. •Openness to share market on national and international levels	•Production is largely dependent on climatic conditions. • Input and capital costs are relatively high

Opportunities	Threats
•Strong demands in Europe during summer months, particularly so in the UK Potential growth from increasing demand from avocado processing	•Potential competition from Spain, Israel, Kenya, Peru and Mexico for the lucrative European market. •Port abilities and shipping cycles still pose a threat as delays and can easily reduce shelf life by five to ten days.

Source: (SAAGA, 2010)

2.2.4 Impact of climate change on avocado production

According to Lobell et al. (2006), human-induced climate change will induce changes in the agricultural industry. A number of researchers agree with this observation and state that the variation in climate will have an impact on crop yields in different ways for different regions (Downing, 1992; Fischer & Velthuizen, 1996; Yates & Strzepek, 1998; Schultz, 2011).

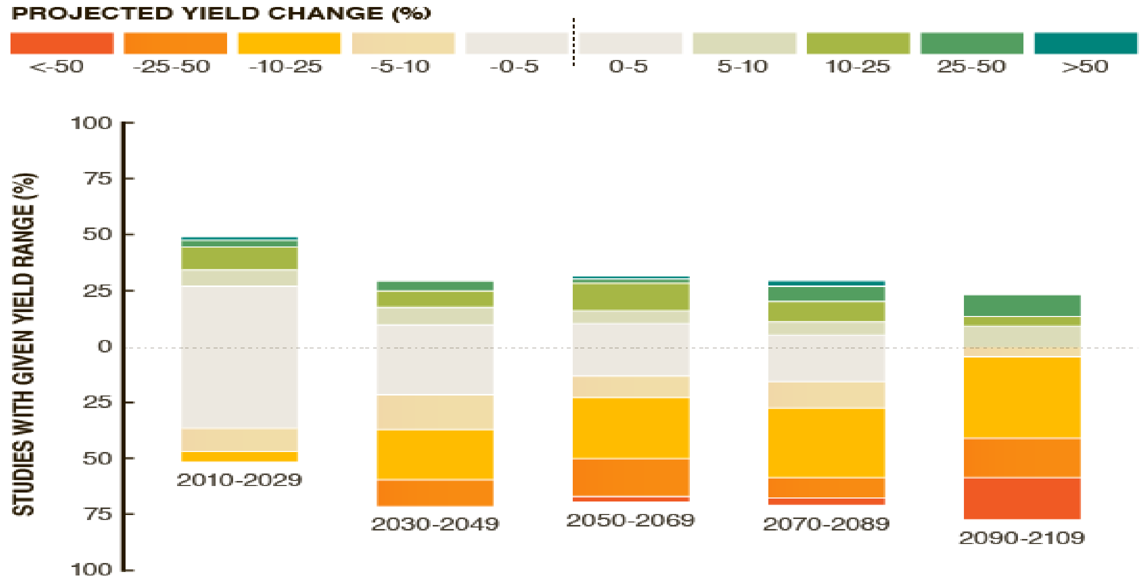

Figure 2.8: Model projections of the effect of climate on agricultural crops yield dynamics

Source: Challinor et al. (2014a)

According to Araujo and Johnston (2014), in the last two decades, farmers have seen temperatures drop in summer and increase in winter, as well heavy rains in January, resulting in various negative impacts on fruit production. These impacts tend to favour the incidence of diseases and/or the retardation of the setting growth stages in the fruits' life cycles. Predictions on the possible effects of global warming suggest that the South African region will experience variable and unpredictable rain, with higher frequencies of drought and high-intensity rainfall (UNICEF, 2011). The effect of climatic elements on the growth, quality and market performance of avocado will form the subject of this section.

According to Cordes (2016a), the higher temperatures and drought incidence in South Africa has resulted in early avocado maturity, which makes the consumers sceptical about the quality and therefore results in a reduction in sales. Since avocados consume relatively more water than other fruit crops do, drought conditions during the growing period will result in increased irrigation demands (Figure 2.9). Howden et al. (2005) studied the influence of climate change on the avocado industry in Australia and attested to the influence of heat stress on fruit set and fruit size. They continued to recommend that marketing plans be adjusted so as to accommodate the effects of climate change during harvest times. Below is a graph (figure 2.9) that indicates irrigation water consumption by various crop

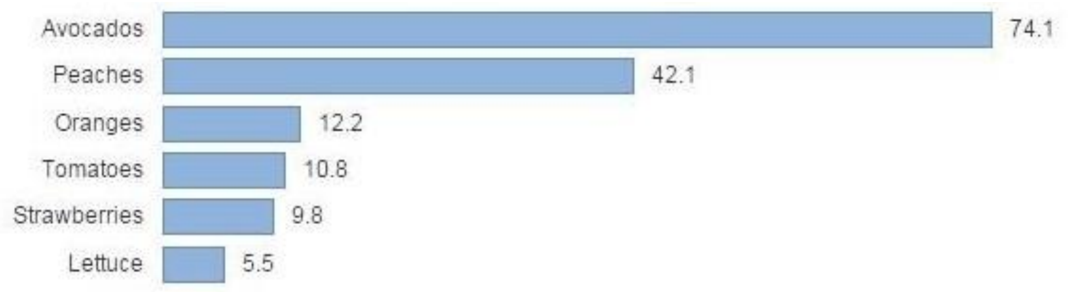

Figure 2.9: Irrigation water consumption by various crops

Source: Donavan (2015)

According to Moretti et al. (2010), when avocado trees get exposed to high temperatures during fruit growth and development, their fruits tend to ripen later than those trees that were not exposed to higher temperatures. Cordes (2016a) also states that hailstorms can cause the destruction of up to 30% of avocado crops in most regions, resulting in a drop of about 1.5 to 1.7 million cartons. Zabata (2016) estimates that climate change will cause a 40% decrease in avocado production in the next 30 years.

2.2.5 The importance of weather on avocado production

Temperature in avocado production is very important because it affects avocados in numerous ways, including influencing the timing and consistency of flowering, fruit growth, ripening, and fruit value. There are three horticultural races or ecotypes of avocados, termed the Mexican, Guatemalan and West Indian or Antillean races (Zentmyer et al. 1987). These races have markedly different temperature tolerances, primarily due to their areas of origin (Malo et al. 1977). The West Indian avocado race is cold sensitive and is thus susceptible to extremely low temperatures (Joubert & Bredell, 1982). South African farmers are producing five varieties of avocados: Fuerte, Hass, Ryan, Edranol and Pinkerton. These varieties belong to the Guatemalan and Mexican races. Favourable climatic conditions for producing avocados in South Africa range from temperatures between 4°C and 31°C and annual rainfall of 660 to 1500 mm. According to Gafni (1984), temperatures higher than 42°C are unfavourable for avocado production. Temperatures less than 12°C can affect flowering and reduce fertilisation (Sedgley & Grant, 1982).

Additionally, if temperatures rise up to and above 30°C for a number of days, it would affect fruit production because an increase in temperature during spring and summer affects photosynthesis in a negative way (Ferrini et al. 1995; Jackson & Lombard, 1993). These conditions have also been said to cause harmful effects to the roots of the trees (Whitmore, 1986), which is a serious concern and has led to cropping strategies such as mulching. Lahav and Trochoulias (1982) have established that high temperatures might result in reduced leaf area and increase competition between vegetative growth and fruit set. Persistent wet conditions also reduce overall tree vigour, hamper fruit set, and cause fruit drop (Banks, 1980; Baxter, 1981). At the same time, water stress throughout fruit development is critical as some cultivars such as Edranol shed fruit if stressed, while others keep their fruit at the expense of size and quality (Bower & Cutting, 1988).

2.2.6 Annual avocado growth stages with responses to climatic conditions

An avocado tree has three phases in its annual growth cycle (SAAGA, 1979). The first phase of the avocado growth stage starts with bud differentiation, which occurs during the months of April and May, and continues during the month of June (Robertson, 1969). The second phase starts in June, with flowering, and this continues until

October. In a study done by Sedgley (1977), pollination under temperatures between 12 and 17°C was found to be unsuccessful at most times, which is due to the pollen germ tube failing to reach the ovary. If the temperature rises above 28°C, flowers are inclined to absciss. After flowering, comes the fruit set and fruit drop stage, which takes place from the end of September (Robertson, 1969), and this is said to be the heart of the success or failure of fruit production. The fruit drop is completed towards the end of December. Phase 2 is a critical stage of fruit production, which period in South Africa is mostly characterised by drought and very hot conditions, during the months of October to December (SAAGA, 1979). Any water stress during this critical period encourages fruit drop. The final phase of avocado fruiting starts from the end of December and completed when the seed reaches maturity and a reduction of fruit growth sets in towards the end of April. Any action that will be taken during this period by the farmer to stimulate leaf growth will enhance the size of the fruits (SAAGA, 1979).

2.3 EMPIRICAL LITERATURE

2.3.1 Empirical comparative studies

In this section of the chapter, the findings of various researchers on the subject of climate change and its expected effects are discussed. This is important because knowledge on this subject is integral to the sustainability of the industry. The amount of information that is available needs to be presented and understood from a practical perspective. It is of the utmost significance to know the dynamics, influential factors, and possible solutions to each of the challenges.

A number of papers have been published reporting on the continued growth of the South African industry with respect to export markets (Voster, 2001; Ntombela et al. 2013; DAFF, 2015). The growth can be recognised by numerous factors such as physical growth in the form of increased plantings, improved cultivars, and year-round avocado production (McShane, 2015). It has been reported that nurseries produce an average of 110 000 trees per annum (DAFF, 2015). According to Dodd et al. (2008), post-harvest scientists who develop new, and upgrade existing, technologies deserve credit for the increase in the performance of South African fruit in export markets.

Turpie et al. (2002) did a similar study looking into the economics of climate change in the South African context, specifically looking into the natural, agricultural, man-made and human capital, by means of a production function approach. The production function approach was used to quantify the natural capital lost through global warming. There are other studies, such as that of Downing (1992), that also used the production function approach, but these studies argued that climate change might actually be beneficial to agricultural production, especially in arable lands, although in arid zones, it may have negative effects.

Fischer and Velthuizen (1996) predicted that in 2025 there would be an enormous fall in crop productivity as a consequence of global warming. According to Downing (1992), Kenya is expected to experience an increase in food production, if increased temperatures are accompanied by increases in precipitation. Schultz et al. (2011) also contributed to these arguments by arguing that the production of maize in Zimbabwe will decrease due to high temperatures that cause the crop growth period to be shortened. Schultz et al. (2011), however, found different results in their study done in South Africa, Lesotho and Swaziland, which assessed climate change to be related to production increases in maize yields, even though they at the same time argued that where yields are already low, it would have little to no impact.

Lobell et al. (2006) looked into the impacts of future climate change on perennial crop yields in California. They concluded that yield changes will show a combination of negative effects related with increasing temperatures, as well as positive effects that come with improved technology and management practices, and increased atmospheric carbon dioxide. Moretti et al. (2010) continue to assert that increased greenhouse gases (GHGs) levels that come with climate change can encourage visual injury and biological disorders, accompanied by changes in quality parameters, in the produce, whether fruits or vegetables. High rainfall during a harvest season can cause fruit rot and sunburn, and poor fruit set, which can result from temperatures above 36°C and 38°C, respectively (Araujo & Johnson, 2014).

A study on African climate done by Abidoye and Odusola (2015) shows that adverse climate change will eventually lead to declines in GDP. However, they argue that adaptation by promoting the improvement of water resources management infrastructure would be of importance in years to come. Evidence from Ayinde et al. (2011) reveals that temperature change produced negative effects, while precipitation change exerted positive effects, on agricultural yields. South Africa is expected to experience higher temperatures and less rainfall as a result of climate variation (Calzadilla et al. 2013).

There is consensus on the studies, compared through these passages, that climate variation will certainly have effects on the agricultural sector, and that these will affect the economy. There are, however, disagreements with regard to the manner or direction of the influence. Some authors support the observation that yields will be affected negatively due to a number of different factors (Moretti et al. 2010; Schultz et al. 2011; Araujo & Johnson, 2014). In contrast, other researchers advocate for positive changes, citing differences in site-specific conditions for each region (Downing, 1992; Lobell et al. 2006).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 STUDY AREA

The Limpopo province (located between longitudes 26° 0'0" E & 32° 0'0" E and latitudes 22° 0'0" S & 25° 30'0" S) is sited in the northern part of South Africa. The province has international borders with Botswana, Zimbabwe and Mozambique. The province is adjacent to Gauteng, Mpumalanga and the North West provinces. It is sub-divided into five districts, i.e. Capricorn, Mopani, Sekhukhune, Vhembe and Waterberg, which are in turn divided into twenty-two local municipalities.

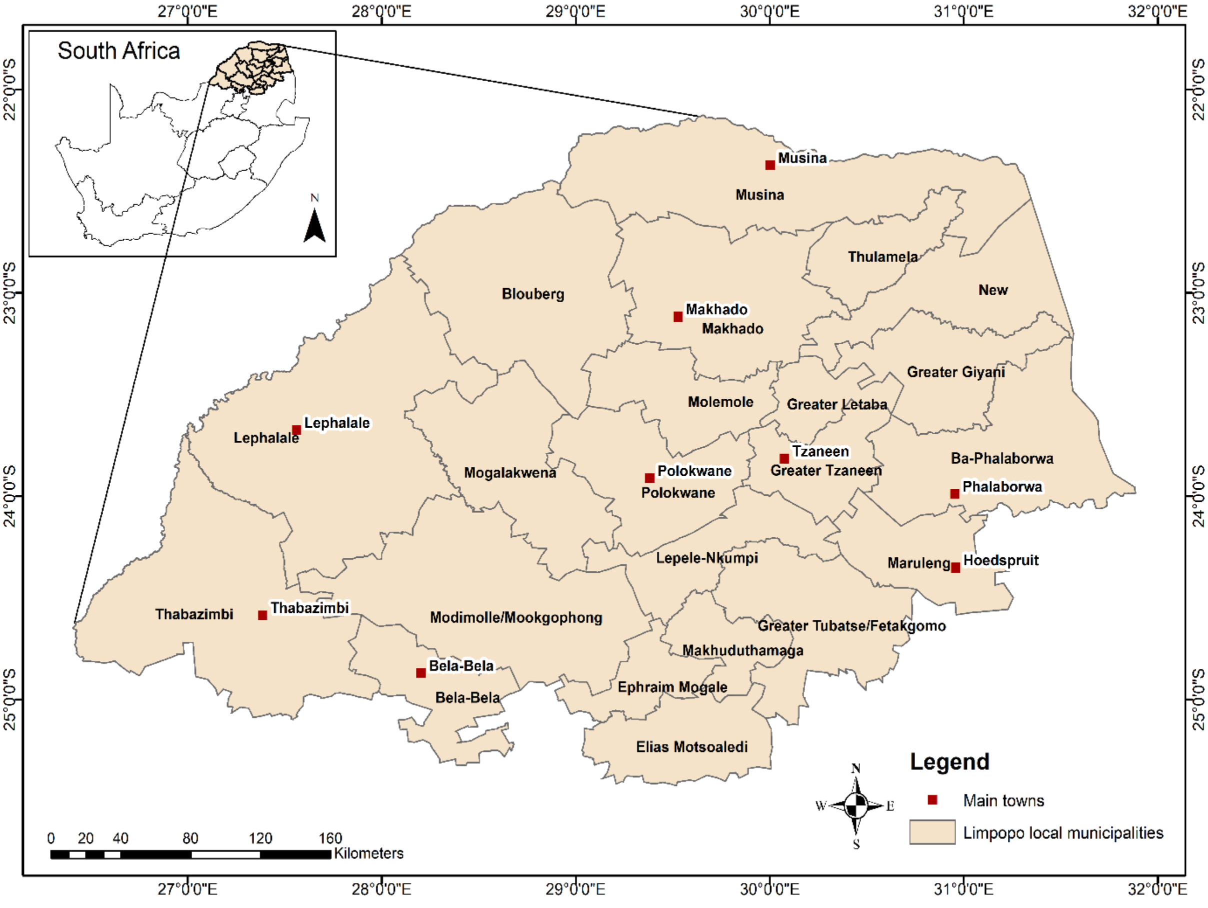

Figure 3.1: Map of Limpopo Province
Source: ARC-SCW (2018)

The province is very rich in agricultural terms, and has abundant avocado fields and other fruits, i.e. bananas, mangoes etc. (LDA, 2012). Agriculture utilises about 8 million ha of land in the province, of which 10 per cent is being utilised as arable land, 67 per cent for natural grazing, 10.4 per cent for nature conservation, 1.1 per cent for forestry, and lastly, 2% is utilised for other purposes (LDA, 2012).

The province can also be divided into numerous topographic zones; for instance, the eastern part of the province is characterised by flat, gently undulating lowveld, while the western part is bounded by the northern Drakensberg ridge and Soutpansberg with steep and slopes (DBSA, 1998). The province is amongst the areas that are exposed to climate change danger, which is attributable to the province's exposure to extreme weather events (Tennant & Hewitson, 2002; Cook et al. 2004).

The Limpopo province has three distinct climatic regions: there is the low veld region, middle veld region and Highveld regions (Oni et al. 2012). The semi-arid and the escarpment regions have a sub-humid climate, with rainfall in excess of 700 mm per annum (Oni et al. 2012). The climate allows the Limpopo province to produce a wide range of fruits and vegetables, including avocados, as shown in Figures 3.2 and 3.3 below.

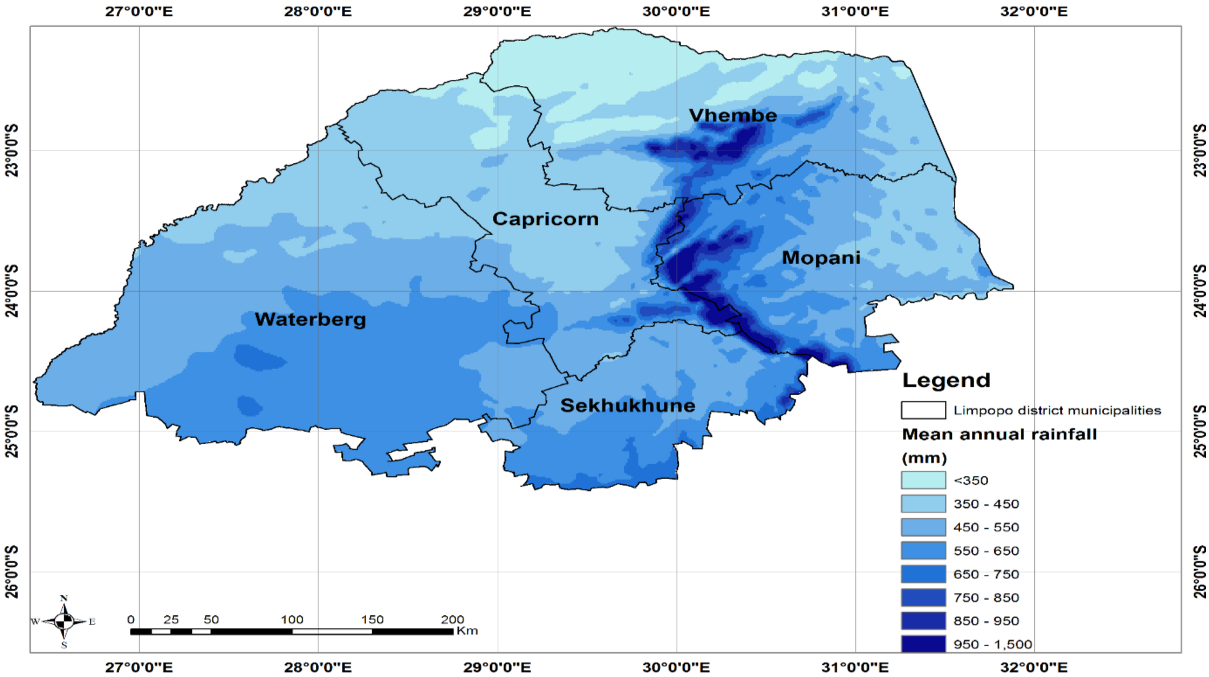

Figure 3.2: Limpopo mean annual rainfall

Source: ARC-SCW (2016)

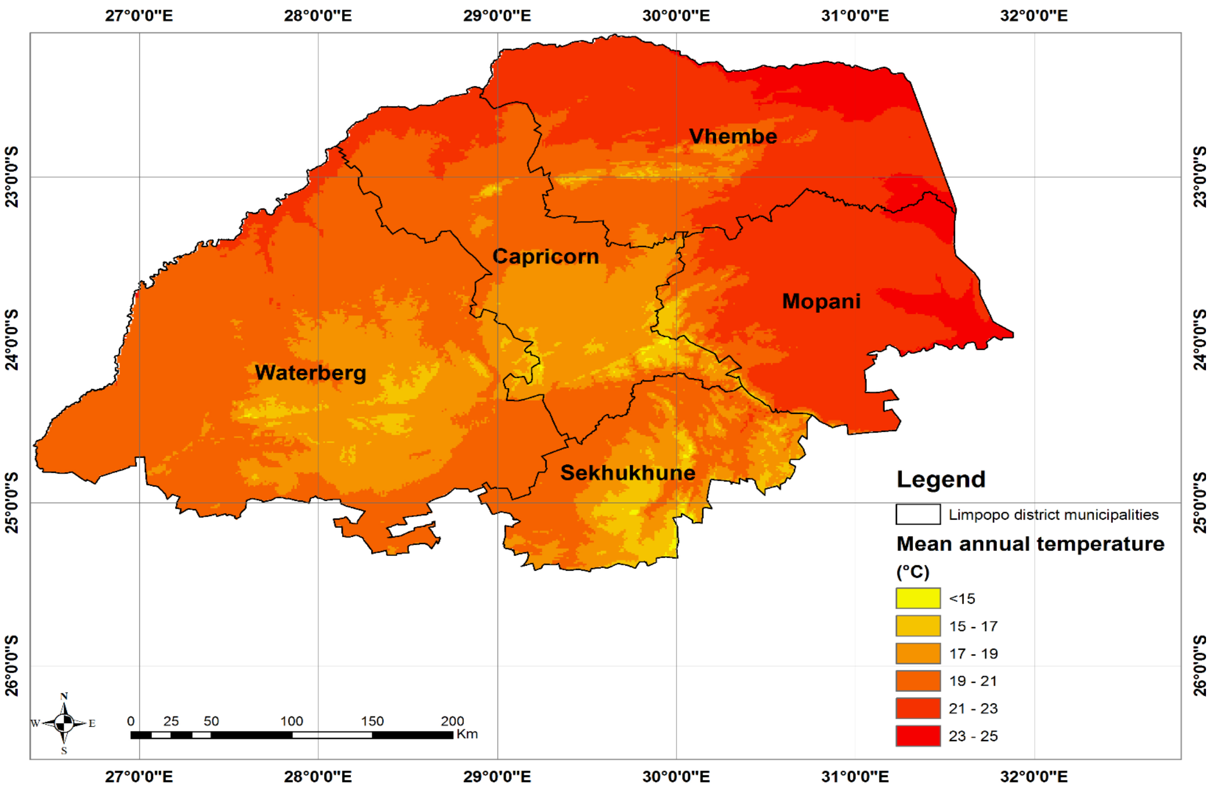

Figure 3.3: Limpopo average annual temperature

Source: ARC-SCW (2016)

The province is typical, developing area, which not only exports primary products, but also imports manufactured goods and services (Tshiala & Olwoch, 2010). It is also known that the province is amongst the poorest regions of South Africa, with a huge gap between the poor and the rich, especially amongst those who reside in rural areas (Statistics SA, 2015). Nevertheless, the province has shown great improvements in its economy and standard of living. In agricultural terms, enormous amounts of agricultural commodities are exported from this area (LDA, 2015). Subtropical fruits of different kinds are well established in the eastern part of this province. The province contributes 61% of national avocado production (DAFF, 2015), with approximately 6 400 ha being under avocado cultivation in the year 2010 (SAAGA, 2010). The Letaba and Soutpansberg districts are the areas in the Limpopo province where most of the avocado trees are planted.

The Real Economy Bulleting Review (2016) has summarised the contribution of agriculture to the province's economy. According to this report, Limpopo contributed only 7 % of the national GDP in 2014, with the real economy making up 33% of Limpopo's output, while in contrast, agriculture accounted for just 2%.

3.2 APPROACH AND METHODS OF THE STUDY

3.2.1 Agro-economic factors that affect production of avocados

The first step in determining the first objective of the study was to develop a survey questionnaire in relation to this objective, as well as to obtain additional information. The questionnaire was carefully designed to capture all the relevant information that could be used in addressing the research problem. A questionnaire comprises a written set of questions that are to be completed by respondents (Welman & Kruger, 2001).

Primary data was collected in the Limpopo province, specifically in the Vhembe and Mopani districts, from August to September, 2015. The population comprised small-scale and commercial farmers who are in the avocado production area in the region. The data was obtained using structured questionnaires (Appendix B) that include open- and closed-ended questions. Face-to-face interviews were conducted during which all respondents were requested to answer a set of structured questions. The interviews were conducted at Tzaneen, Lwamondo, Levubu and Phiphidi, where all respondents were avocado producers. The interview took 10 to 20 minutes per interview, on average. A minimum of 46 farmers were interviewed to gain greater details on how climate change is impacting on the economic sustainability of avocado production. The reason for this small sample number is that the study was only focused on a specific area, looking only into farmers whose main crop is avocado. The interview also included questions on farmers' adaptation methods, as these comprise an important aspect.

The survey questionnaire was structured into seven parts, designed to capture information coherently. Part one captured general information, while part two captured the respondents' incomes. The questionnaire further included sections on production, agro-economic information, marketing information, climate change questions, and lastly, an adaptation measures section. Questions designed specifically to capture objective two were asked in part five, which inquired into the knowledge, perception and influences of climate change on avocado production. The last part asked debriefing questions so as to ensure the validity and reliability of responses.

Specifically, the following information was collected and utilised:

- Data on general information included gender, interviewee, the name of the farm, municipality, and the town in which the farm is located. Other information included the size of the farm, size of avocado production area, and the total number of interviewees who have been farming avocados.
- Information on production included area planted over the years and tons of avocado produced in those specific years, while constraints encountered in production were also stated. Lastly, the total costs incurred in avocado farming were covered.
- The marketing section included information on who the farmers sell their products to, whether they export or not, and whether they have any contractual agreements.
- Questions to check their knowledge on climate change were also included to see what they understood and how they think that climate change is impacting on their production. The final section was on adaptation measures.

The primary data collected was coded and entered into computer software using STATA software, where descriptive statistics were used to find the percentages and mean and standard deviations to evaluate the significance of the variables.

3.2.2 Impact of climate change (temperature and rainfall) on the production of avocados

To determine the second objective of the study, climatic data consisting of daily rainfall and temperature was obtained from the Agricultural Research Council –Institute of Soil, Climate, and Water. From their 94 weather stations around the Limpopo province, four stations around the sub-tropical areas were randomly chosen, being the Letaba, Levubu, Duiwelskloof (Modjadjiskloof) and Lwamondo stations. The avocado production data over the years was obtained from the South African Subtropical Growers' Association.

Table 3.1: List of investigated weather stations in the Limpopo Province

Station name	Data type	altitude	latitude	longitude
Letaba	Tmin, tmax, rainfall	623	-23.867	30.3167
Levubu	Tmin, tmax, rainfall	880	-23.042	30.151
Duiwelskloof	Tmin, tmax, rainfall	858	-23.733	30.117
Lwamondo	Tmin, tmax, rainfall	648	-23.044	30.374

ARC-ISCW

The above four weather stations are closest to the avocado producing areas, in respect of which the study took secondary rainfall and temperature data. The temperature and rainfall data had missing data (gaps) which needed data imputation, and the ARC stand-alone data patch function was used to impute the data. The function employs the multiple linear regression (MLR) and the inverse Distance Weighting (IDW) methods (Shabalala & Moeletsi, 2015). Multiple regression was run to assess the impact on avocado production according to price, temperature and rainfall. Firstly, multiple regression was run, using maximum temperature, price, and total annual rainfall, to assess the oval impact on avocado yields. Secondly, 10-, 15- and 20-year moving averages were calculated to obtain long-run data required for this climate change study. Subsequently, the standard deviation was calculated to measure the weather (temperature and rainfall) fluctuations, while the price index was also calculated in the analysis to measure changes in a set of prices over time.

3.2.2.1 Statistical analysis

Moving averages

The study employed a **moving average** model because this is a climate change study, and long-run data is needed. Time series had regular fluctuation, moving averages smooths out the noise of random outliers and emphasize long term trends. Moving averages were calculated over a range of years (10, 15 and 20). Moving averages were calculated by taking the arithmetic mean of a given set of values for the specific, needed years.

Moving Averages Model:

$$MA = \sum_{i=0}^{n} T_i(R_i)\ /N$$

MA = moving average

Ti = temperature in period i

Ri = rainfall in period i

Standard deviation

The study then employed another model "standard deviation" to quantify the volume of variability or dispersion around average temperature and rainfall. This expresses how spread out the responses are, and if they are intense around the mean, or scattered, far and wide. The greater the spreading or variability is, the greater the standard deviation is. The slighter this dispersion or variability is, the lower the standard deviation is.

The following steps were followed when calculating the standard deviation:

Step 1: Find the mean.

Step 2: For each data point, find the square of its distance to the mean.

Step 3: Sum the values from Step 2.

Step 4: Divide by the number of data points.

Step 5: Take the square root

Standard Deviation Model:

$$\sigma = \frac{\sqrt{\sum (x - \bar{x})^2}}{N}$$

where

σ = the standard deviation

x =each value in the population (temp and rainfall)

$\bar{x}$ *=the mean of the values (temp and rainfall)*

N = the number of total respondents.

Price index

An avocado Price index was also included in the analysis to measure the percentage change in prices over the period from 1970 to 2014.

To **calculate** the **Price Index**, the **price** of the Market Basket of the year of interest was taken and divided by the **price** of the Market Basket of the base year, then multiplied by 100.

Price Index Model:

$$I_{t=\frac{Yt}{Ybase}} * 100$$

where:

It =price index

Yt = avocado price of current year

Ybase = avocado price of base year.

Multiple regression

Multiple regression was run to assess the impact on avocado production from the price, temperature and rainfall.

Y= α+$b_1X_1 + b_2X_2 + b_3X_3 \ldots + B_1X_1 + u$

Y= production

X1 = Price

X2= Temperature

X3 =Rainfall

3.2.3 Climate variability adaptation strategies

To determine the third objective of the study, a section on adaptation measures was included in the questionnaires. The questions were open ended to allow farmers to describe their own strategies that they feel would their boost their economic returns. A literature review was done to assess what other authors say about the topic in hand, and to also review strategies to derive over-all strategies that might assist avocado producers in the Limpopo region.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results and discussion of the study, and is organised into three sections: Section 4.1 presents results and discussion for objective one, Section 4.2 presents results and discussion for objective two, and finally, Section 4.3 presents results and discussion for objective three.

4.1 AGRO-ECONOMIC FACTORS THAT AFFECT PRODUCTION OF AVOCADOS

The first objective of the study was to investigate the possible agro-economic factors that affect the production of avocados. To investigate this, a section in the questionnaire was added to assess the economic indicators that are being impacted upon by climate variability. Each farmer was interviewed in response to what he or she is currently facing on his or her individual farm. The findings were coded and analysed using Microsoft's Excel program.

4.1.1 General information

The aim of this sub-section is to go through the general information that was reported in the survey questionnaires. This is to give the background information on who the respondents were in terms of gender and their sources of income. Their marketing information is also included.

4.1.1.1 Gender of farmers

A skewed female-to-male ratio is largely evident in this sample population. The gender distribution reveals that there are more male-headed avocado farms (97%) than female-headed farms (7%) (See figure 4.1). This shows that even though most farms are female headed, male farmers are still dominant in the avocado sector. Women tend to have least access to and control of productive resources such as land, capital and agricultural services like credit and training that are necessary for increasing yields and moving from subsistence to market oriented production (Jiggins et al. 1997; FAO 2011).The current trend showing that men are increasingly moving into food crops as well as into the previously neglected fruit trees as the prices of traditional export crops fall suggests that there is immediate need for intervention to improve women's access to profitable markets (Bolzahi, et al. 2010).

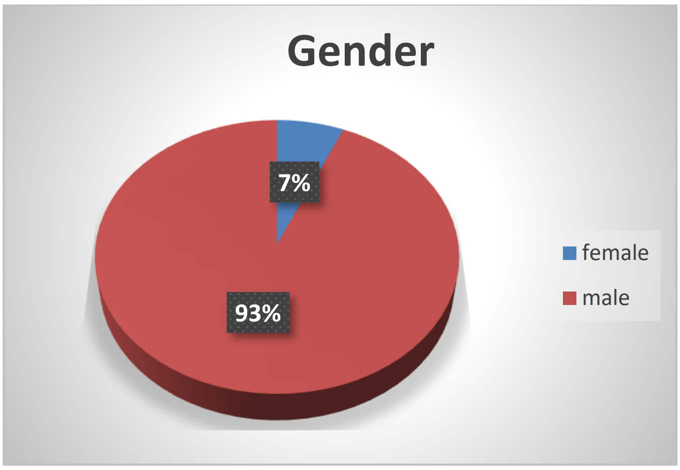

Figure 4.1: Respondents' Genders

4.1.1.2 Sources of income of the respondents

In order to gain a clear view of the economic setting of the farmers, this section presents the different sources of income for the surveyed farmers. Figure 4.2 below provides a distribution of the major sources of income for the avocado farmers.

Most of these farmers (87%) make their living from fruit crop production, and as they depend on this for their livelihood, it is therefore essential for them to get returns. The remainder (13%) have salaries to supplement the income from their farms. From this, we can conclude that avocado and other fruits play a major role for these farmers; through fruit farming, they are able to provide for their families and for their livelihoods.

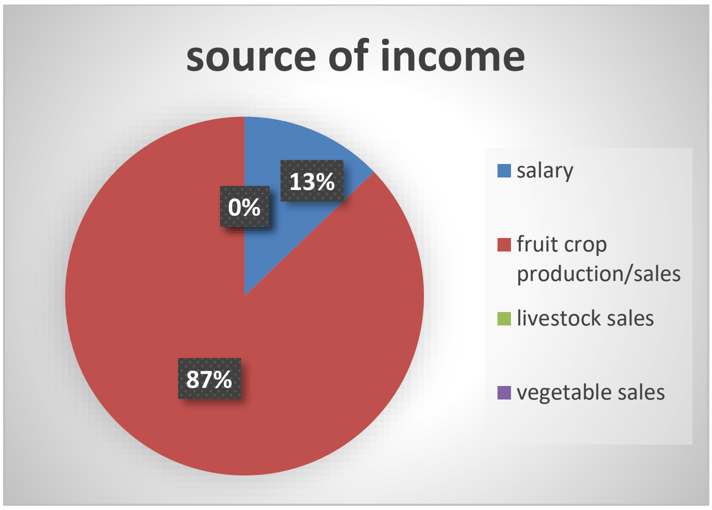

Figure 4.2: Respondents' sources of income

4.1.2 Production constraints on Avocado farmers

In the survey carried out, 67% of the farmers interviewed are commercial farmers, exporting their fruit to international markets in Europe and the United Kingdom, while the remaining 33% sell their products to local markets. Most of these farmers have signed contractual agreements with agribusinesses, selling their products through them, which makes logistics easier for them. These farmers further stated that they make more profit from exporting their fruit than selling them locally, as international markets give greater returns.

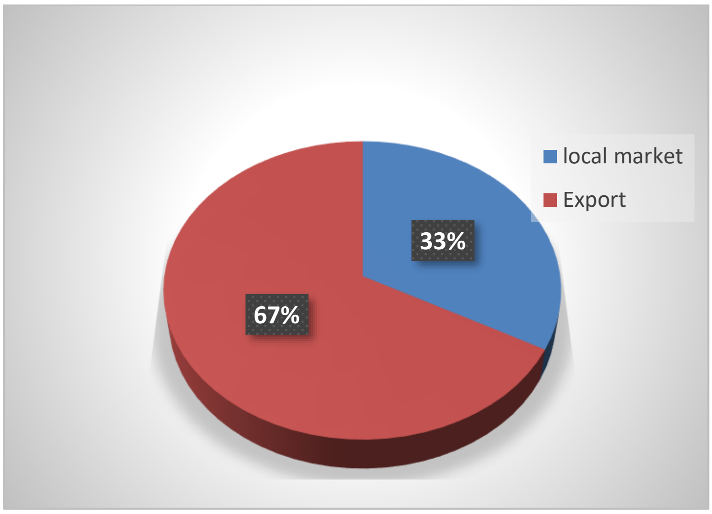

Figure 4.3: Avocado sales in Limpopo region

The participants were further asked through open-ended questions whether they were experiencing any challenges in avocado production. Almost all the participants reported that they are now experiencing many challenges in the production of avocados, and they believe that some of these challenges are due to the high-climate variability that they are now experiencing, as weather patterns are generally changing. It is becoming warmer, with little to no rain. They are worried that this will have an impact on the future production of avocados.

Because of climate variability, farmers are now spending more money on inputs, and the use of pesticides and irrigation requirement is increasing. According to the farmers, the quality of fruit is decreasing and this is negatively affecting their income, as they cannot export fruit that does not meet an international standard. Although some of the farmers have already implemented adaptation measures, not every farmer can afford to do so, especially the small-scale farmers. However, most of these farmers have implemented better control mechanisms and moisture monitoring systems. Set out below are some of the biggest challenges they encounter:

Main constraints encountered by avocados producers in the Limpopo province of South Africa:

- Water (both quality and quantity)
- Funding
- Theft
- Veld fire, animals
- Drought/floods, hail and severe temperature
- Marginal soils
- Increasing labour costs, input costs and transportation costs
- Increasing pest populations and diseases
- Poor roads, infrastructure.

Access to water for irrigation is one of the largest challenges that most farmers are experiencing, especially small-scale farmers, and this is greatly affecting production. Most farms are situated far-off from the dams, or they do not have dams at all, resulting in farmers having to arrange their own irrigation pipelines or boreholes, which is quite costly. Most small-scale farmers cannot afford to drill boreholes and this affects their production size.

Farmers are experiencing severe temperatures and this is causing a great decline in their production. The severe temperature is not only causing a decline in production, it is also affecting the fruit quality and the fruit size. Unseasonal low cold minimum temperatures in winter damage crops, while very high summer temperature extremes are not conducive to production. Farmers who farm under dry land conditions are experiencing loss of flowers on their fruits due to lack of rain, which results in reduced yields, while other trees are flowering earlier than normal because of these changes. Production is under pressure. Diseases are another challenge which results in high pesticide costs.

4.2 IMPACT OF CLIMATE CHANGE ON PRODUCTION OF AVOCADOS

The second objective of the study was to analyse the impact of temperature variability and rainfall on avocado yields. Firstly, the climate variability in the region was investigated using weather information (Figures 4.4 and 4.5 below). To determine the respondents' knowledge, they were asked during the survey to indicate whether they believe the weather pattern is generally changing, and to indicate what they are currently experiencing in terms of weather for the past few years. They were further asked if they think these changes are currently affecting, or will affect, the production of avocados. The results of this analysis are presented in Tables 4.2 and 4.3 below. Secondly, to determine climate change impacts on the production of avocado, the following was done: a regression was run, assessing the overall impact of climate change in the Limpopo province, after which 10-, 15- and 20-year moving averages and standard deviations of temperature and rainfall were calculated. A multiple regression was then run to assess the impacts on avocado production yields according to price, temperature and rainfall. These independent variables explain 95% of the variability of our dependent variable (see Tables 4.4 and 4.5 below). Lastly, the potential impact of climate variability on avocado production was established (see Table 4.6).

4.2.1 Climate variability

The graphs shown below (Figure 4.4) represent the annual rainfall over the years from 1970 to 2014 in all the four weather stations employed in the study. Some weather stations receive more rain than other stations do, which indicates that the avocado-producing areas in the region do not receive the same amounts of rainfall. The Duiwelskloof station receives less rainfall than the other stations do, with the Levubu station receiving the greatest amount of rainfall. There are a number of years (1982, 1994 and 2002) across the stations where rainfall was recorded to be below 500 mm per annum, The Duiwelskloof station experienced a minimum rainfall of 400 mm in the year 1992. In the year 2000, all stations received above average rainfalls, only to drop heavily in the following year.

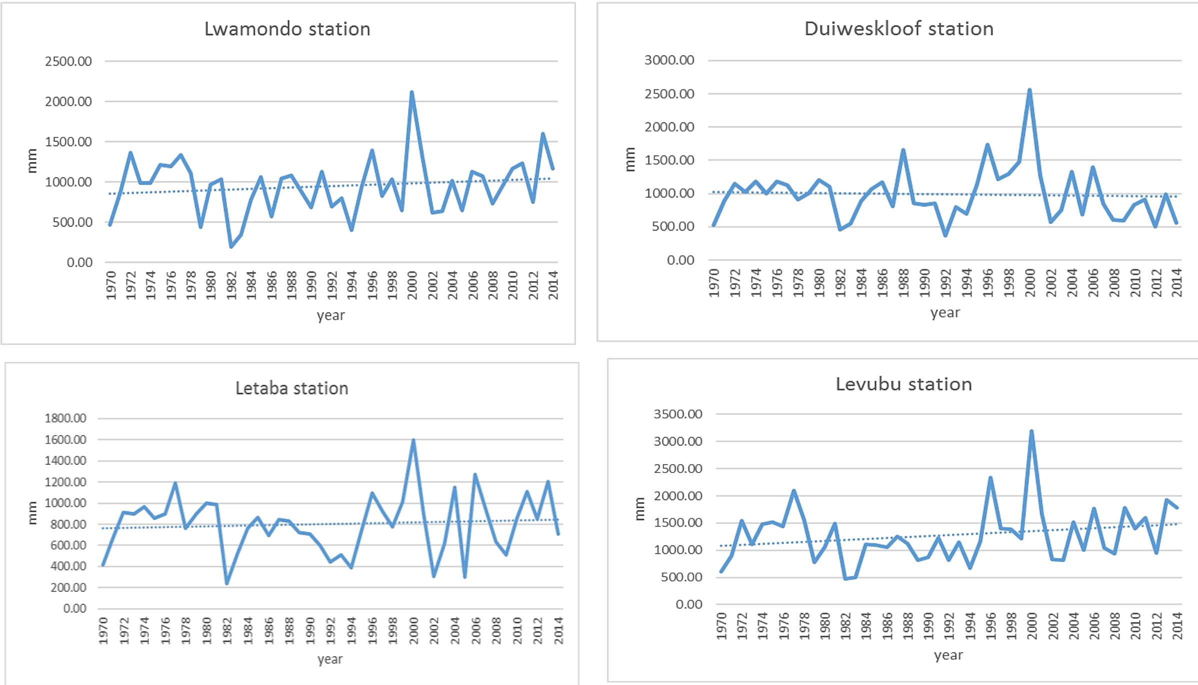

Figure 4.4: Annual rainfall data for all four weather stations in the study (1970–2014)

The below graphs(Figure 4.5) represent annual maximum temperature data for all the four weather stations in the study, for the years 1970 to 2014.as can be seen, there are temperature variations across the stations , with similarities in some of the years. The Letaba station experiences higher temperatures than the other stations do, followed by the Lwamondo and Levubu stations. These are the areas where most of the avocado producers are based. The Duiwelskloof station experiences temperatures within the threshold range of the avocado tree.

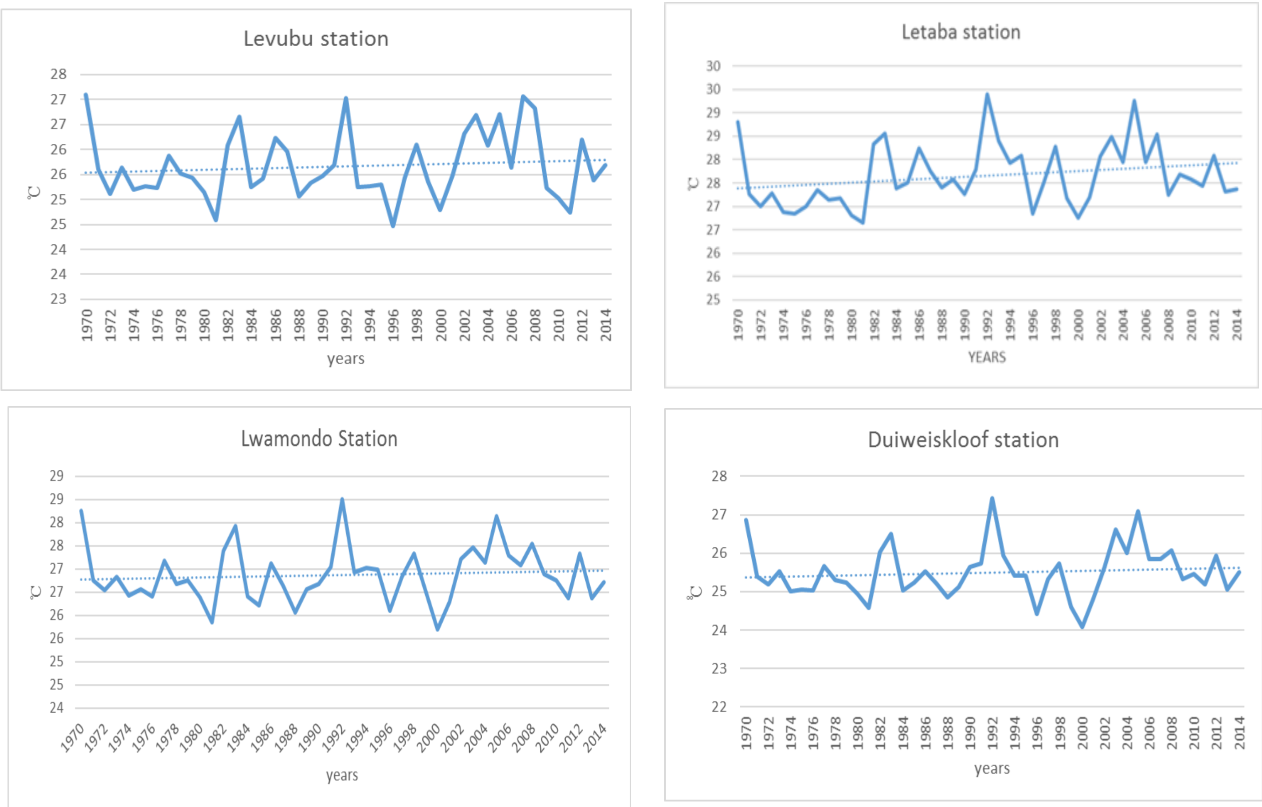

Figure 4.5: Annual maximum temperature data for all four weather stations in the study (1970–2014)

4.2.2 Farmers' perceptions on climate change

The main deduction that can be drawn from these sample results (Table 4.1) is that the respondents are very aware of the change in weather patterns that we are currently facing. The majority (87%) of the respondents acknowledged that the weather pattern has been changing over the past few years, while only 13% of respondents stated that they do not feel any changes. From this, we can then conclude that the weather pattern is indeed changing and is being felt by many.

Table 4.1: Respondents' perceptions on climate change

Questions asked	yes	no
Do you feel the pattern of weather is generally changing?	(87%)	(13%)
Do you think climate change is affecting or going to affect avocado production?	(87%)	(13%)

Source: Author's elaboration

It is also clear from the table presented above that climate variability is something that is already affecting the avocado industry. The majority (87 %) of respondents state that the changes in the weather pattern are causing major challenges in avocado production, while only 13% do not think the challenges they are currently facing are the results of climate variability.

2. State what you are currently experiencing in relation to weather for the past years

Table 4.2: Respondents' perceptions on climate change

	Percentage participants
Warmer	16%
colder	2%
More rain	0%
Less rain	78%
Still the same	4%

Source: Author's elaboration

Based on the sample results set out in Table 4.2, the study confidently concludes that temperature is rising; it is becoming warmer while there is less rain, which is causing a decrease in precipitation. The majority (78 %) of the respondents reported that they are currently experiencing less rain, with 16 % of the respondents stating that the weather is becoming warmer. Only 2% believe that it is becoming colder by the day, while the remaining 4 % believe that nothing has changed.

Table 4.3: Summary of multiple regression analysis predicting avocado yields (1970–2014)

Dependent variable: Avocado yield

Explanatory variables	Avocado yield
Price	1.05 ***
	(0.05)
Temperature	0.03
	(0.15)
Rainfall	0.001
	(0.001)
Adjusted R^2	0.91

Standard errors in parentheses

*.*p<0.05 **p<0.01 *** p<0.001)*

A multiple regression analysis was conducted to examine the overall relationship between avocado yields, price, temperature and rainfall in the Limpopo province of South Africa. Table 4.3 above summarises the analysis results, and as can be seen, price is statistically significant and can be explained by the model. Temperature and rainfall are not statistically significant

From the above results, we can conclude that price is statistically significant at 1 % (p<0.001). For each unit increase in price, the avocado yield is predicted to increase by 1.05 percent when all other factors are held constant.

Table 4.4: The relationship between avocado production and price, temperature and rainfall under 10-, 15- and 20-year moving averages (MA) in the Limpopo province of South Africa, 1970–2014

Dependent variable: Avocado yields

Explanatory variables	10MA	15 MA	20MA
Price	1.19 ***	1.15 ***	1.25 ***
	(0 .05)	(0.07)	(0.07)
Temperature	-1.60***	-2.65***	-2.24 **
	(0.34)	(0.57)	(0.91)
Rainfall	-0.002	-0.002	-0.003
	(0.001)	(0.001)	(0.001)
Adjusted R^2	0.95	0.95	0.93

Standard errors in parentheses

*. *p<0.05, **p<0.01, *** p<0.001)*

The output shows that the price has a statistically significantly relationship with the avocado yields under all categories (P< 0.001). Under the 10-year moving averages, for each 1 rand increase in price, there is an increase in avocado production by 1.19 kg/ha, when all other variables are held constant. This indicates that there is a positive relationship between prices and avocado production in the region. The same is seen when regressed under 15- and 20-year moving averages, and we can therefore conclude that as prices go up, the production also increases.

Higher prices induces farmers to want to supply and produce more. The increase in avocado production when prices increase might be the result of avocados being in demand, nationally and internationally. Prices that were realised in the export markets in the year 2014 increased to R14 866.27 from R9 209.86 per ton in 2012 (DAFF, 2015), while it is evident from the avocado quantity offered for sale that there was an increase of 60% in export prices. Gilbert and Morgan (2010), together with FAO (2011), indicated in their study that short-term fluctuations in food prices on international markets depend on factors such as extreme weather events.

From the above results, we may also conclude that there is a relationship between temperature and avocado yields, which is statistically significant at 1 percent (P< 0.001). For each unit increase in temperature, avocado production decreases by 1.60 kg/ha under 10-year moving averages. The high summer temperature is negatively impacting on the avocado yields. It has also been found in a number of studies (Porter et al., 2014; Tao et al., 2013, Lewis & Witham, 2012; Hatfield et al., 2011) that high temperature may have major negative impacts on crop production. This can affect both local and international markets.

The regression results show no significant relationship between rainfall and avocado production. Looking at the respondents in this study, 90 % of the respondents were commercial farmers who are farming under irrigation. The small-scale farmers, however, produce under dry land conditions, and the costs of irrigation are very high, presenting a challenge to small-scale farmers that most of them cannot afford.

Table 4.5: Relationship between avocado yields and temperature & rainfall under standard deviation (stdv)

Dependent variable: Avocado yields

Explanatory variables	10SD	15SD	20SD
Price	1.17 ***	1.14 ***	1.25 ***
	(0.04)	(0.07)	(0.09)
Temperature	1.75	0.35	-2.47
	(0.80)	(1.08)	(1.51)
Rainfall	0.001	0.001	0.01
	(0.001)	(0.001)	(0.001)
Adjusted R^2	0.95	0.95	0.95

Standard errors in parentheses

*.*p<0.05, **p<0.01, *** p<0.001)*

Under standard deviation, the output shows that the price has a statistically significantly relationship with the avocado yields under all categories (P< 0.001) there was no relationship observed between avocado yields, temperature and rainfall. The model was insignificant (see Table 4.5 above).

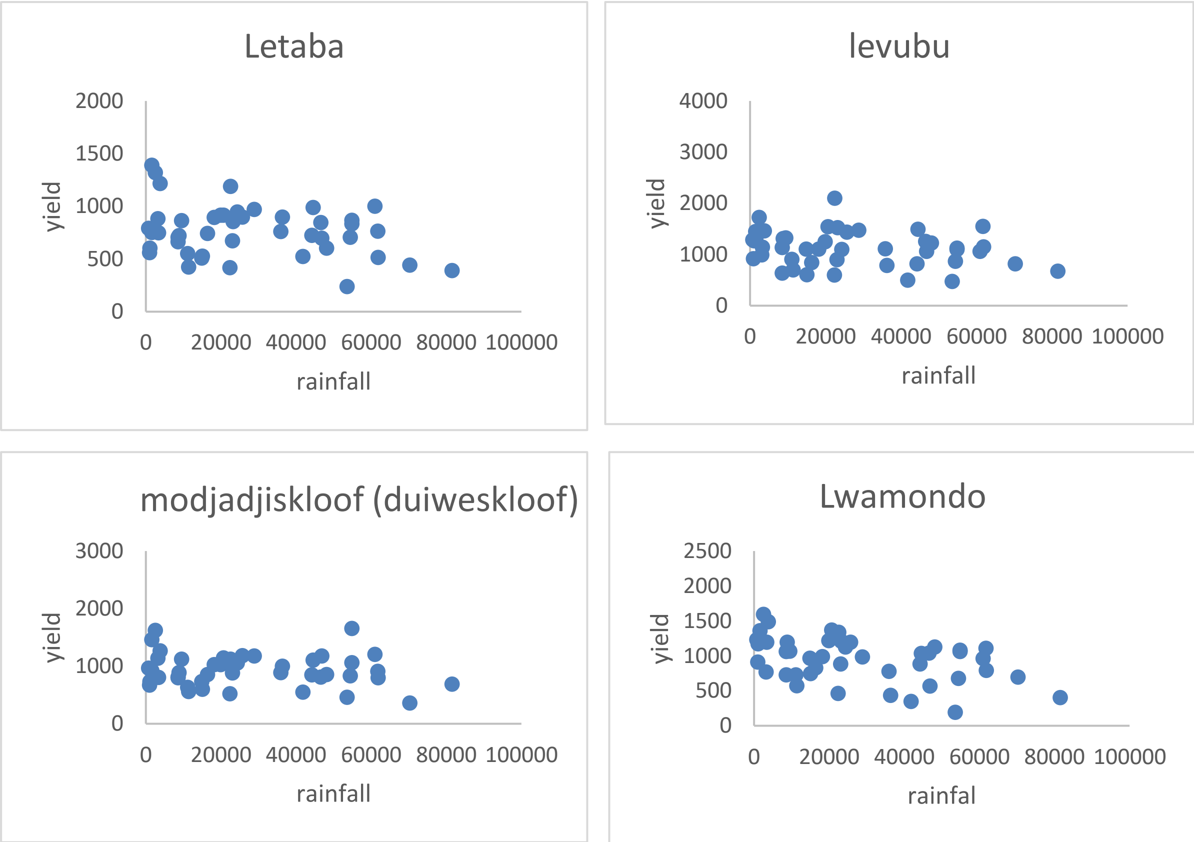

Figure 4.6: Correlation between rainfall and avocado yield

The scatter diagrams above (Figures 4.6) measures the strength and direction of a relationship between avocado yield and rainfall in each and every station investigated. The scatter diagrams above appear not to be correlated, the data points are spread randomly therefore it doesn't appear that there is significant relationship, which could be a result of the fruit being produced under irrigation. The diagrams were prepared using the study raw data. A study done by Gbetibouo and Hassan (2005) on the analysis of the economic impact of climate change on main South African crops shows similar results. They discovered that crops are more sensitive to marginal changes in temperature than to changes in precipitation.

4.2.3 Farmers' perceptions on climate change and its potential effects on avocado production

Table 4.6 below illustrates the perceived impacts of climate change on some of the economic indicators concerning a farm. Because of the changes in weather patterns, there are also perceived changes experienced in the inputs for avocado production.

However, little effect was observed on fertiliser, herbicides and pesticides use, with only a few farmers (30%) seemingly experiencing changes in fertiliser, herbicide and pesticide use. Irrigation water usage is observed to be on the increase (67%) due to the reduced rainfall being currently experienced, which is perceived to be affecting the quality of crop immensely. The main conclusion that can be drawn from this table is that; it appears that not many economic factors are being affected by climate variability, and as can be seen from the table, there are little to no effects on markets, replanting costs and dead tree disposal.

Gornall et al. (2010) indicated that changes in the climatic state, especially extreme weather events such as high temperatures, may have indirect impacts on crop growth, while water availability may become scarce, wildfires may occur, and pests and diseases may proliferate. Porter et al. (2014) agree with what Gornall et al. (2010) said and they further state that the impact of climate change is indeed projected to have bigger negative effect on productivity, compared with no climate change, although in some regions, productivity will be positively impacted upon.

Table 4.6: Impacts of climate change on economic indicators at farm level

indicator	No effect	increased	decreased
Fertilizer use	(76%)	(24%)	(0%)
Herbicide & pesticides use	(50%)	(30%)	(20%)
Water usage	(24%)	(67%)	(9%)
Farm maintenance	(61%)	(30%)	(9%)
Quality of crop	(41%)	(20%)	(39%)
Markets	(65%)	(15%)	(20%)
Replanting costs	(65%)	(33%)	(2%)
Disease monitoring	(65%)	(33%)	(2%)
Dead tree disposal	(63%)	(35%)	(2%)

Source: Author's elaboration

4.3 CLIMATE VARIABILITY ADAPTATION STRATEGIES

The aim of the third objective of the study was to suggest strategies that would help farmers to boost their economic returns, even though weather patterns are changing. To be able to devise these strategies, open-ended questions were included in the questionnaires. These questions were aimed at ascertaining whether the farmers were already implementing change management practices to adapt to climate change and variability, and to assess the actions they might have already taken for optimum production. The questions asked, together with the results are set out below.

1. Have you changed the following management practices to adapt to climate change and variability?

Table 4.7: Management practices

indicator	**No**	**Yes**	**Future changes**
Cultivar change	59%	26%	15%
Production size	52%	30%	17%
Moisture monitoring systems	54%	41%	4%
Better control mechanisms	46%	41%	13%

From the table above (4.7), one can conclude that the largest percentage of farmers have not yet taken any action regarding climate change and variability in terms of their management practices, while only a few farmers have introduced better management practices to increase their production. This may be the result of farmers sticking to the methods that they have been using for years and which have been working for them. This is especially so with small-scale farmers, as it is not easy for them to adopt new management practices, and accordingly they prefer to stick with the practices they know best and which have been working for them for the years that they have been farming. Table 4.7 further illustrates the point that only a few farmers are considering changing their management practices in the near future: this is still something that they are considering and have not yet implemented. This tells us that there is a need for farmers to engage in adaptation strategies for achieving greater yields in years to come. A study done by Mendelsohn and Dinar (1999) found, when analysing at the farm level, that a reduction of climate change impacts is possible if farmers fully implement adaptation measures.

2. What are other actions introduced for optimum production

The current actions that a few of avocado producers in the areas of Limpopo have introduced to adapt to climate variability are set out below:

- Upgrading pump systems
- Improving irrigation management

- Increased watering of trees
- Tree canopy management and selective pruning
- Disease control
- Fire belts
- Introduction of drip irrigation
- Mulching.

Only 41% of the 46 respondents have introduced better control mechanisms and moisture monitoring systems. These are the farmers who have introduced tree canopy management and selective pruning, and some of these farmers have improved their irrigation management by introducing drip irrigation. Other farmers only do mulching to retain the moisture since they are experiencing high temperatures and no rainfall. These high temperatures are also said to be causing veld fires, and farmers have created fire belts to deal with the fires. There seem to be several possibly substantial influences of climate change on the avocado industry, some of which may be beneficial to the industry, while some may negatively affect productivity. It is essential to devise management strategies that will help avoid the negative impacts and that may be used to take advantage of the positive impacts.

Studies show that assessments have been made for other industries to cater for such adaptations (Howden et al. 2005). The major conclusion that may be drawn from all these studies is to continue developing the capacity and knowledge to manage the existing climate variability more efficiently, which will be the best defence against the future threats of climate change. It is of importance for farmers to also adapt their marketing plans, as it is expected that there will be changes in harvest times. Most of the expected changes that might result from climate variation point towards the need to implement high standards in terms of farm management in order to conquer these changes (Schulze & Kunz, 1995).

4.3.1 Potential options that farmers may implement when faced with challenges due to climate variability

4.3.1.1 Higher summer temperatures

An increase in water storage capacity would help when faced with drought. Moisture monitoring systems need to be implemented for attaining better yields. It is also essential for farmers to use overhead evaporative cooling irrigation systems (Blight et al. 2000), and with careful management techniques, it will be possible to reduce incidence of avocado stress. It is also of importance to use mulch and growth regulators to improve fruit (Wolstenholme, 2001).

4.3.1.2 Increase in frequency of droughts

This challenge applies to small-scale farmers who are producing on dry land. To avoid the problem of days on which it does not rain, farmers may capitalise on the days where high rainfall is experienced by installing water harvesting and storage structures. There is also a great need for installing irrigation scheduling systems, together with moisture monitoring systems. These systems would help by making sure that the whole farm gets access to water, but by using far less water with quicker turn around. Furthermore, farmers should practise mulching, as this retains moisture.

4.3.1.3 Increase in number of storms events

Farmers may implement canopy management systems, which would improve not only the productivity, but fruit quality as well. This also keeps the tree size smaller, which helps when faced with storms because a smaller tree size reduces the structural damage experienced.

4.3.1.4 Insect activity

While it is essential for farmers to have better control mechanisms in place, they also have to carry out closer monitoring of insect pests. Integrated Pest Management (IPM) practices are essential for keeping pests below economic threshold levels. This should be done to reduce potential risks that may be harmful to humans and other species. Protective cropping structures may also be applied when producing vegetables on areas that are vulnerable to salt water intrusion. This may be done together with using harvested water for irrigation purposes. The use of models developed specifically for climate change scenarios can also be considered for forecasting potential pest outbreaks, based on meteorological data.

4.3.1.5 Commodity Insurance

Commodity insurance can be of importance in maintaining production levels, especially when experiencing current climate change challenges. Farmers may look into insurance services to insure their crops and fruits, which will be beneficial for them in avoiding losses each time their produce is affected by climate change impacts.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

The main objective of this study was to assess the impact of climate variability on avocado production in the Limpopo province. Specifically, it aimed at establishing the respondent farmers' perceptions on climate change and its potential effects on avocado production, while also determining the agro-economic factors that affect the production of avocados, as well as the impacts of climate change in terms of temperature and rainfall on the production. Lastly, the study aimed at assessing climate variability strategies and understanding adaptation options as proposed by farmers in the province. This chapter presents the conclusion of the study and recommendations.

5.2 CONCLUSION OF THE STUDY

There are several conclusions that can be derived from this study. First, there is sufficient evidence to suggest that the avocado producers in Limpopo province have high levels of knowledge about climate change. Many respondents were aware of the current changes in weather patterns, with consequential changes in the inputs for avocado production and water usage being on the increase. The study confidently concludes that temperatures are rising, while precipitation is decreasing. Temperature was observed to have a negative and significant impact on avocado yield, and these results are similar to findings of other empirical studies.

Climate change is predicted to negatively affect avocado yields in the Limpopo region, and productivity levels are expected to be lower due to changes in temperature and crop water requirements. Water is the biggest challenge that small-scale farmer are experiencing, which affects production greatly. Most farms are situated far-off from dams, or do not have dams at all, resulting in costly measures being implemented by farmers, such as constructing their own irrigation pipelines to drilling their boreholes. Most small-scale farmers cannot afford to drill boreholes and this affects their production size.

The severe temperature is not only causing a decline in production, it is also affecting the fruit quality, together with the fruit size. Farmers who farm on dry land are experiencing the loss of flowers on their trees due to lack of rain, which results in them achieving smaller yields, while other trees are flowering earlier than normal because of these changes. We can therefore see that production is under pressure. Secondly, when determining climate change impacts in terms of temperature and rainfall, the study concludes that high summer temperatures negatively affect avocado production. No correlation was found between rainfall and avocado production, mainly because 90 % of the respondents were commercial farmers who are producing under irrigation. Avocado production is observed to be generally more sensitive to changes in temperature than in rainfall in the Limpopo province.

Finally, we can conclude that adaptation measures for avocado production are essential for coping with climate variability. Adaptation measures that are aimed at reducing negative climate change impacts must not only reflect, but also enhance, practices that are designed to overcome the current adverse weather conditions.

5.3 RECOMMENDATIONS

In the view of the major findings of the study and the above conclusion, I recommend the following:

Farmers need to play their part in adapting to climate change: they should increase, or rather improve, their water storage capacity by capitalising on incidences of high rainfall. They could also apply water conservation measures. Farmers should change their farming practices to adapt to changes in climate conditions. They need to adopt risk, or rather adaptive management, and approaches. When faced with higher summer temperatures, farmers should apply careful management techniques, in which the use of mulch and growth regulators to improve fruit size is of importance. When there is an increase in the frequency of droughts, the installation of adequate water harvesting infrastructure by farmers is of importance. It is essential for farmers to have better control mechanisms in place, especially for the purpose of closer monitoring and responsive management of insects. Canopy management systems could be implemented to improve productivity and fruit quality.

Efforts at the national level are of necessity, because without government intervention through policies, it might be impossible for farmers to create sustainable and productive management techniques. My recommendation to policy makers is that future agricultural research should focus on, or rather take into consideration, the development of high-temperature-tolerant avocado varieties, as it is seen that a rise in temperature above the critical threshold level appears to have negative effects on avocado yields. Research on technological advances could improve yields, even where temperatures are on the rise. Research capacity needs to be strengthened because the avocado industry is export oriented and has to adhere to high standards set by the markets.

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APPENDIX A: LETTER OF CONSENT

INTRODUCTION:

Good day! My name is **MULALO QUEEN RANDELA**. I am a student at University of Pretoria and I am currently working on a research project about how the climate change is impacting the avocados production funded by the Agricultural research Council. This research is being carried out in the Limpopo area, looking more into your farming activities. Your help and assistance in completing this questionnaire will be invaluable for the study.

Your participation is voluntary, if you don't want to answer all the questions, you don't have to-please just do what you can.it shouldn't take long to complete, and I hope you'll enjoy it.

The study will hold no risk for every participant. All information that you will provide will be kept confidential and you will not be identified by name or address in any of the reports that I plan to write.

Navrae/ Enquiries: Mrs Mulalo Queen Randela

Email: mphephum@arc.agric.za

APPENDIX B: SURVEY INSTRUMENT

Climate Change Questionnaire

Date: ____

Interviewee: ____

Name of farm____

Municipality: ____

Village/Town: ____

SECTION A: General Information

Size of farm (hectares)	
Avocado production area (ha)	
No. of years farming	

A. Gender

1. Female	
2. Male	

SECTION B: INCOME

B. What is the main sources of income for the family?

1. Salary	
2.Fruit crop production/sales	
3.Livestock production/sales	
4.Vegetable production sales	

SECTION C: PRODUCTION, AVOCADOS GROWING FARMERS

C. For how long have you been growing avocados (in years)? ________________

Year	Area Planted(ha)	Production (tons)
2014/15		

2013/14		
2012/13		
2011/12		
2010/11		
2009/10		
2008/09		
2007/08		
2006/07		
2005/06		

D. Will you still continue growing avocados in future? Tick below

1.Yes	2.No	3.Uncertain

E. Mention the main constraints that you encounter in avocados production?

____
____
____
____
____
____
____
____
____

F. In your opinion, what do you think needs to be done to solve these problems?

____
____
____
____
____
____
____
____

1. Local markets	
2. Export	

____

____

G. What were the costs incurred in avocado farming?

Items inputs applied	**Quantity used (in bags, litres etc.)**	**Costs incurred per year in rands**
seeds		
fertilizer		
Herbicides & insecticides		
Labour(wages)		
water		
Electricity		
Transport costs		
Other (specify)………………		
TOTAL		

SECTION D: MARKETING INFORMATION

H. Who do you sell your production to?

1. Local market	
2. Export	
3. Both	

I. Percentage are you exporting________________

J. Where does most of your returns/ income comes from?

K. Do you have any **contractual agreements or a guaranteed/ready market?** (Formal or informal, written or verbal) with any agribusiness company?

1. Yes	
2. No	

SECTION D: CLIMATE CHANGE

L. Do you feel the pattern of weather is generally changing?

1. Yes	
2. No	
3. Don't know	

M. What are you currently experiencing in relation to weather for the past years, is it becoming?

1. warmer	
2. colder	
3. more rain	
4. less rain	
5. still the same	

O. Do you think climate change is affecting or going to affect avocado production?

1. Yes	
2. No	
3. Don't know	

P. If yes, in what way(s) is it affecting, or going to affect the production?

____

____

____

____

____

____

____

Q What are the impact of climate change on the following economic indicators on your farm?

Indicator	No Effect	Increased	Decreased
fertilizer Use			
Herbicide			
Pesticide use			
Water usage			
Farm maintenance			
Quality of crop			
Markets			
Replanting costs			
Disease monitoring			
Dead tree disposal			

R. Have you ever taken any action out of concern for climate change?

1. Yes	
2. No	

SECTION E: ADAPTATION MEASURES

S. Have you changed the following management practices to adapt to climate change and variability?

Indicator	No	Yes	In Future
Cultivar change			
Production size			
Moisture monitoring systems			
Better control mechanisms			

T. What are other actions did you introduce to make sure that weather variation does not affect your productivity?

____

____

____

____

____

Thank you very much for your cooperation and participation in this project!!!!