RISK AND VULNERABILITY ANALYSIS OF DRYLAND AGRICULTURE UNDER PROJECTED CLIMATE CHANGE: ADAPTIVE RESPONSE IN SOUTH AFRICAN SUMMER RAINFALL AREAS

by

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THESIS
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DECLARATION

I declare that the **RISK AND VULNERABILITY ANALYSIS OF DRYLAND AGRICULTURE UNDER PROJECTED CLIMATE CHANGE: ADAPTIVE RESPONSE IN SOUTH AFRICAN SUMMER RAINFALL AREAS** thesis, hereby submitted to the University of Limpopo, for the degree of **DOCTOR OF PHILOSOPHY** in **GEOGRAPHY** has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

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Surname, Initials (title) Date

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This Thesis is dedicated to my parents:

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ABSTRACT

Agriculture in South Africa, particularly in the summer rainfall areas, faces the challenge of optimal crop production in the face of climate change. Climate change scenarios for South Africa have been predicted to have a negative impact on agriculture particularly in the summer rainfall areas because of its dependence on climate variables. Within the context of the South African agricultural sector, it has become important to identify who and what is most vulnerable to impacts of climate change, so that support for adaptation can be targeted appropriately. The aim of this study was to assess the hazard of climate change in relation to the production of selected dryland crops, namely: sunflower, soybean, and groundnut in the summer rainfall areas and to model their vulnerability and response to climate change as well as to develop coping and adaptation strategies.

A survey of 800 farmers was carried out in three agro-ecological zones of Limpopo and Free State. The population was purposively selected and were present for focus group discussions and questionnaire administration. Questions on agronomic practices, cost of production, climate change impact on productivity, coping and adaptation methods used in the face of climate change were asked. The response showed that farm production was not at the optimum, not only because of the influence of climate but as a result of the poor agronomic practices by the farmers. Following a factor analysis, 70% of the decline in crop yield was attributed to poor farming decisions. A further look at climatic factors affecting farmers indicated that frost with a 0.989 loading was the most climate extreme affecting most of the farmers. In order to buffer the effects of climate change, the farmers undertook various changes in their farm management and also received some support from the various governmental and non-governmental institutions. It was however, found that though there were policies in place for farmer support, such supports were not administered in a timely fashion and some support types were not adequate for the farmers. A correlation between the number of supports received and yields showed an increase in yield for farmers who received more than one type of support and with such variations evident across the agroecological zones.

Physical modelling was conducted to model crop suitability based on downscaled data from the Special Report on Emissions Scenarios A2, (SRES A2) for the time periods centred on 2020, 2050 and 2080. The results showed areas which were not suitable for either soybean, sunflower or groundnut production in the future over time with some areas gaining and losing under different farm input regimes. To establish the effects of climate change on yield, a field experiment was carried out for two consecutive seasons and the results obtained were used to feed the AquaCrop crop simulation model to model the effects of climate change on yield under different management conditions.

The results obtained from the survey, field experiments and climate indices guided the development of vulnerability indicators in a spatial manner. Using the socioeconomic and biophysical results, the vulnerability of the summer rainfall area was calculated. The results showed that areas in Limpopo, North West, Eastern Cape, and Northern Cape were the most vulnerable. Based on the types of adaptation options employed by farmers which included a change in planting dates, employing support from institutions, other sources of income, farming practices and recommendations for future adaptation, various scenarios were run in a crop simulation model to determine the cropping regimes suitable for the study area. Options included technology, on-farm management, out of farm management, human and social factors. The results indicated that coping and adaptation measures are place specific and the effects of a climate extreme are felt differently by different farming communities and farmers in the same community. It is hence recommended that the government in its policies towards alleviating the risk of farmers to climate change should look at site-specific options and not a one model fits all. Farmers should also play a role in enhancing their adaptive capacity as well. It is only when barriers are bridged and a proper network of communication established alongside resource provision, will there be a change in farmer’s attitude toward implementing suggested adaptation options.

Keywords: Adaptation, Adaptivecapacity, Climate change, Small holder farmers, Summer rainfall, Risk, Vulnerability.

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ACRONYMS

AEZs:	Agroecological zones
AR4:	Fourth Assessment Report
AR5:	Fifth Assessment Report
BIS:	Biofuels Industrial Strategy
COP7:	Conference of the Parties
CEEPA:	Centre for Environmental Economics and Policy in Africa
CSA:	Climate-Smart Agriculture
CC:	Climate Change
DAFF:	Department of Agriculture, Fisheries, and Forestry
DEA:	Department of Environmental Affaire
DEROs:	Desired Emission Reduction Outcomes
DSS:	Decision Support System
DSSAT:	Decision Support System for Agrotechnology Transfer
DWAF:	Department of Water Affairs
FAO:	Food and Agricultural Organisation
FTDB:	Free State Freight Transport Data Bank
GAEZ:	Global Agroecological Zones
GCMs:	Global Climate Models
GHGs:	Greenhouse gases
GIS:	Geographic Information Software
IBSNAT:	International Benchmark Sites Network for Agrotechnology Transfer
ICASA:	International Consortium for Application of Systems Approaches to Agriculture
IIASA:	International Institute of Applied Systems Analysis
INDCs:	Intended Nationally Determined Contributions
IPCC:	Intergovernmental Panel on Climate Change
KMO:	Kaiser-Meyer-Olkin
LDA:	Limpopo Department of Agriculture
NAPA:	National Adaptation Action Programmes
NCCRP:	National Climate Change Response White Paper
NFNSP:	National Food and Nutrition Strategic Plan
OECD:	Organization for Economic Co-operation and Development

RCP: Representative Concentration Pathways

SRES: Special Report on Emission Scenario

UNFCCC: United Nations Framework Convention on Climate Change

UNDP/BCPR: United Nations Development Program/Bureau of Crisis Prevention and Recovery

UNISDR: UN International Strategy for Disaster Reduction

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Chapter One

Introduction

1.1 Background

Relevant literature provided by the Intergovernmental Panel for Climate Change (IPCC) Fourth Assessment Report (IPCC 2007b; 2014) shows unequivocal evidence that climate change is happening, and its impacts are already observable in many parts of the world. These impacts are expected to become more severe as changes in climate intensify in the near future. Climate change is expected to affect all sectors of society both at global and local levels. Observed and anticipated changes in the climate such as sea-level rises, changes in precipitation resulting in flooding and drought, heat waves, the intense and frequent occurrence of hurricanes and storms, and degraded air quality, will affect various sectors of the society especially the agricultural sector, directly and indirectly. Discernable changes in the climate are mostly noticed by changes in temperature and precipitation regimes. Whilst many schools of thought among climate models agree that temperatures are increasing, there is less agreement among these models on how precipitation is changing across the globe (IPCC, 2007b; Ziervogel *et al*., 2008; Tadross, 2011). The difficulties that arise from different models producing similar results can be attributed to the high variability associated with both the spatial and temporal variability of rainfall (Tadross, 2011). Ziervogel *et al*. (2008), further point out that the predictability of changes in climatic variables differs between regions, with changes in these variables being more predictable in some regions than in others, thus affecting the homogenization of predicted changes by climate change models.

Climate change poses a significant threat to South Africa’s water resources, food security, health, infrastructure, as well as its ecosystem services and biodiversity. Studies indicate that over the last century, mean temperature levels in Africa have increased whereas precipitation levels have declined (IPCC 2001, IPCC 2014). The temperature of the continent has also seen an increasing number of warm days and a decreasing number of extremely cold days (IPCC, 2012; IPCC,2014). Such observed and anticipated changes and occurrences are of key concern to South Africa. This is because the country’s mean annual temperatures have increased by at least 1.5 times the observed global average increase of

0.65^{o}C over the past five decades and the country is experiencing an increase in the frequency of extreme rainfall events (Ziervogel *et al*., 2014).

Rainfall distribution is uneven across the country, characterized by humid, subtropical conditions in the east, and dry desert conditions in the west. South Africa experiences an average annual rainfall of 450 mm per year (Geography and climate, South Africa), which is below the world's average of 860 mm, compounded by comparatively high evaporation rates (Department of Water Affairs (DWAF), 2013). In this situation where the average evaporation rate exceeds precipitation, water is a critical limiting factor for agricultural activities. In South Africa, of all the land available for agriculture, only 12% of the country is suitable for the production of rain-fed crops in spite of the high linkage of productivity to rainfall. Thus, climate change directly affects agricultural production and renders the sector inherently sensitive to climate variables such as temperature, humidity, and precipitation (IPCC, 2011). As a result, declining rainfall makes both commercial and subsistence farming a challenging endeavour. These challenges are expected to vary across the different agro-climatic zones, provinces and different agricultural systems in the country. Climate change predictions are that rainfall will be more infrequent but more intense in some parts of the country. This will shrink the country's arable land and increase agricultural unpredictability. The agriculture sector in South Africa currently accounts for about 60% of water utilization. Changes in water demand and availability will significantly affect farming activities; with the western regions predicted to have 30% reduced water availability by 2050. Under these conditions, the irrigation demand will increase especially in the affected drier western parts of the country, adding to the pressure on water resources. This puts the agricultural sector in a difficult position on how to manage irrigation as a means of ensuring food security and at the same time manage agricultutural water use.

Africa is highly vulnerable to climate change and climate variability since most of the populations in Africa depend on subsistence rain-fed agriculture (Boko *et al*., 2007). Considering South Africa's high levels of poverty and inequality, these impacts pose critical challenges for national development (Department of Environmental Affairs (DEA), 2011). The rate and magnitude of the impacts of climate change on the agricultural sector will depend on factors such as the extent to which current temperatures or precipitation patterns are close to or exceed tolerance limits for important crops, per capita income, the percentage of economic activity carried out in the agricultural sector and the existing condition of the agricultural land base (Watson *et al*., 1998). These impacts may, however, be mitigated by the effectiveness of a country's or community's systems that are established to address or prepare for threats posed to the agricultural sector. Such impacts will likely vary by region, the sensitivity of the crops, the extent, and length of exposure to climate change impacts, as well as the society's ability to adapt to change.

1.2 Problem Statement

Agriculture is acutely sensitive to climate change, with outdoor production processes that depend on particular levels of temperature and precipitation. Challenges are inherent in quantifying the impact of climate change on the agricultural sector because of the different scales and magnitude of likely impacts, different agricultural systems, soils, as well as time used for assessment. Each crop and crop variety have a specific climatic tolerance that is optimal for its sustainability. The inter-annual, monthly and daily distribution of climate variables affects the physical, chemical and biological processes that drive the productivity of agricultural systems. The distribution of crop, pasture and forest species is a function of the current climatic and atmospheric conditions (Leff *et al*., 2004; Mueller et al.,2012, Van Ittersum et al.,2013). Total seasonal precipitation, as well as its pattern of variability, are both major determinants of crop yields (Meetpal, 2018). Hence, a change in the variability of climate as well as the CO_2 concentrations is decisive to crop health and productivity. A new climate regime will modify the rate at which heat units and chill units accumulate, affecting growing locations, crop yields, planting and harvest dates, pest or disease incidence. A changing climate regime will also affect dry land and irrigated crop production.

The impacts of climate change on agricultural activities are reported to be significant for low-input farming systems in developing countries in Africa. This is because the poorer population groups are those most directly dependent on the natural environment and ecosystem services for their survival and livelihoods (Raffaele *et al*., 2015; Holland et al., 2017). A recent study by Kephe *et al*. (2016), indicated that changes in seasonal rainfall regimes pose a serious threat to biodiversity, society and development sectors, thereby expanding their vulnerabilities. A continued decline in rainfall in any region will affect economic growth negatively in terms of water use and agricultural productivity, thereby making these sectors of the economy vulnerable (Kephe *et al*., 2016).

Within the context of the South African agricultural sector, it has become important to identify who and what is most vulnerable to impacts of climate change, so that support for adaptation can be targeted appropriately (Ziervogel, 2008, Boko *et al*., 2007). Farmers have various strategies to cope with the current climate variability experienced in South Africa. These strategies, however, may not be adequate to cope with projected future climatic changes. The shortcomings of these strategies could potentially increase the vulnerability of farming systems significantly. The identification of new adaptation strategies and in some instances, the re-thinking of existing strategies to reduce financial vulnerability is of paramount importance for the future sustainability of the agricultural sector in South Africa. This study seeks to assess vulnerability to climate change by linking climate change and vulnerability to food insecurity for farmers in the summer rainfall areas of South Africa.

Given the complexity of South Africa's physiography, climate, and socio-economic milieu, detailed local scale analyses are needed to assess the potential impacts of climate change (Schulze, 2011). In order to address this disconnectedness between climate science and African agriculture, the aptitude to link existing climate data and agricultural decision making needs to be created. This is as much an institutional challenge as it is a technical and human resource challenges. The nature of climate change adaptation demands that efforts to support African agriculture in the face of climate change should incorporate a multi-disciplinary set of stakeholders including climate science experts, agricultural practitioners and technicians, local communities/civil society, donors and policymakers (Ziervogel *et al*., 2008).

It is envisaged that climate change will significantly reduce the areas suitable for cultivation of a wide range of crops in Sub-Saharan Africa. Europe and North America, on the other hand, will experience an increase in the area suitable for cultivation because they have the greatest capacity and resources to manage the impacts of climate change (Turral *et al*., 2011).

A major challenge for policy and decision-makers at different levels of government in South Africa is to understand how, where and in what form the projected impacts of climate change will occur. This is because climate change projections are a function of the temporal and spatial models at which climate data are provided. Hence adaptation methods currently employed may become obsolete in the future. Furthermore, the way in which these projections are reported and perceived in terms of the reliability of the data raises questions on their relevance to agriculture, and further complicated by the difficulty in accessing and understanding the data (Ziervogel *et al*., 2008). This task is made complex by several factors such as the relationship between changes in climatic variables (for instance changes in precipitation), impacts (for instance increased flooding) and system response (for example adaptive capacity) which is unclear. A further complication is that vulnerability is dynamic, and both directly and indirectly related to a range of environmental, social, economic and political factors.

One of the obstacles confronting decision-makers is how to deal with the inherent levels of uncertainty regarding changing long-term climate conditions and their associated impacts on agriculture. Making medium-to-long-term decisions today based on unreliable information is one of the greatest challenges. Effective climate change adaptation will require long-term planning approaches at the national, regional, and local levels. Reacting to changes in the short-term or medium-term, without paying attention to changes that might occur or remain over the long-term, will result in poor investment decisions which might be costly not only to the agricultural sector but to the whole South African economy and ecosystems.

1.3 Rationale

Sub-Saharan Africa, which includes South Africa, is one of the areas in the world that is currently highly vulnerable to food insecurity (Kotir, 2011; Connolly-Boutin et al., 2016;). The vulnerability of agriculture to climate change has become an important issue because of reduced crop productivity from adverse climate changes, especially in Africa. Primary production, especially in agriculture, is the foundation of most developing African economies. As one of these economies, South Africa needs to ensure a healthy agricultural industry that contributes to the country’s gross domestic product (GDP), food security, social welfare, job creation, and ecotourism. There is a need to assess the vulnerability of crops to the changing climate and how this will affect food production and security in the future.

The South African agricultural sector is highly diverse in terms of its activities and socio-economic context and comprises commercial, small-holder and subsistence farmers, with activities across a wide variety of climatic conditions. Roughly 90% of the country is sub-arid, semi-arid, or sub-humid and about 10% is considered hyper-arid. Only 14% of the country is potentially arable, with one-fifth of this land having high agricultural potential (Liebenberg, 2012; DAS,2012). Climate is important in determining potential agricultural activities and suitability across the country, especially in smallholding and homestead settings. Therefore, in order to support local areas and local agricultural systems to become resilient to climate change, it is necessary to investigate and understand the nature of vulnerability from their perspective. It is crucial to map such vulnerability so that likely location(s) are identified for a range of likely possible climate futures. Furthermore, in order to develop a coherent national adaptation response, there is a need to integrate climate science, impacts and vulnerability studies, as well as results from assessing various adaptation options, into both sectoral and cross-sectoral decision-making processes.

Southern Africa is expected to become warmer and drier (Christensen *et al*., 2007). Considerable work has been done in recent years in assessing the potential impacts of climate change on the local climate through the application of downscaling techniques to Global Climate Models (GCMs). The climate change information required for many impact studies, however, is of a spatial scale much finer than that provided by the global climate models. This is especially true for regions of complex topography, coastal locations, and regions with highly heterogeneous land-cover (Wilby *et al*., 2004). The source GCMs are coarse in resolution (in the region of 300 x 300km) and need to be downscaled to account for local variables and variations. Local experts have made substantial contributions in the field of downscaling (for instance; Hewitson & Crane, 2006; Engelbrecht et al., 2011; Kalognomou et al., 2013; Engelbrecht et al., 2013). Recent studies on global “hotspots” generally show South Africa to be high on the scale of negative impacts with regard to crop production under future climate change (Fraser *et al*., 2013; Osborne *et al*., 2013). The impact projections are generally presented as world or continental-scale maps, where impacts on the regional/local scale production cannot be readily distinguished within South Africa. It is important that local impact models investigate more localized impacts. Taking into consideration the complexity of the country’s physiography, climate, and socio-economic milieu, detailed local scale analyses are needed to assess potential impacts (Schulze, 2011).

Most impact analyses carried out in South Africa on crop reaction to climate change narrowly focus on specific crops such as maize and wheat, and most often do not specify which cultivar was used. Whereas responses between cultivars are likely to be different.

Studies conducted of wheat response in Australia found impacts ranging from -34 to +65% for the same climate scenario and site depending on which known, and currently grown wheat cultivar was specified in the crop model (Wang *et al.,* 1996; Wang et al.,2011). Similarly, Matthews *et al.* (1994a, b) concluded that the severe yield losses for rice in many scenarios in South, South-East and East Asia was due to a threshold temperature effect that caused spikelet sterility but that genetic variation about the threshold likely provided significant opportunity to switch varieties as temperatures rose. Thus, an impact analysis that narrowly specifies a crop variety is likely to generate a much different estimated impact than an analysis that specifies responses based on the genetic variation across existing cultivars (for example Easterling *et al.,* 1993).

Insufficient information and knowledge on the present and future food crop production efficiency, the sensitivity of crops to climate change and the coping strategies sustaining crop production will inhibit designing and formulating appropriate policies to meet present and future food crop production demands of the country. Results from this study are expected to give direction for policymakers in designing appropriate public policies at a fine scale of local as well as regional areas so as to increase agricultural productivity, mitigating effects of climate change on food crop production, as well as adapting to unfavorable climatic episodes. It will provide a useful guide to international and local donor agencies interested in climate change mitigation and adaptation in their provision of grants and funds for environmental and resource management studies. The results of this study will also assist stakeholders in their planning activities by providing useful climate data that will guide in planning public (or planned) adaptations to complement the farm-level (or autonomous) adaptation strategies.

The projected shifts in current agro-ecological zones due to spatial and temporal changes in precipitation and temperature (Kurukulasuriya & Mendelsohn, 2008) seriously impact the viability of dryland subsistence agriculture (Challinor *et al*., 2007; Bapuji et al., 2011). Since the climate is a primary determinant of agricultural productivity, any changes will potentially influence crop growth and yield, hydrologic balances, supplies of inputs and other components of managing agricultural systems. Yet the nature of these biophysical effects, and the human responses, including adaptation, remain complex and uncertain. Climate change and its impacts on water and agriculture are critical to the very survival of the African continent and its people. The rate and magnitude of the impacts of climate change on the agricultural sector will depend on factors such as the extent to which current temperatures or precipitation patterns approach or exceed tolerance limits for important crops; per capita income; the percentage of economic activity based on agricultural production and the existing condition of the agricultural land base (Watson *et al*., 1997). Climate change could lead to severe reductions in agricultural productivity if no adaptation measures are taken (El-Shaer *et al*., 1997; Kurukulasuriya & Rosenthal, 2013, Thornton et al.,2011; Müller,2013; Waha et al., 2013). These impacts will extend beyond food shortages and in the process, negatively affect national economies. Therefore, in order to support local areas and local agricultural systems to become resilient to climate change, it is necessary to investigate and understand the nature of vulnerability from their perspective. It is crucial to map such vulnerability so that likely locations are identified for a range of possible climate futures. Furthermore, in order to develop a coherent national adaptation response, there is a need to integrate climate science, impacts and vulnerability studies, as well as results from assessing various adaptation options, into both sectoral and cross-sectoral decision-making processes.

There is a gap in information and knowledge on the present and future food crop production efficiency, the sensitivity of crops to climate change, and the coping strategies essential to sustaining crop production. It is therefore important to assess the vulnerability of crops to changing climate in the future and how this will affect food production and determine the associated response. Studies on global “hotspots” generally show South Africa to be high on the scale of negative impacts about crop production under future climate change (Fraser *et al*., 2013; Osborne *et al*., 2013). The impact projections are generally presented as world or continental-scale maps, where impacts on the small micro climate zones such as the, summer rainfall areas cannot readily be distinguished from a generalized projections of South Africa as a whole. Given that the climates in the summer rainfall areas differ markedly from each other and from the climate in the rest of the country, it is important that local impact models attempt to investigate more localized impacts. Moreover, most of these global studies tend to focus on maize production in South Africa since maize is a major national grain and food crop (Department of Agriculture, Fisheries, and Forestry (DAFF), 2011), rather than on other important cash crops including oilseed crops.

Oilseed crops have attracted much attention as potential renewable sources of raw material for liquid fuel compatible for various uses. With the rising focus on renewable energy sources, oilseed crops are good candidates as sources of biodiesel. Amongst the seed oils available in South Africa and targeted for biodiesel production are soybean, sunflower, and peanut oils (BIS, 2007; FTDB, 2008). Production figures indicate a general decline in oilseed yield from 2005/06 to 2006/07 and a corresponding decrease of the area planted, thus confirming the concern over oilseed under-production and land under-utilization (FTDB, 2007). The decline can be as a result of several factors amongst which is climate change. This study will provide information to stakeholders concerning the vulnerability of these oil crops to future climate change. This will help in policy framework which is reliable and objective oriented.

The emergence of sustainability science and climate change has drawn a considerable attention to the unique nature of developing countries and their vulnerability to climate change (Karki & Gurung, 2012). The specific needs of these countries are covered in Article 4 of the United Nations Framework Convention on Climate Change (UNFCCC) clause 8. This clause stipulates for parties to "give full consideration to meet specific needs and concerns of developing country parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures especially on countries that are highly vulnerable to climate change (arid and semi-arid); countries with areas prone to natural disasters and countries with areas liable to drought and desertification. In view of the above statement, this study seeks to assess the vulnerability in South Africa's summer rainfall areas.

This study will address the gaps in the methodology used in the previous vulnerability assessments and the type of data collected in South Africa. The impacts of climate change on agriculture in South Africa have been estimated using two main approaches: Structural modelling of crop and farmer response. Farmer response combines crop agronomic response with economic or farmer management decisions and practices while spatial analogue models or cross-sectional models measure observed spatial differences in agricultural production (Adams, 1999). However, no place-based, vulnerability assessment has previously been conducted using GIS. This study will employ a GIS-based spatial analysis of vulnerability to identify locations and populations that may be at higher risk due to climate change in the summer rainfall areas. The research will combine social vulnerability data with biophysical and climate data so as to build an understanding of the summer rainfall areas within the broader vulnerability context. It will further explore the feasibility of using the ‘Hazards of Place Model’ of vulnerability to map socioeconomic and physical vulnerability in summer rainfall areas, and ultimately produce a crop sensitivity and place vulnerability map for the study region.

1.4 Aim

The primary aim of this study is to assess the risk posed by climate change to the production of selected dryland crops namely soybean, sunflower, and groundnuts in South Africa and to model their vulnerability and response to developing coping and adaptation strategies using primarily the Limpopo and Free State Provinces as a case study.

1.5 Objectives

1. Assess the climate and agronomic responses of selected oil seed crops (sunflower, soybean, and groundnut) in relation to their current production areas;
2. Model and map the vulnerability of these crops to climate change;
3. Determine the risk of dryland oil seed crop production under projected future climate change scenarios;
4. Examine the vulnerability of smallholder sunflower, soybean, and groundnut farmers to a changing climate;
5. Develop coping and adaptation strategies and recommend alternative production options and;
6. Develop a decision support system for production regimes under the changing climate.

1.6 Hypotheses

The above-stated objectives will be achieved by performing tests of the following hypotheses:

1. Sunflower, soybean, and groundnut respond to agronomic factors in their current production areas.
2. Dryland crop production of oil seed crops (Sunflower, soybean, and groundnut) are vulnerabile to future climate change.
3. Dryland crop production under projected future climate change scenarios face risk.
4. Farmers in the summer rainfall areas of South Africa are vulnerable to the negative impacts of climate change.

5. The development of coping and adaptation strategies will increase the adaptive capacity of farmers.
6. The development of a decision support system for production regimes under the changing climate will enhance production.

1.7 Study Area

The study was conducted primarily in the Limpopo province and then the Free State provinces of the Republic of South Africa, where crop production is dependent on the summer rainfalls received in the months of October to March. Due to logistical issues and existing data constraints, the study in the Free State data focused only on the social vulnerability component of the study.

Limpopo province is the northernmost province of South Africa and is the fifth largest province amongst South Africa's nine provinces (South African Government, 2013). The province is made up of five (5) districts, namely: Greater Sekhukhune, Mopani, Capricorn, Waterberg and Vhembe (LDA, 2012). However, this study focused on the locations representing the distinct climatic regions following the GAEZ (2012) classification. The entire province covers an area of 12.46 million hectares, which is 10.2 % of the total area of South Africa (Oni et al., 2012). This province has three distinct climatic regions that can be classified as the Lowveld (arid and semi-arid) regions, the middle veld, Highveld, semi-arid region, and the escarpment region which has a sub-humid climate with a 700 mm rainfall per annum (LDA, 2012). The climatic variation experienced in Limpopo allows this province to produce a variety of agricultural products such as tropical fruits, cereals, and vegetables. Agriculture is seen as a cornerstone of the province's economy and has been earmarked as one of the economic priority areas alongside mining and tourism, for development in the Province by the Provincial Government (Botha, 2006a). However, there are two types of agricultural production systems taking place in Limpopo province, because of past apartheid regime policies (Oni et al., 2012), namely the large-scale commercial farming system and the smallholder farming system.

1.8 Thesis organization

Figure 1.1 represents the layout of this thesis. As shown, Chapter 1(introduction) describes the background, problem statement, and objective of the study. It further demarcates the study area and study area characteristics. Chapter Two (literature review) looks at the status quo of exposure, risk, vulnerability assessment methodology, adaption as well as the anticipated impacts of climate change on dryland agriculture. Chapter two hence looks at relevant literature pertaining to climate change, methods of assessing vulnerability in the agricultural sector as well as the impacts of climate change. The definitions of the various analytical framework of the thesis are shown. This pertains to the foundation for relating the study to the concept of risk, vulnerability, and adaptive capacity, assessment methodologies, the use of crop simulation models and geographic information systems. Chapter three (materials and methods) summarizes the material and methods used in the study, structured according to the analytical methodology. Chapter four (results) presents the results from the field survey in Limpopo and Free State, the field crop experiment in Limpopo, crop simulation, spatial analysis and various statistical analysis. Chapter five presents the synthesis of the findings related to the five research objectives. Chapter six presents a discussion and conclusions.

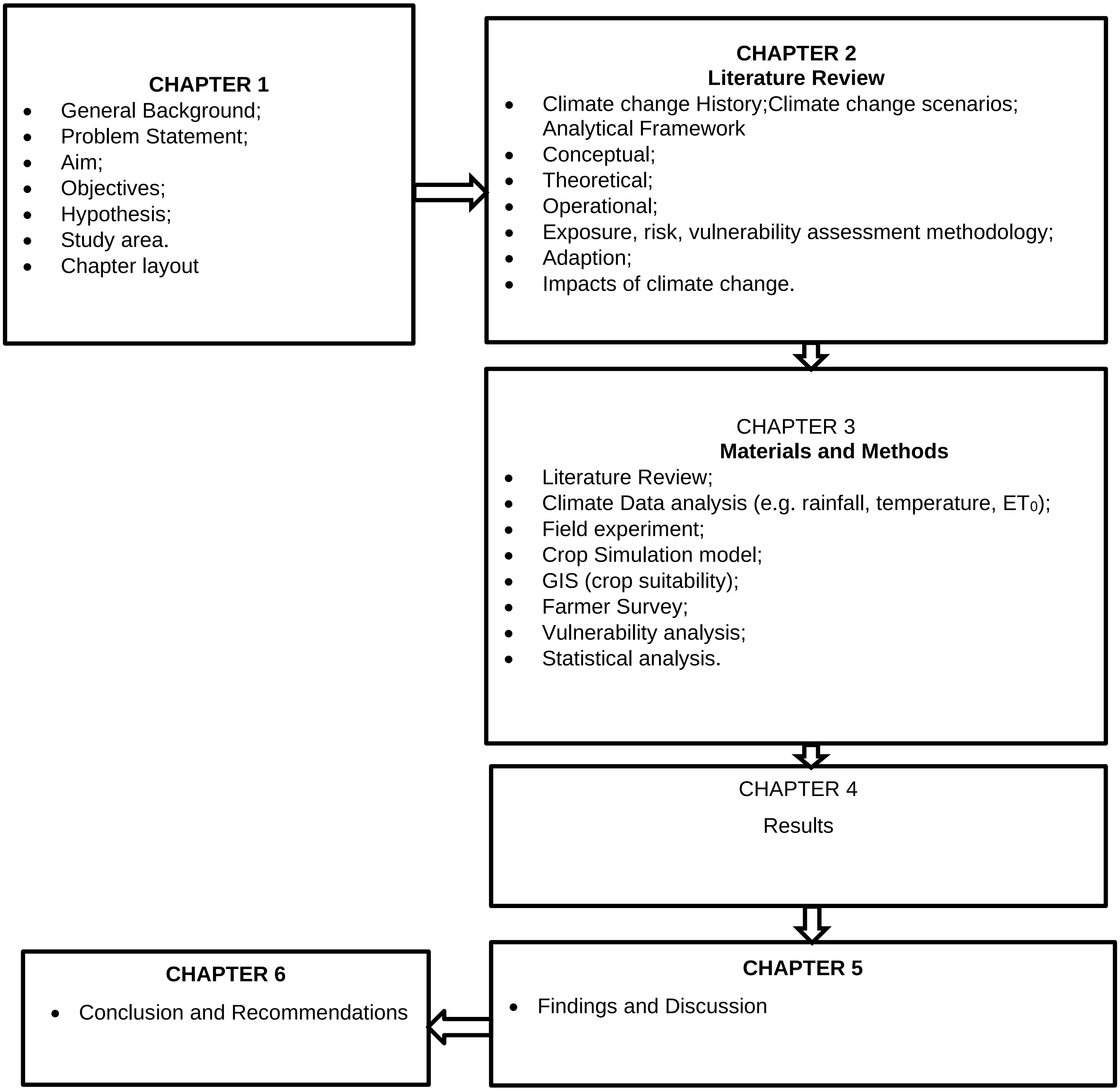

Figure 1.1: Chapters Outlay.

1.9 Summary

This chapter presents the problem statement, aims, and objectives of the study. The next chapter presents the status quo and studies relating to climate change, risk and vulnerability assessment.

Chapter Two

Literature Review

2.1 Introduction

This chapter deals with relevant literature pertaining to risk and vulnerability. It starts off by defining theoretical, analytical and practical frameworks of vulnerability, the definition of climate change followed by a brief history of climate change research. The literature review progressively examines research works pertaining to climate change from a global level, to a local level and the study of expected impacts at the regional scale with relevance to agriculture. This is followed by an appraisal of the literature on approaches of vulnerability and assessing adaptation to climate change.

2.2 Concept of climate change

The United Nation's Framework Convention on Climate Change (UNFCCC) defines climate change as a change of climate attributed directly or indirectly to human activity which alters the composition of the global atmosphere and in addition to natural climate variability over comparable time periods (Intergovernmental Panel on Climate Change (IPCC), 2001). Comparatively, the IPCC (IPCC, 2001b) defines climate change as a change in the state of the climate which can be identified (via the use of statistical tests for instance) by changes in the mean and/or the variability in its properties and is persistent for an extended period, typically decades or longer. Even though the earth's climate changes constantly and naturally over time, the rate of the change as experienced and predicted for the future shows that the rate of future climate change may be more rapid than at any time in the last 10000 years. Due to the influence of human activities, the expected climate change would differ from previous climate change in the nature of anthropogenic forcing. It is because of this reason that Koehler-Munro and Goddard (2010) defined climate change as the slow change in the composition of the global atmosphere, which is caused directly and indirectly by various human activities in addition to natural climate variability over time. They further remarked that the atmosphere has an effect like a greenhouse on the earth's atmosphere. The energy from the sun reaching the earth is balanced by the energy that the earth emits back to space. Greenhouse gases (GHGs) trap some of this energy that the earth releases to space and act as a thermostat controlling the earth's climate. Without this natural greenhouse effect, the average temperature on earth would be -18^{o}C instead of the current $+15^{o}$C, which will make life impossible on earth. This transformation in the GHGs had been predicted by earlier scientists as a change that will be disastrous to various systems if not controlled.

2.2.1 History of climate change with an emphasis on CO_2 concentrations

The history of the centuries-long effort to document and understand climate change is often complex, marked by successes and failures, and has followed a very uneven pace. Testing scientific findings and openly discussing the test results have been the key to the remarkable progress that is now accelerating in all domains, despite inherent limitations to predictive capacity (Le Treut *et al*., 2007).

19th-century Predictions

The latter part of the 19th century saw Tyndall (1863) and Arrhenius (1896) positing that climate change may be induced by a change in CO_2 concentration in the atmosphere. Arrhenius (1896) was the first scientist to link the contribution of carbon dioxide to the greenhouse effect. The author hypothesized that increases in the atmospheric concentration of carbon dioxide would contribute to long-term variations in climate using data from Samuel P. Langley's study on the incidence radiation of rays from the moon hitting the earth at angles of deviation ranging from 35^o to 40^o. Arrhenius based his calculations on the principles that the quantities of CO_2 and H_2O are proportional to the path of the ray which traverses them. His results showed that when the quantity of CO_2 increases in geometric progression, temperatures will increase nearly in arithmetic progression. This effect was different for different parts of the globe depending on the amount of CO_2 in the air. Furthermore, the influence was predicted to be greater in summer than in winter and an increase of CO_2 will diminish temperature differences between day and night.

Arrhenius et al., (1903) further predicted that a doubling of CO_2 which would have taken 3000 years if the world was a single land mass, will take 500 years due to coal burning. The author further estimated a projected temperature increase of 3-4^{o}C during this latter period. He predicted that increases in CO_2 in the atmosphere could warm the earth by as much as 9^{o}C if CO_2 of his day could triple. He calculated that the 9^{o}C warmer temperature is what prevailed in the balmy Tertiary artic regions. Hence, for the ice temperature to prevail between the 40th and 50th parallels, the CO_2 level had to sink to 55-60% of the level of his day, which translates to a lowering of temperature by 4-5^{o}C. Unfortunately, due to the ideology of "optimistic evolutionism" prevailing at that time, Arrhenius (1896) did not see this as a dire situation for future generations. He is quoted to have said, "it will allow our descendants, even those of a distant future, to live under a warmer sky and in a less harsh environment than we were granted". The work of Arrhenius (1896) was the first model which made possible predictions of both global warming and cooling (Crawford, 1997).

Subsequent researchers such as Callender (1938): Plass (1956); Kondratieve and Niilisk (1960); Kaplan (1960) Moller (1963) amongst others followed suit and evaluated CO_2-induced warmings from a condition of radiative heat budget at the earth's surface. Callender (1938) stated that through fuel combustion, man had added about 150 billion tons of carbon dioxide to the air during the second half of the preceding century, with an estimation that approximately three-quarters of this CO_2 had remained in the atmosphere. The temperature observations at zoo meteorological stations showed that world temperatures had actually increased at an average rate of 0.005°C per year during the preceding half-century. Most of the studies at that time employed similar approaches for the estimation of CO_2 induced warming of the earth surface. Kaplan (1960) takes into consideration the effect of cloud cover on the CO_2 induced change in the downward flux of terrestrial radiation; Kondratieve and Niiliskin (1960) incorporate the effect of overlapping between an absorption band of H_2O vapour and CO_2 in their composition; Moller tried to improve these estimates by taking into consideration the effect of CO_2-induced change in H_2O vapor in the atmosphere. His results revealed that an increase in H_2O vapor content with rising temperatures causes a self-amplification effect which results in large temperature changes. When the air temperature is around 15^oC, the doubling of CO_2 content results in a large temperature increase of 10^oC.

In the early 1970s, the rise of environmentalism started to raise public doubts about the benefits of human activity for the planet. Curiosity about climate turned into anxious concern (Weart, 2008). Alongside the greenhouse effect, some scientists pointed out that human activity was emitting dust and smog particles into the atmosphere, where they could block solar radiation and cool the earth. Broecker (1975) popularized the term "global warming" and explained how ocean currents affect abrupt climate change.

20th-century Predictions of Climate Change

Climate change scenarios are a physically consistent set of changes in meteorological variables, based on generally accepted projections of CO_2 as well as trace gas levels. Scenarios of climate change were developed and utilized in agricultural milieu to estimate their effects on crop yields, extents of land with cultivation potential, and the number and type of crop combinations that can be cultivated. The IPCC's emissions scenarios form the basis for the majority of long-term climate change projections. The emissions scenarios of the Intergovernmental Panel on Climate Change (IPCC) have significantly evolved from the First assessment SA90 in1990; the Second IS92 in 1995, to the Third Assessment Report (TAR) (2000, SRES) (IPCC, 1990b, 1995, 2001a) to the Fourth Assessment Report (AR4) and the fifth Assessment Report 5(AR5).

What is consistent in these discussions is the inherent changes in climate due to changes in the composition of various greenhouse gases with effects on the climate regimes. These changes in mean temperatures and rainfall regimes place various areas and activities at risk both at global and regional scales.

2.2.2 Climate change at the global and regional context

Reports from the Intergovernmental Panel on Climate Change (IPCC) confirms the observed unequivocal warming of the global system and predict further warming into the 21st century under current emissions scenarios. Even under the most conservative emissions scenarios, CO_2 levels are expected to continue to rise steeply as indicated in Figure 2.1.

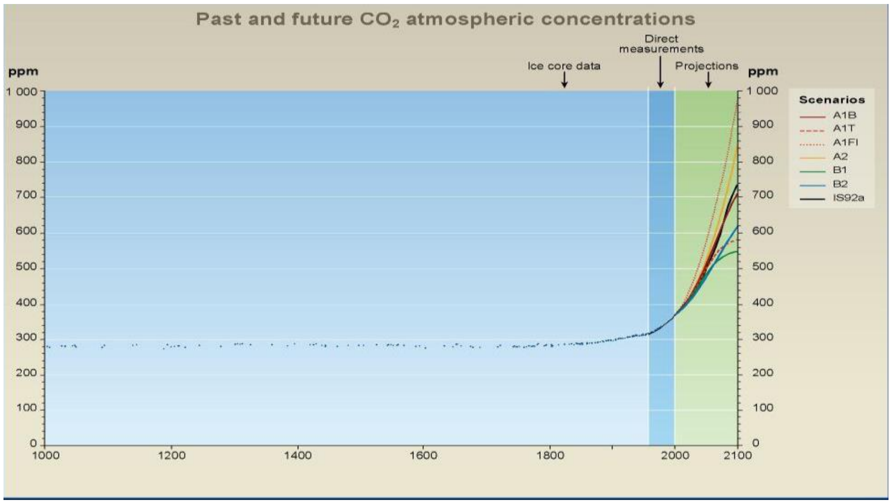

Figure 2.1: Past and projected future CO_2 emission concentrations SRES scenario (IPCC, 2007).

According to the IPCC (2007c), the highest emission scenario projects an increase of 2.4 - 6.4^{o}C in global average surface temperature by the year 2100, relative to the 1980-1999 base period. The rate of temperature increase during the two decades, 2010-2030 is estimated at about 0.20^{o}C per decade across all IPCC emission scenarios. However, Wheeler (2007) is of the opinion that the IPCC assessments (i.e. IPCC, 2007b) of global warming could be on the conservative side since recent studies have indicated a relatively enhanced accelerating rate of change. A high risk of extreme temperature events is projected by the IPCC (2001; 2007b) in future climates. Furthermore, the expected warming will cause a rise in sea level in the range 0.18-0.59m during the period 2090-2099, relative to the 1980-1999 periods, across all IPCC emission scenarios.

Precipitation, on the other hand, shows variation among climate models on future projections (IPCC, 2007b; Ziervogel *et al*., 2008) with projections over tropical regions being more uncertain than those at higher latitudes (IPCC, 2007b). Nevertheless, projections with a high probability (95%) show that precipitation will increase in higher latitudes while in the sub-tropics, it is likely to decrease by as much as 20% by 2100. The expected ranges and best estimates (given as the difference in magnitude between the lower and upper limit values of the likely range) for global average surface air warming differ for the different Special Report on Emission Scenarios (SRES) as shown by Table 2.1.

Table 2.1: Projected globally averaged surface warming and sea level rise at the end of the 21st century (IPCC.2007b).

	TEMPERATURE CHANGE (°C BY 2090-2099 RELATIVE TO 1980-1999)		**SEA-LEVEL RISE (CM BY 2090-2099 RELATIVE TO 1980-1999)**
CASE	BEST ESTIMATE	LIKELY RANGE	MODEL-BASED RANGE EXCLUDING FUTURE RAPID DYNAMICAL CHANGES IN ICE FLOW
CONSTANT YEAR 2000 CONCENTRATIONS	0.6	0.3 - 0.9	NA
BI SCENARIO	1.8	1.1 - 2.9	18.0 - 38.1
A1T SCENARIO	2.4	1.4 - 3.8	20.1 - 45.0
B2 SCENARIO	2.4	1.4 - 3.8	20.1 - 42.9
A1B SCENARIO	2.8	1.7 - 4.4	21.1 - 48.0
A2 SCENARIO	3.4	2.0 - 5.4	23.1 - 51.1
A1F1 SCENARIO	4.0	2.4 - 6.4	25.9 - 58.9

The projected sea level rise also differs, with the B2 scenario (lowest CO_2 emission scenario) having the least rise of 1.80-3.8 m and the A1F1 (highest emission scenario) having the greatest rise of 2.59-5.89 m over the period 2090-2099, relative to the 1980-1999 period (Table 2.1). Given that the IPCC SRES scenarios are grounded on projected future greenhouse gas emissions (mostly CO_2), which are determined by factors such as social, economic and technological changes, the level of vulnerability to climate change will also be determined by these factors (IPCC, 2007c).

Empirical evidence shows that Africa is expected to experience particularly dire impacts of climate change. Some of the projected impacts and consequences as illustrated from studies such as that of Boko et al., (2007) posit that:

- There will be an increase in water stress due to climate change by 2020;
- Yields from rain-fed agriculture in some countries could be reduced by up to 50% by 2020;
- Agricultural production and access to food in many African countries will be severely compromised, thereby enhancing issues of food insecurity and exacerbating malnutrition.
- Adaptation cost could amount to at least 5-10% of the Gross Domestic Product (GDP).
- There will be an increase of 5-8% of arid and semi-arid land in Africa by 2080.

The whole of Africa is expected to experience warming greater than the global mean values in all seasons (IPCC, 2007b) and by the end of the 21st century, the median temperature increase will be between 3°C and 4°C, which is about 1.5 times the global mean response (Eriksen *et al.,* 2008). Moreover, future warming is expected to be greatest over the interior of semi-arid margins of the Sahara and central southern Africa (Eriksen *et al.,* 2008). Drying is projected throughout southern Africa while increases in rainfall over parts of eastern Africa are expected (IPCC, 2007b). Indications show that the intensity of rainfall events and the frequency of droughts are increasing in southern Africa (Eriksen *et al.,* 2008; Kandji *et al*., 2006). These extremes and their frequencies and climate variability make it unconducive for agricultural production as detailed below.

2.2.3 Climate change and agriculture

According to IPCC (2014), without the implementation of adaptation measures, climate change is projected to reduce crop production for local areas with temperature increases of 2°C or more (above late 20th-century levels) up to 2050. Even though it is projected that increased CO_2 levels will have some beneficial effects on crop yields (IPCC, 2014), these impacts are modified and limited by increased temperatures, especially at critical growth stages. Climate change will be particularly hard on agricultural production in Africa and Asia (IPCC, 2014).

Climate-related risks for agriculture are particularly acute in developing countries. This is so because farmers lack resources fundamental to resilience including finance, technology, and knowledge (IPCC, 2014). Moreover, climate-related risks interact with existing environmental stressors such as biodiversity loss, soil erosion, and water contamination, and with social stressors such as inequality, poverty, gender discrimination, and lack of institutional capacity (IPCC, 2014). These interactions compound risks to agricultural production and food security.

In many regions, the change in the levels and patterns of precipitation, melting snow and ice, as well as the retreating glaciers are altering hydrological systems, thereby affecting water resources and quality (IPCC, 2014). Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions. Each degree of warming is expected to decrease renewable water resources by at least 20% (IPCC, 2014).

Southern Africa is identified as a region likely to experience negative impacts under future climate change. A study carried out by Ericksen et al. (2011) in South Africa to identify areas that are potentially food insecure and vulnerable to the impacts of future climate change. The study developed thresholds of climate change exposure which were deemed important for agricultural systems to assess the vulnerability of agriculture to changing climates. Results from the study demonstrated that, although South Africa has a high GDP, there are many people who still live in poverty. The authors further reported that South Africa contains regions of high agricultural sensitivity to climate change. The study, however, did not consider climate change and food security “hotspot” in the context of this study.

Thornton *et al.* (2010), examined bean and maize responses to climate change in East Africa using Decision Support System for Agrotechnology Transfer (DSSAT) production models, the MarkSim daily weather generator and combinations of two GCMs under two SRES emission scenarios. The aim of the study was to determine adaptation options at a community level, for which large, spatially contiguous study domains would be unsuitable. Even though the overall yields of both bean and maize were expected to decrease by 2050, different results were presented by the GCMs and SRES scenario used. The study showed the spatial and temporal heterogeneity of results and the importance of high-resolution, localized modelling. Benhin (2006; 2008) uses a Ricardian modelling approach to assess climate change impacts on agriculture in South African. Three climate scenarios used indicated that temperatures will increase by between 2.3°C and even 9.6°C by 2100, while precipitation will decrease by between 2 and 8% by 2100. The results predicted a net crop revenue fall by as much as 90% by 2100 if adaptation measures are not implemented. A similar study carried out by Gbetibouo and Hassan (2005) using an economic-simulation approach speculated that wheat production in the Western Cape would disappear as winters become warmer over the next 50 years and crops such as sunflower and soybean may become the preferred cash crop of the region. On the other hand studies such as that of Farooq et al.(2011); Hatfield et al.(2011); Ottaman et al.(2012) Wheeler et al. (2000) expect a reduction in the yield of wheat because of an increase in mean seasonal temperatures of 2 to 4°C and shorter crop duration (reduced grain fill period).

As identified in the literature, climate change will impact the availability of water resources for agriculture in the future through changes in precipitation, potential and actual evaporation, and runoff at the watershed and river basin scales. Both the demand for and supply of water for agriculture will be affected by changes in the hydrological regimes. There will be concomitant increases in future competition for water with non-agricultural users owing to population and economic growth (Strzepek *et al.,* 1999; IPCC,2014).For key horticultural crops for example deciduous fruit such as apples and pears, warm winters will caus insufficient chilling (e.g Migdley et al., 2011)

Efficient agricultural production is dependent on optimum conditions of temperature and water as well as other climate resources of sunlight and carbon dioxide. Changes in these projected climatic variables will adversely affect plant and animal systems over the next 10 to 30 years (Hatfield, 2008; Bellard et al., 2012; Hallman et al., 2017). The direct and indirect impacts of climate change on agriculture could have large impacts on agricultural production in the summer rainfall areas of South Africa. Increased precipitation variability will cause uncertainty in the amount of water available during the year, which could negatively impact plant production and have a profound effect on pasture and hay or grain supplies for all livestock. Rising temperatures over the next 30 years will have an impact on crop yield because of the impacts of temperatures that are above optimal during the pollination stage in all crops (FAO, 2011; Hatfield et al., 2014). Incidences of such temperatures will cause yield reductions which could be further decreased by shortages of water required for optimal plant growth. Such effects will be noticeable in grain, forage, fiber, and fruit crops.

Climate change is therefore expected to worsen food supply and exacerbate the widespread poverty in Africa (Centre for Environmental Economics and Policy in Africa (CEEPA), 2002; Hope, 2009; Kotir, 2011). According to Kotir (2011) the impact of adverse climatic changes on agriculture is exacerbated in Africa by insufficient adaption strategies, owing to the lack of institutional, economic and financial capacity to support such actions. Such an inadequate capacity to adapt to these changes may be devastating to the agriculture sector, which is the main source of livelihood for the majority of the population. Impacts on and the adaptive capacity of a system may vary substantially over the next decades and within countries given that vulnerabilities can be highly dynamic in space and time. As a result, there is a need to build resilient agricultural systems that have a high capacity to adapt to stress and changes and can absorb disturbances.

The conclusion drawn from the literature is that increases in temperature will invariably increase the vulnerability of the agricultural sector. Increased temperature will cause increases in the rate of evapotranspiration and can lead to an increase in the demand for water for irrigation. This will be an addition to the competition for available water required for household and industrial needs. For instance, irrigation demand is projected to increase by 0.4% – 0.6% per year up to between 2030 and 2080, according to projections from the Food and Agriculture Organization (FAO, 2011). Furthermore, if the anticipated impacts of climate change are added, projected demands will increase to between 5 to 20% by 2080. Adaptation is therefore essential in order to be able to contain the future impact of the projected climate changes. Given the expected impact of climate change on the agricultural sector, it is important to measure the sensitivity of the agricultural sector to such changes. Accordingly, a discussion on the concept of vulnerability and the measurement of the sensitivity of the agricultural sector follows.

2.3 Concept of vulnerability

The concept of vulnerability has been widely used in different fields of specialization and has been defined in reference to each field. The variations in the concepts and definitions of vulnerability come from the angle from which it is evaluated and around the explanation of lack of adaptive capacity in both social and natural systems. In order to understand the relationships among climate change, vulnerability and agriculture it is important to understand the key elements linked to vulnerability: hazards, risks, and disasters. Though not mutually exclusive but often used interchangeably, these concepts mark the progression and impacts of vulnerability within an explicit spatial domain. An understanding of these elements is important in any vulnerability research. In order to accommodate differing perspectives, literature allows for a range of definitions of these terms in relation to vulnerability research (Miller *et al.,* 2010) as seen in the following paragraphs:

- Risk is defined as the probability of sustaining harm or the likelihood that some type of injury or loss would result from a hazardous event (Cutter *et al*., 2009; Mitchell & Kate, 2011). Factors at risk from climate change include amongst others, agricultural systems, human population, settlements, landuses, economic activities and services. Risk is equated when vulnerability and hazards combine. This relationship is encapsulated in the formula:
  Risk = Hazard x Vulnerability (Kumpulainen, 2006).

Differences in measurement approaches to vulnerability among the disciplines are explained by their tendency to focus on different components of risk.

- Sensitivity is the degree to which a system will respond to a change in climatic conditions (O'Brien,2004) such as the extent of change in the composition of an ecosystem, its structure including primary productivity resulting from change and functioning in temperature or precipitation.
- Exposure is defined by the IPCC (2012) as the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.
- Resilience is defined as the ability "to withstand short-term or long-term shocks and be able to return to pre-shock or pre-trauma conditions" (Petrillo & Prosperi, 2011). According to Adger *et al.*, (2011) resilience is the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedback.

Given the fact that the focus of this study is on risk and vulnerability linked to climate change and variability, it applies the IPCC (2007) definition of resilience which is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization and the capacity to adapt to stress and change.

2.3.1 Interpretations of vulnerability

Vulnerability can be interpreted from two different perspectives "the end point" and a "starting point" (O'Brien et al.,2004) as seen in Table 2.2. The "end point" approach views vulnerability as a residual of climate change impacts minus adaptation. According to this perspective, vulnerability embodies the net impacts of climate change and serves as a means of defining the degree of the climate problem and providing input into policy decisions regarding the cost of climate change versus costs associated with the greenhouse gas mitigation efforts (Fussel, 2007). Research within this viewpoint assesses the distribution of some hazardous conditions, human habitation of hazardous zones, and the extent of loss of life and property emanating from a hazardous event.

The "starting point" approach regards vulnerability as general characteristics created by multiple factors and processes and examines the pre-existing conditions and focuses more on potential exposure to hazards (O'Brien *et al*., 2004; Cutter, 2009; Birkmann et al., 2013). Thus, researchers from different disciplines use these interpretations and different meanings and concepts of vulnerability, which, in turn, have led to diverse methods of measuring vulnerability. Additionally, research interest is now focused on empirically measuring vulnerability (e.g. Armas, 2008; Myers *et al.,* 2008; Mendes 2009; Chen *et al*., 2013a), especially social vulnerability.

Several frameworks, conceptual models as well as vulnerability assessment techniques have been developed to increase the understanding of theoretical emphasis and practical applications of vulnerability (for instance, Manuel-Navarrette *et al*., 2007; Polsky *et al*., 2007; McLaughlin & Dietz, 2008; Letsei, 2015; Mafi-Gholami et al., 2016). Even though these various models and frameworks are different, they do have several common elements as assessing vulnerability from a social-ecological perception; are place-based studies; vulnerability is conceptualized as an equity of human rights issue (Sarewitz *et al*., 2003); and the use of vulnerability assessments to identify hazard zones, in so doing establish the base for pre-impact and hazard mitigation planning (for example O'Brien *et al*., 2004; Brooks *et al.,* 2005; Posey,2009) as presented below and in Table 2.2.

Table 2.2: Summary Characteristics of Vulnerability Approaches
Source: Based on O'Brien et al., (2004); Smit et al., (1999); Burton et al., (2002); Füssel and Klein, (2006).

Attributes of vulnerability investigated	End point interpretation	Starting point interpretation
Root problem	Climate change	Social vulnerability
Policy context	Climate change mitigation, comprehension, technical adaptation	Social adaption, sustainable development
Illustrative policy question	What are the benefits of climate change mitigation	How can the vulnerability of societies to climatic hazards be reduced?
Illustrative research question?	What are the expected net impacts of climate change in different regions?	Why are some groups more affected by climatic hazards more than others
Vulnerability and adaptive capacity	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Reference for adaptive capacity	Adaptation for future climate change	Adaptation to current climate change
Starting point analysis	Scenarios of future climate hazards	Current vulnerability to climatic stimuli
Analytical function	Descriptive, positivist	Explanatory, normative
Main discipline	Natural sciences	Social sciences
Meaning of vulnerability	Expected net damage for a given level of global climate change	Susceptibility to climate change and variability as determined by socioeconomic factors
Qualification of terminology	Dynamic cross-scale integrated vulnerability (for a particular system) to global climate change	Current internal socioeconomic vulnerability (of a particular social unit) to all climatic stressors
Reference	Mccarthy *et al* (2001)	Adger (1999)

2.4 Concept of adaptation

Adaptation refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate (Wamsler,2013). According to Nhemachena and Hassan (2007), the adaptation of the agricultural sector to climate change pertains to those changes in agricultural management practices as a response to changes in climate conditions. There are various types of adaptation amongst which are: anticipatory and reactive adaptation; private and public adaptation; autonomous and planned adaptation. Individual or autonomous adaptations are seen as those that take place in reaction to climatic stimuli (which is after the manifestation of initial impact) without the intervention of any public agency (Smit *et al.,* 2001).

Autonomous adaptations are broadly interpreted to be initiatives by private actors (excluding the governments) which are usually triggered by market or welfare changes, induced by actual or anticipated climate change. Policy-driven or planned adaptation is often taken happens as a result of a deliberate policy decision on the part of a public agency, based on an awareness that conditions are about to change or have changed, and that action is required to minimize losses or benefit from opportunities (Pittock & Jones, 2000).

Autonomous and policy-driven adaptation largely corresponds to private and public adaptation, respectively (Smit *et al.,* 2001). Therefore, the responses of autonomous adaptation will be based on the individual farmers in terms of costs and benefits. It is further anticipated that farmers will adapt, given that markets alone can encourage efficient adaptation in traded agricultural goods (Gouel & Laborde, 2018). However, given a situation where market imperfections exist, for example, the absence of information on climate change or land tenure insecurity, climate change will further reduce the capacity of individual farmers to manage risk effectively. Consequently, there is the need to have an appropriate balance between public sector efforts and incentives such as capacity building, creation of risk insurance and private investment so as to shift that burden away from poor producers (Rosegrant, *et al.*, 2008).

Adaptation is often the result of interactions between climatic and other factors, and hence, it does not only vary with respect to their climatic stimuli but also with respect to other, non-climate conditions. These conditions referred to as intervening conditions, serve to influence the sensitivity of systems and the nature of their adjustments. A series of droughts, for example, may have similar impacts on crop yields in two regions, but differing economic and institutional arrangements in the two regions may well result in quite different impacts on farmers and hence in quite different adaptive responses, both in the short and long terms (Smit *et al.,* 2000).

It is therefore essential to show that the relationship between a changed climate system (for instance, higher temperatures, altered precipitation regime) and impacts on human systems is not necessarily linear as has been portrayed by early approaches used in climate impact studies. Human agencies along with institutions can play a crucial role in not only minimizing the adverse impacts of climate change but also in making use of opportunities resulting from climate change. In particular, the role of adaptation, whether reactive or anticipatory, spontaneous or planned is crucial for assessments of potential impacts of climate change (Smit *et al.,* 2000).

2.4.1 Characteristics of adaptations

There exist a variety of measures or actions that could be undertaken in the agricultural sector to adapt to climate change (Smit & Skinner, 2002; Otitoju,2013; Ukwuaba,2017) as well as numerous characteristics by which adaptations can be distinguished and also serve as bases for a typology of agricultural adaptations (Burton,1993 cited in Biagini et al.,2017; Smithers & Smit, 1997; Stakhiv, 1993). Some distinguishing characteristics of adaptation include intent and purposefulness; timing and duration; scale and responsibility.

2.4.2 Adaptation and policies

The degree of success of any adaptation plan is dependent on various factors such as the level of technological advances, institutional arrangements, availability of financing, and information exchange (Watson *et al.,* 1996). The negative impacts of climate change will probably undermine the goal of sustainable development in many parts of the world, and in areas such as South Africa, where the social and economic costs of climate change are already being incurred and are a growing threat to the achievement of South Africa's sustainable development goals, the poor will be the most vulnerable. Nevertheless, it is worth noting that some of these projected adverse effects can, to some degree, be reduced through proactive adaptation measures (IPCC 2000b). Several international and national policies have been geared towards fostering and or enhancing the drive towards adaptation to climate change.

The United Nations Framework Convention on Climate Change (UNFCCC) recognizes the need to adapt to climate change and to assist those countries that are least able to adapt. Within this framework, adaptation has been regarded as one of the keys "developing country issues" in the context of the climate negotiations. UNFCCC efforts to address the issue of adaptation can be seen in the following:

Article 4.1 of the UNFCCC where Parties are committed to formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures… to facilitate adequate adaptation to climate change

Article 4.1. (b) stipulates for cooperation in the preparation for adaptation to the impacts of climate change; developing and elaborating appropriate and integrated plans for coastal zone management, water resources, and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, which is affected by drought and desertification, as well as floods (Art. 4.1 (e).

Article 4.4 states for the developed country parties and other developed Parties included in Annex II to also assist the developing country parties that are particularly vulnerable to the adverse effects of climate change in meeting the costs of adaptation to those adverse effects.

Articles 4.8 and 4.9 make explicit reference to developing country parties, especially the least developed countries. These articles specifically mention funding and transfer of technology "to meet the specific needs and concerns of developing country parties arising from the adverse effects of climate change" (UNFCCC 1992). Furthermore, article 4.8 makes note of the Special attention that is to be granted to those countries considered most vulnerable such as small-island countries, those countries with arid or semi-arid areas amongst others.

Article 4.4 of UNGCCC convention falls in line with that in the Kyoto Protocol which makes provisions for the funding of adaptation activities in the most vulnerable countries. In particular, article 12.8 of the Protocol states that: The Conference of the Parties… "*shall ensure that a share of the proceeds from certified project activities is used to… assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation*."

The Conference of the Parties amongst others endorsed the staged approach to adaptation. This involved among the suggested actions to be taken by Annex II countries, pilot or demonstration projects "to show how adaptation planning and assessment can be practically translated into projects and integrated into national policy and sustainable development planning" (UNFCCC 2000b:4). Accordingly, Decision 11/CP.1 of the Conference of the Parties divides adaptation activities into the following three stages:

- Stage I Adaptation: Planning. This includes studies of possible impacts of climate change, identification of particularly vulnerable countries or regions and policy options for adaptation and appropriate capacity building";
- Stage II Adaptation: Measures. This involves the inclusion of additional capacity building, which may be taken to prepare for adaptation as envisaged in Article 4.1 (e);

- Stage III Adaptation: Measures. Sees to the facilitation of adequate adaptation, together with insurance and other adaptation measures as envisaged in Articles 4.1 (b) and 4.4.

Besides these two international bodies spearheading the need for adaptation, the IPCC is worth commending in its efforts as well. This organization has taken strides in assessing climate change impacts and vulnerability as well suggesting adaptation to climate change. Worth noting are:

- IPCC’s Technical Guidelines for Assessing Climate Change Impacts and Adaptation (Carter *et al.,* 1994);
- Handbook on methods for impact assessment and adaptation strategies prepared by Feenstra et al. for UNEP (1998);
- The Compendium for Decision Tools to Evaluate Strategies for Adaptation to Climate Change prepared for the UNFCCC (1999).

These resources describe approaches, methods, and models that can be used for impacts and adaptation assessments as well as a wide range of decision tools used in different sectors.

2.5 Conceptual framework of vulnerability

Climate change events, such as droughts and floods place agricultural activities at risk. The effects of these events are curbed and reduced through the process of adaptation. Corresponding adaptation strategies that are being used or some agronomic practices already practised are being intensified by the food crop farmers in order to cope with the change in climate as shown in Figure 2.2. The expected results should be improved efficiency and productivity in food crop production thereby reducing the vulnerability of farmers.

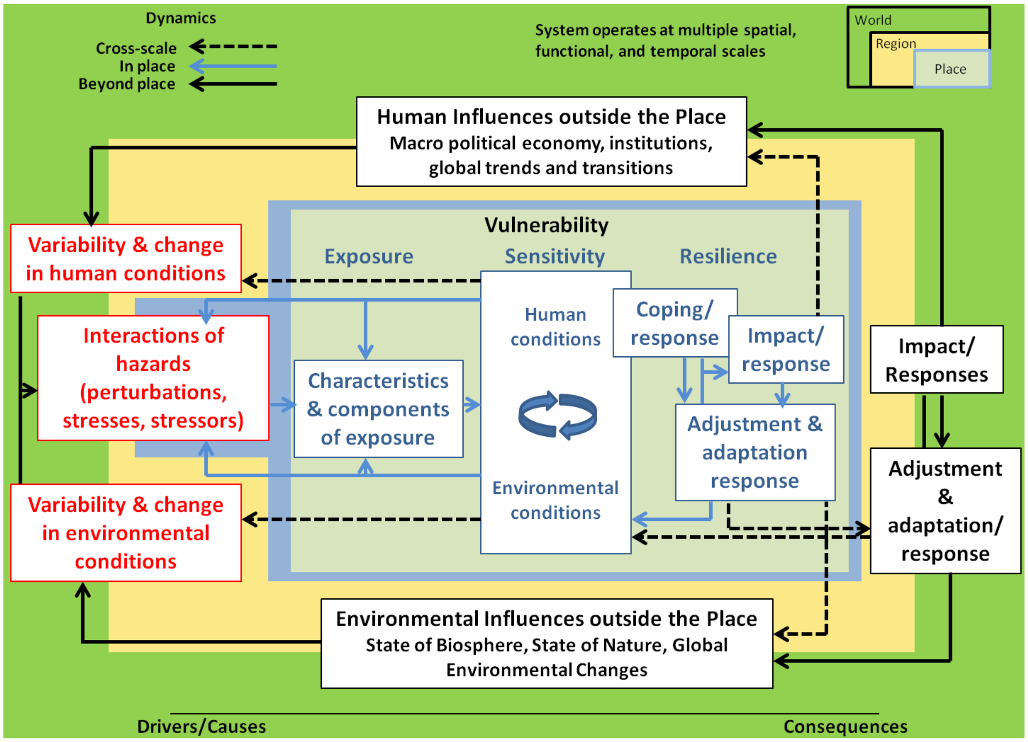

Figure 2.2: Vulnerability conceptual framework.
Source: Turner et al., (2003) in Birkmann (2006).

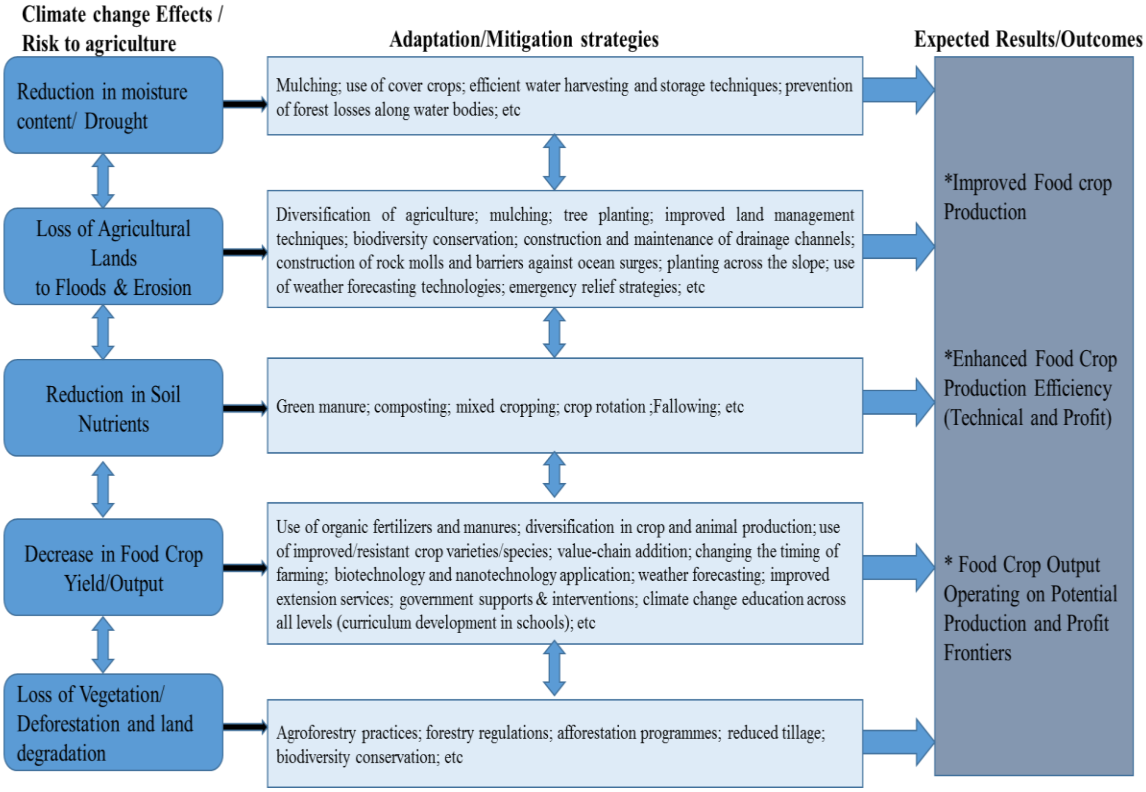

Figure 2.3: A conceptual framework of the effects of climate change and possible adaptation strategies on food crop production efficiency and security.
Source: Adapted from Ozor et al., (2010).

2.6 Theoretical framework - Hazard of Place

Projections of vulnerability over time poses major challenges. This can be because adaptive capacity depends on many socioeconomic variables with uncertain coefficients; sensitivity and exposure can only be predicted with great uncertainty (Vincent, 2007 cited in Ghimire 2010; Fussel, 2012; Biagini et al.,2014). In order to reduce this uncertainty using the current status of adaptive capacity or adaptation of a social system, a series of acceptable proxies have been identified as the capacity to adapt to future climate change (e.g Cooper *et al*.,2008 cited in Below, 2012; Challinor *et al*., 2009 cited in Xiao,2013).

Several conceptual frameworks have been presented that attempt to extend the generic model of vulnerability by characterizing its elements in greater detail (e.g. Burch & Robinson, 2007; Fussel, 2007). In spite of their intention of providing generally applicable guidelines, most studies provide only limited references to local-level adaptation processes and, especially, to the adaptation of small-scale farmers.

The theoretical base of this research is a methodical spatial combination of biophysical and social components in a place-specific assessment of vulnerability, known as the hazards of place vulnerability model (Cutter, 1996; Preston *et al*., 2011 cited in Frigerio & De Amicis,2016). This model stems from natural hazards research and the human ecological perspective as shown by Figure 2.4.

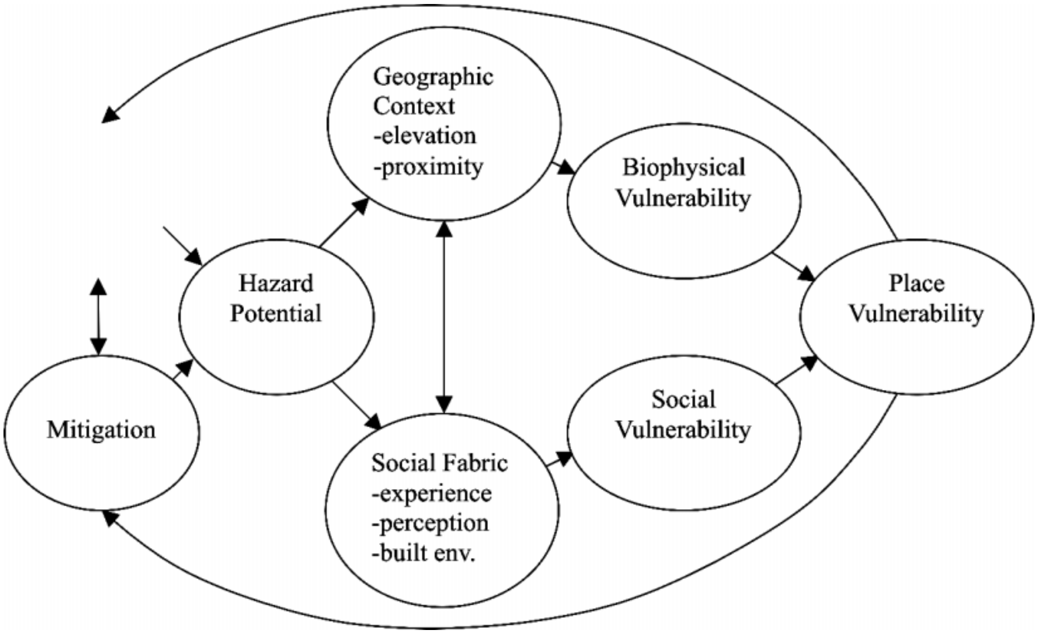

Figure 2.4: The Hazards-of-Place model of vulnerability (Cutter et al. 2003).

Given its local level approach, the hazards of place vulnerability model make it possible for climate change attributes and their influence on the overall place of vulnerability to be examined. The main advantage of the model is the incorporation of both social and physical factors in the vulnerability assessment of a place. This conceptual model shows how the hazard potential interacts with the geographic context and social fabric to produce both biophysical and social vulnerability. Some methodological approaches used in this framework are integrated modelling and simulation techniques (Rotmans & vanAsselt, 2001) and statistical downscaling.

A particular strength of the place-based analysis is its potential for increased public involvement and collaboration. A disadvantage of the model is that concepts used to construct the model are very broad and could be defined and/or interpreted very differently, depending on who is adopting the model. However, this research has addressed this by defining the concepts that are applicable to the study at hand.

Within the hazard of place model, the research follows the conceptual approaches of Yohe and Tol (2002) and Chambers (1989) as these authors provide explanations for the variability of farmers' vulnerability, adaptive capacity, and adaptation at a local scale. The construct of Yohe and Tol's work is based on the Third Assessment Report of the IPCC. According to this report, there are five determinants of a community's adaptive capacity: economic wealth, technology, information and skills, infrastructure, and institutions and equity (Smit *et al*., 2001). This concept is further extended into eight major determinants of adaptive capacity (Yohe & Tol, 2002) as follows: the range of available technological options for adaptation; the availability of resources and their distribution across the population; the structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed; the stock of human capital, including education and personal security; the stock of social capital, including the definition of property rights; the system's access to risk spreading processes; the ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision makers and the public's perceived attribution of the source of stress and the significance of exposure to its local manifestations. These determinants are also valid predictors of adaptation because they influence how adaptive capacity translates into adaptation (Burch & Robinson, 2007).

Even though Yohe and Tol’s (2002) determinants of adaptive capacity are specific enough to explain local adaptation processes, they do not target a particular sector and do not fully explain the realities of small-scale farmers’ efforts to adapt to climatic variability and changes. Chambers (1989) on the other hand, built his theory of vulnerability and adaptation on numerous case studies of poor small-scale farmers. His conclusion was that poor people usually seek to reduce vulnerability not by maximizing income, but by developing and diversifying their portfolio of capital assets. “Most poor people do not choose to put all their eggs in one basket”, and thus, tradeoffs exist between security and income (Chambers, 1989). The concept of capital assets developed by Chambers (1987) was further elaborated by Scoones (1998) to a sustainable livelihood framework. This framework has become a popular analytical structure to understand the complexity of local livelihoods and identifies five types of capital assets that people can build up: human, natural, financial, social and physical (Scoones, 1998).By integrating these concepts the hazard of place model was utilized in assessing the risk and vulnerability of the farmers in the study area.

2.7 Operational definitions of vulnerability as used in this study

According to Costa and Kropp (2013), the development of frameworks is essential in the conceptualization of vulnerability. They reasoned that the practical operationalization of vulnerability is closely associated with specific social or environmental contexts, as in the ‘biophysical’ and ‘social’ perspectives on vulnerability which ties in with what Brooks (2003) had posited. According to Brooks (2003), ‘biophysical vulnerability’ is a function of a system’s exposure and sensitivity to physical hazards (e.g. physical manifestations of climatic variability or change) on the one hand, while social vulnerability exists within the system independent of external hazards (i.e. an inherent property of a system). Brooks (2003) argued that in distinguishing between biophysical and social vulnerability, the conflict between different formulations of vulnerability in the climate change literature can be resolved.

Biophysical vulnerability comprises the impacts of hazards, which could be measured in terms of the damage experienced from that hazard. Social vulnerability, on the other hand, is not a function of hazard severity or probability but is nevertheless hazard specifically in terms of, for example, indicator selection (Brooks 2003).

Kelly and Adger (2000) and O'Brien et al. (2007) have defined frameworks of vulnerability as the 'end-point' or 'outcome' and 'starting point' or 'contextual'. Based on these frameworks, various characteristics of vulnerability have been examined and the conclusions indicate that outcome vulnerability assessments are usually physical science-based and employ quantitative methods, whereas contextual assessments generally have a social science theoretical basis and draw on qualitative methods (Pearson et al., 2011; Bruno Soares et al., 2012).

Another way of looking at vulnerability frameworks according to Wolf et al. (2013) is to look at it based on their characteristics as 'future-explicit', 'present-based', or 'combined' assessments. Future-explicit assessments contain impact scenarios for evaluating harms, and the aggregated harms together describe the vulnerability of the system. Present-based assessments, on the other hand, are based on measurements of the present state of the social-ecological system, considering its vulnerability and/or adaptive capacity. Hazards may, however, not be explicitly represented in present-based assessments, but they cannot be neglected since the capacity to adapt only becomes relevant with respect to a system's exposure. This argument corresponds to Brooks' (2003) stand on social vulnerability and the necessity of being hazard specific. 'Combined assessments' merges the future-explicit and present-based methodologies. However, how the two are combined differs between assessments (Wolf et al., 2013). Wolf et al. (2013), in describing combined assessments argued that their categorization of approaches extends the previous literature (e.g. Kelly& Adger 2000; Brooks, 2003; O'Brien et al., 2007) on vulnerability assessment frameworks. Nevertheless, such 'combined approaches could fit in with the 'integrated' vulnerability concept (e.g., Füssel & Klein 2006).

In climate change vulnerability research, studies carried out, frequently attempt to have an 'integrated' perspective, with the purpose of addressing both the biophysical and social dimensions of vulnerability in theory as well as in operationalization (e.g. Eakin & Luers 2006; Füssel & Klein 2006). Even though Bruno Soares et al. (2012) sees this integrated perspective as the current paradigm of climate change vulnerability analysis, they however, also recognize the challenges that arise due to the requirements in synthesizing the different methods of performing and analyzing vulnerability assessments. As with the vulnerability concept, 'integrated' vulnerability has various meanings and is operationalized differently in various studies (Füssel 2007).

A question which arises thereof is that, where outcome and contextual vulnerability intertwine, does this point of intersection form the operationalization of ‘integrated’ vulnerability, given that integrated vulnerability has been proposed to be the current paradigm for climate vulnerability assessments (Soares et al. 2012)?. O’Brien et al. (2007) believe that it will be problematic to conjoin the two interpretations due to their different framings. They argued that these approaches should instead complement each other since they have different means of recognizing the linkages between climate change and society. Though outcome vulnerability is frequently equated with biophysical vulnerability and contextual vulnerability with social vulnerability (e.g., Soares et al. 2012; Wolf et al. 2013), an integration of biophysical and social vulnerability could be understood as identical to the integration of contextual and outcome vulnerability. This viewpoint is similar to that of Pearson et al. (2011), who argue that it is possible to integrate the two interpretations of vulnerability because the results of outcome assessments may serve as input to contextual assessments.

Furthermore, it is generally accepted that climate change vulnerability cannot be estimated only by either biophysical, social, economic, or political factors, but by the integration of these factors (e.g. Gomez, 2015). This, however, is not necessarily the same as integrating different interpretations of vulnerability. In the discussion on integrated vulnerability, a distinction must be made between the integration of human–environmental aspects and the combination of vulnerability interpretations.

The term, ‘integrated vulnerability’ as used in this thesis involves the integration of a system’s biophysical and socio-economic dimensions, which is different from the integration of approaches as shown by Pearson et al. (2011). It should, however, be noted that cognizance is taken of the fact that different assessment methods can be combined into hybrid approaches (Wolf et al. 2013; Tonmoy et al. 2014).

The interpretation of vulnerability within this thesis is guided by the understanding that the vulnerability of a place is defined within the integrated human-environmental system as the sum of a system’s exposure, sensitivity, and capacity to adapt to climate change stimuli. Therefore:

- *Exposure* is seen as the manifestation of climate change (Räsänen et al. 2016) as well as ‘the nature and degree to which a system is exposed to significant climatic variations’ (IPCC 2001).
- Sensitivity, as defined by the IPCC, (2007), is seen as the degree to which a system is affected, either adversely or beneficially, by climate variability or change. In which case, the effects can either be direct or indirect. The sensitivity of a system specifies whether or not that system is sensitive to climatic or non-climatic stressors, and it is subsequently interpreted as an inherent property of the socio-ecological system with system attributes existing before the stressor (e.g., Gallopín 2006).
- adaptive capacity is used to describe the capacity and likelihood of adaptation as per IPCC’s definition which states, ‘The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences’ (IPCC’s, 2014a).

To evaluate a system’s vulnerability to climate change, the capacity for and the likelihood of adaptation must be addressed (Smit et al. 1999). Integrated vulnerability assessments assume that it is not the availability of adaptation options but the capacity to implement these options (Füssel & Klein 2006) or the avoidance of *maladaptive* outcomes (Juhola et al. 2016) that determine a system’s vulnerability to climate change. Adaptive capacity like sensitivity is a system characteristic that exists prior to climate stress. Other terms as used in this study to describe a vulnerable system include:

- **Stressor***:* climate change events or trends (i.e., *climate exposure factors*) or non-climatic external factors influencing the human–environment system (e.g., O’Brien et al. 2004; Räsänen et al. 2016);
- **Vulnerability indicators:** observable variables functioning to indicate theoretical concepts and the function of variables indicating vulnerability: sensitivity, adaptive capacity, or exposure (Hinkel, 2011).

2.8 Relevant studies on vulnerability and adaptation to climate change

The multidisciplinary nature of the concept of vulnerability and its analysis thereof can be seen in the number of relevant literature available on the topic. In the light of climate change research, vulnerability studies have been undertaken under broad headings such as:

- The vulnerability of various sectors to climate change;

- Adaptation of various sectors to climate change;
- Impacts of climate change on various sectors;
- Sectorial responses to natural hazards, especially those initiated by climate change;
- Indicators of vulnerability (biophysical and socio-economic);
- Sustainability.

Research findings from the above-mentioned areas contribute to the understanding of the extent of the problem, the environmental and human factors that determine coping and adaptive capacity and the plethora of methods available and tested for measuring these factors. Agricultural vulnerability to climate change as linked to the definition of vulnerability by the IPCC assessment report is the manifestation of the agricultural sensitivity and adaptive capacity to climate changes (Wang, 2003 cited in Tao et al., 2011)). Such changes are inclusive of the location, time, and socio-economic and environmental situations. Agricultural vulnerability to climate change is, therefore, a function of the characteristics of climate variability, the magnitude, and rate of variation within the agricultural system, as well as the system's sensitivity and adaptive capacity to the degree to which the system is susceptible to, cope or unable to cope due to the adverse effects of climate change including climate variability and extreme events (Hou & Liu, 2003 cited in Tao et al., 2011; Thornton et al.,2014). Research work in the quantitative assessment of agricultural vulnerability to climate change has gone through the following three stages:

1. Studying the vulnerability of crop yield, growth period among other indicators to temperature, precipitation, and other climate factors (e.g. Li et al.,2015; Iglesias *et al.,* 2012; Antwi-Agyei et al., 2012);
2. Adaptation capability with a focus on the exploration of adaptation and response measures (e.g. Engle,2011; Reidsma,2010; Burton *et al.,* 2002);
3. Looking at the sensitivity of agriculture to climate change and adaptability, as well as climate change mitigation (e.g. Mertz,2009).

Vulnerability has been assessed at many different levels from, regional, national to global. In this review, a few studies covering different aspects of vulnerability at the regional scale are summarized.

2.8.1 South African agricultural vulnerability to climate change

Climate change studies conducted in South Africa have focused on several facets which range from physical, socio-economic to political. From the angle of physical impacts, various studies, for example, Midgley *et al*., 2007; Walker & Schulze, 2008; Gbetibouo *et al*., 2010; Haverkort *et al*., 2013) looked at the effects of climate change on crop yield and production. From the economic perspective, impacts are calculated based on economic impacts derived from yield losses (e.g. Blignaut *et al*., 2009, Kurukulasuriya *et al*., 2006). Other comprehensive economic studies comprising vulnerability include that of Deressa *et al*., (2008); Seo *et al*., (2009); Gbetibouo *et al*., (2010); Hassan *et al*., (2010) and others on adaptation options include Deressa *et al*., (2005) and Benhin (2008).

Erasmus *et al*., (2000) sought to determine the effects of climate change on the Western Cape farm sector. Their results indicated that climate change will lead to lower precipitation, which implies that less water will be available to agriculture in the Province. This will have a negative overall effect on the Western Cape farm economy. Both producer welfare and consumer welfare will decrease. Total employment in the farm sector will also decrease as producers switch to a more extensive production pattern. The total decline in welfare, therefore, will fall disproportionately on the poor.

Gbetibouo and Hassan (2005) measured the impact of climate change on South Africa's field crops and analyzed potential future impacts of further changes in the climate with particular emphasis on seven field crops (maize, wheat, sorghum, sugarcane, groundnut, sunflower, and soybean). Their results indicate that the production of field crops was sensitive to marginal changes in temperature as compared to changes in precipitation. Temperature rise positively affects net revenue whereas the effect of reduced rainfall is negative. The study also highlights the importance of season and location in dealing with climate change; showing that the spatial distribution of climate change impact and consequently needed adaptations will not be uniform across the country.

With regards to adaptation, Deressa *et al*., (2005), showed that climate change has significant non-linear impacts on net revenue per hectare of sugarcane in South Africa with higher sensitivity to future increases in temperature than precipitation. Irrigation did not prove to provide an effective option for mitigating climate change damages on sugarcane production in South Africa. The study suggests that adaptation strategies should specifically focus on technologies and management regimes that will enhance sugarcane tolerance to warmer temperatures during winter and especially the harvesting phases.

Gbetibouo *et al.,* (2010) examined climate adaptation strategies of farmers in the Limpopo Basin of South Africa. Survey results show that while many farmers noticed long-term changes in temperature and precipitation, most could not take remedial action. Lack of access to credit and water were cited as the main factors inhibiting adaptation. Common adaptation responses reported include diversifying crops, changing varieties and planting dates, using irrigation, and supplementing livestock feed. A multinomial logit analysis of climate adaptation responses suggests that access to water, credit, extension services, and off-farm income and employment opportunities, tenure security, farmers' asset base, and farming experience are key to enhancing farmers' adaptive capacity. This implies that appropriate government interventions to improve farmers' access to and the status of these factors are needed for reducing the vulnerability of farmers to climate adversities in such arid areas.

Gbetibouo *et al.,* (2010a) analyzed the vulnerability of South African agriculture to climate change and variability. They developed a vulnerability index and compared vulnerability indicators across the nine provinces of the country. Several environmental and socio-economic indicators were employed to identify vulnerable provinces. The results showed that the provinces most exposed to climate change and variability did not always overlap with those experiencing high sensitivity or low adaptive capacity. However, the vulnerability of provinces to climate change and variability were intrinsically linked to socioeconomic development. Furthermore, the agricultural sector in South Africa is shown to be characterized by diverse social, economic political and environmental conditions. Therefore, the rural infrastructure development and farming systems varied across the country, indicating a considerable variation in vulnerability to climate change across the country's provinces. The study went on to rank the provinces based on their level of vulnerability which was acquired from a calculated vulnerability index. According to the ranking, a vulnerability index below -2 were classified as "low vulnerability"; an index ranges from -2 to 0 as "low to medium vulnerability"; a range from 0 to 2 as "medium vulnerability"; and an index above 2 as "high vulnerability". The vulnerability ranking showed that Limpopo, KwaZulu Natal, and Eastern Cape were the most vulnerable provinces to climate change with vulnerability indices of 3.09, 2.11 and 2.49, respectively. The least vulnerable provinces were Gauteng and Western Cape with vulnerability indices of -4.44 and -2.49, respectively.

Conversely, a closer look at the components of vulnerability (exposure, sensitivity and adaptive capacity) showed a rather interesting view of the provinces' vulnerability to climate change and variability. The exposure index showed that Eastern Cape, KwaZulu-Natal, and Western Cape are the most exposed provinces to climate change while North West and Free State are the least exposed provinces. In terms of sensitivity, it was observed that the Eastern Cape, KwaZulu-Natal, and Limpopo are the most sensitive while the least sensitive provinces were Gauteng, Western Cape, and Free State. The adaptive capacity also showed variation with the Western Cape having the highest adaptive capacity and the Eastern Cape having the lowest.

The vulnerability indices further showed that provinces with the highest climate exposure index do not necessarily rank highest on the vulnerability index. Take Limpopo for example which had the lowest climate exposure index but had the highest vulnerability index. In contrast, Western Cape showed high exposure to extreme events and climate change, but it also has the highest adaptive index. Conclusively, Western Cape is less vulnerable to climate change and variability due to this high adaptive capacity.

2.9 Vulnerability assessment methods

The methods used in vulnerability assessments tend to be closely related to the concept and interpretation of vulnerability. Dessai and Hulme (2004), following the outcome and contextual interpretations of vulnerability highlight the different approach that the two (seen earlier as “end point” and “outcome) concepts take. Outcome vulnerability concepts concentrate on physical vulnerability and tend to follow a top-down approach to inform climate adaptation policy. Contextual vulnerability concepts, on the other hand, concentrate on socio-economic vulnerability and follow a bottom-up approach (Dessai & Hulme, 2004; IPCC-TGICA, 2007). A top-down approach typically proceeds from global climate projections, which can be downscaled and applied to assess regional impacts of climate change. An important feature of bottom-up approaches is typically the involvement of the population and stakeholders of the system in identifying climate-change stresses, impacts and adaptive strategies. The diversity of interpretations and concepts of vulnerability results in a variety of methodological approaches and tools that have evolved to assess it, which is also reflected in a vast variety of vulnerability assessments in the agricultural sector.

Assessing impacts and vulnerability to climate change and working out adaptation needs requires good quality information. Such data include climate data such as temperature, rainfall and the frequency of extreme events, and non-climatic data, such as the current situation on the ground for different sectors including water resources, agriculture and food security, human health, terrestrial ecosystems, biodiversity, and coastal zones (UNFCCC, 2007). The summarized procedure for assessing vulnerability is as follows:

1. Defining the system/identify the target group
2. Identify risk factors faced by the system/group
3. Assess sensitivity to the risk factors
4. Measure adaptive capacity
5. Calculation of vulnerability index and mapping

Each of these different methods yields information on different types of impacts. For example, simple agroclimatic indices can be used to analyze large-area shifts of cropping zones, whereas process-based crop growth models analyze changes in crop yields. The effects on income, livelihoods, and employment are assessed using economic and social forms of analysis. The major challenge facing all agriculture-climate evaluations is the incorporation of qualitative changes derived from complex interactions. For example, a decrease in crop yields in developing countries leads to severe qualitative changes. Whether the resulting chain of interactions (e.g., from malnutrition to social conflicts) can be modelled is uncertain.

Approaches to vulnerability assessment are discussed in the subsequent paragraphs.

2.9.1 Agroclimatic indices and GIS

This approach combines agroclimatic indices with GIS to provide an initial evaluation of both global agricultural climate change impacts and shifts in agricultural suitable areas in particular regions. The indices are based on simple relationships of crop suitability to climate (for instance, identifying the temperature thresholds of a given crop or using accumulated temperature over the growing season to predict crop yields (for example the study of Holden, 2001). This type of empirically derived coefficient is especially useful for broad-scale mapping of areas of potential impact.

When combined with a spatially comprehensive database of climate, crops, and GIS, simple agroclimatic indices are an inexpensive and rapid way of mapping altered crop potential for quite large areas. Examples of the application of agro-climatic indices in Africa include the study of Badini *et al.,* (1997); Akponikpè, Gerard and Bielders (2014); Kengni et al. (2017). These studies provide analysis and understanding of the intricate relationships among the weather, soils and agricultural production systems. Furthermore, it shows more especially the complexities associated with the variability and distribution of rainfall and soil type which are essential elements in improving crop production and agricultural planning decision making. Carter and Saarikko (1996) describe three basic methods for agro-climatic spatial analysis and the choice of the method depending on the availability of data.

The first and simplest method to represent zones is to interpolate between site estimates onto a base map. Subjective methods can be employed here so as to account for local features such as soils, altitude or proximity to lakes, which are known to influence crop potential.

The second method is to first interpolate the original environmental data to a finer resolution, such as a regular grid, and compute the measures using the gridded data. This method has been applied both for suitability and productivity purposes.

The third method involves dividing a region into contiguous units of varying sizes depending on the environmental properties. The indices can then be calculated at sites that are considered representative of predefined homogenous areas to derive spatial estimates. The combination of the agro-climatic index, GIS and a synthetic climatic scenario offers rapid and inexpensive means of mapping the effects of climatic change on crop suitability. However, this method is climate-based only and lacks management responses or consideration of carbon fertilization.

2.9.2 Socio-economic approach

The socio-economic vulnerability assessment approach focuses on the socio-economic and political status of individuals or social groups (Adger, 1999; Füssel, 2007). Individuals in a community often differ with respect to education, gender, wealth, health status, access to credit, access to information and technology, formal and informal (social) capital, and political power, amongst others. These variations are responsible for the variations in vulnerability levels. Hence vulnerability is considered to be constructed by society as a result of institutional and economic changes (Adger & Kelly, 1999). This approach specifically focuses on identifying the adaptive capacity of individuals or communities based on their internal characteristics. For example, a study by Adger and Kelly (1999) in the district coastal lowlands of Vietnam analyzed the vulnerability based only on variations in socio-economic attributes of individuals and social groups.

Shortcomings of this method include factors such as overlooking the environment-based intensities, frequencies, and probabilities of environmental shocks, such as droughts and floods. It also does not account for the availability of natural resource bases to potentially counteract the negative impacts of these environmental shocks. For example, areas with easily accessible underground water can better cope with droughts by effectively utilizing this water. Furthermore, the approach focuses only on variations within society (differences among individuals or social groups). In reality, societies vary not only in socio-political factors but also in environmental factors. Thus, two social groups having similar socio-economic characteristics, but different environmental attributes can have different levels of vulnerability and vice versa.

2.9.3 Statistical models and yield functions

This method employs complex multivariate models to give a statistical explanation of observed phenomena by accounting for the most important factors. Examples are predicting crop yields on the basis of temperature, rainfall, sowing date, and fertilizer application. However, a possible weakness in this approach is its limited ability to predict the effects of climatic events that lie outside the range of present-day variability. Besides, it is based on statistical relationships between factors rather than on an understanding of the important causal mechanisms. However, where models are founded on a good knowledge of the determining processes and where there are good grounds for extrapolation, they can still be useful predictive tools in climate impact assessment. Multiple regression models have been developed to represent process-based yield responses to these environmental and management variables. Yield functions have been used to evaluate the sensitivity and adaptation to climate. This method appropriately describes the present-day crop and climatic variations but fail to explain the causal mechanism. It doesn’t capture future crop relationships or CO_2 fertilization.

2.9.4 Process-based crop models

Process-based models use simplified functions to express the interactions between crop growth and the major environmental factors that affect crops (i.e., climate, soils, and management). Most crop-based models used in impact assessment were developed as tools in agricultural management, particularly for providing information on the optimal amounts of input (such as fertilizers, pesticides, and irrigation) and their optimal timing. The aims of such models are to predict the response of a given crop to specific climate, soil, and management factors governing production. Some crop models include those such as the Dynamic crop models, which are designed for specific crops. Examples include:

The International Consortium for Application of Systems Approaches to Agriculture – International Benchmark Sites Network for Agrotechnology Transfer (ICASA/IBSNAT) dynamic crop growth models are structured as a decision support system to facilitate simulations of crop responses to management (DSSAT). The ICASA/IBSNAT models have been used widely for evaluating climate impacts in agriculture at different levels ranging from individual sites to wide geographic areas (e.g. studies such as that of Rosenzweig & Iglesias, 1994, and 1998). This type of model structure is particularly useful in evaluating the adaptation of agricultural management to climate change. The DSSAT software includes all ICASA/IBSNAT models with an interface that allows output analysis.

The WOFOST model suite is generic and includes model parameters for certain crops (Supit *et al.*, 1994; Boogaard *et al*., 1998). There are several versions of the models, which are under continuous development at the University of Wageningen.

The EPIC model (Erosion Productivity Impact Calculator) (Sharpley & Williams, 1990) incorporates simplified crop growth functions that respond to climate, environment, and management; it has been used in some climate impact assessments.

CROPWAT is an empirical irrigation management model developed by the United Nations Food and Agriculture Organization (FAO) to calculate regional crop water and irrigation requirements from climatic and crop data (CROPWAT, 1995, 2004). Net irrigation demand (balance between the crop evapotranspiration and the water available for the crop) can be calculated for more than 1,000 sites around the world included in the FAO Clim database (FAO, 2004). The model can be adjusted to include irrigation efficiency for each region.

Process-based crop models are useful for testing a wide range of adaptation options, as well as testing mitigation and adaptation strategies simultaneously. They are also available for most major crops. Unfortunately, to be able to get good and reliable results, detailed weather and management data are required. This is a problem since more often than not, these data are very difficult to obtain in most poor and developing countries, as well as the quality of data, might be flawed.

Hoogenboom (2000) provides a detailed review of the climatic requirements and development of crop models in close collaboration with the discipline of agrometeorology. The author correctly predicted that in the light of climate change and climate variability, reliance on crop modelling would increase. Weather data in the form of historical data or observations made during the current growing season and short, medium and long-term weather forecasts will play a critical role in impact assessments. White *et al.,* (2011) and other workers conducted an extensive review of crop model and concluded that coordinated crop, climate and soil data resources would allow researchers to focus better on the underlying science and facilitate comparison between results to improve confidence in outputs. The use of a modular approach within models allows for better comparison and integration amongst model user groups.

Van Ittersum and Donatelli (2003b) describes the emergence of crop modelling as a mainstream tool in crop science and the philosophy behind the development of such models. APSIM as one of such models is a modelling environment that uses various component modules to simulate dynamically cropping systems in the semi-arid tropics (McCown *et al*., 1996). It was designed “as farming systems simulator that sought to combine accurate yield estimation in response to management with the prediction of the long-term consequences of farming practice on the soil resource” (Keating *et al.,* 2003). APSIM was developed to simulate the biophysical process in farming systems, in particular where there is interest in the outcomes of management practice in the face of climatic risk. The structure of APSIM was outlined and details of the concepts behind the different plant, soil and management modules were provided.

Penning de Vries (1977) emphasized that simulation models contribute to our understanding of the real system which in-turn helps to bridge areas and levels of knowledge. It is believed that in the conversion of conceptual models into mathematical simulation models the agro meteorologists can understand the gaps in their knowledge. So, the interdisciplinary nature of simulation modeling efforts leads to increased research efficacy and improved research direction through direct feedback. O'Toole and Stockle (1987) described the potential of simulation models in assessing trait benefits of winter cereals and their capacity to survive and reproduce in stress-prone environment. Crop growth models have been used in plant breeding to simulate the effects of changes in the morphological and physiological characteristics of crops which aid in the identification of ideotypes for different environments (Kropff *et al*., 1995).

2.9.5 Biophysical approach

The biophysical approach assesses the level of damage that given environmental stress causes on both social and biological systems. For example, the yield impacts of climate change on crops can be analyzed by modeling the relationships between crop yields and climatic variables (Kaiser *et al.*, 1993; Olsen *et al.,* 2000). Damage to the system is most often estimated by taking forecasts or estimates from climate prediction models (Kurukulasuriy & Mendelsohn 2008a; Martens *et al.,* 1999) or by creating indicators of sensitivity by identifying potential or actual hazards and their frequency (Cutter *et al.,* 2000). According to Füssel (2007), this approach is a 'risk-hazard approach' because it defines the vulnerability relationship as that of a hazard-loss relationship in natural hazard research; a dose-response or exposure-effect relationship in epidemiology; and a damage function in macroeconomics. The biophysical approach focuses on sensitivity (change in yield, income, health) to climate change and misses much of the adaptive capacity of individuals or social groups, which is more explained by their inherent or internal characteristics or by the architecture of entitlements, as suggested by Adger (1999).

2.9.6 Integrated Assessment Approach

The integrated assessment approach combines both socio-economic and biophysical approaches to determine vulnerability. The "hazard-of-place model" (Cutter *et al.,* 2000) is a good example of this approach, in which both biophysical and socio-economic factors are systematically combined to determine vulnerability. The vulnerability mapping approach (O'Brien *et al*., 2004) is another example in which both socio-economic and biophysical factors are combined to indicate the level of vulnerability through mapping. Füssel (2007) and Füssel and Klein (2006) argued that the IPCC (2001) definition, which conceptualizes vulnerability to climate as a function of adaptive capacity, sensitivity, and exposure, accommodates the integrated approach to vulnerability analysis.

Even though the integrated assessment approach corrects the weaknesses of the other approaches, it also has its limitations. Some of its shortcomings include lack of a standard method for combining the biophysical and socio-economic indicators, a limited common metric for determining the relative importance of the social and biophysical vulnerability, or for determining the relative importance of each individual variable (Cutter *et al*., 2000). Furthermore, this approach uses different data sets, ranging from socioeconomic data sets such as race and age structures of households to biophysical factors (e.g. frequencies of floods, droughts, fires) which certainly have different and yet unknown weights. Furthermore, this approach does not account for the dynamism in vulnerability. Coping and adaptation are characterized by a continual change of strategies to take advantage of opportunities (Campbell 1999; Eriksen & Kelly, 2007). This dynamism is missing when the integrated assessment approach is being employed. In spite of the weaknesses, the intergrated approach, however, plays a great role in terms of policy decisions.

2.9.7 Economic models

Economic models are designed to estimate the potential impacts of climate change on production, consumption, income, gross domestic product (GDP), employment, and farm value. Several types of economic approaches have been used for agricultural impact assessment. The most useful of these are simple economic forecasting approaches (for example, Benioff *et al.*, 1996), which are forecasts based on a structured framework of available economic and agricultural information. The classes of the economic model identified are as follows:

2.9.7.1 Economic regression models

This method looks at the statistical relationships between climate variables and economic indicators. Adaptation to local climatic conditions by farmers is considered as well as world food prices and domestic farm output prices as well which are considered constant (Mendelsohn *et al.,* 1994). One form of economic analysis is the use of spatial analogues, that is, cropping patterns in areas with climates similar to what may happen under climate change. This Ricardian approach has been used in a number of applications (for example, Mendelsohn *et al.,* 1994 and 1999). An advantage of the approach is that farmer adaptation to local climate conditions is implicitly considered. On the other hand, the disadvantages are that food prices and domestic farm output prices are considered constant, and key factors that determine agricultural production, such as water availability and carbon fertilization, are not generally considered.

2.9.7.2 Microeconomic models (farm level)

These models are based on the goal of maximizing economic returns to inputs. They are designed to simulate the decision-making process of a representative farmer regarding methods of production and allocation of land, labor, existing infrastructure, and new capital. Such farm models are developed specifically as tools for rural planning and agricultural extension by simulating the effects of changes in inputs (for example, fertilizers, irrigation, credit, management skills) on farm strategy (such as cropping mix, employment). These models tend to be optimized economic models by using linear programming and require quite specific data and advanced analytic skills. Many of these models take a range of farm types that becomes representative of those existing in a region, and for each of these types, simulate the mix of crops and inputs that would maximize farm income under given conditions. These conditions can be varied (variation of weather, prices of crops, and fertilizers) and the appropriate farm response modelled. Changes of climate, instead of variations of weather, can be input, and the farm-level response in output and income is then simulated.

2.9.7.3 Household and village models

The focus in semi-commercial economy may be more appropriate if it were to focus on household or village as the unit of response. Here the objective may be to secure a minimum level of income rather than to maximize income, and the focus of analysis is on the strategies developed to reduce the negative effects of crop yield changes rather than increase the positive ones. Frequently referred to as coping strategies, these have been analyzed in particular detail in the context of risk of hunger (often related to drought). As with farm models, those climate impact assessments that have included successful analyses of responses at the household and village level have tended to borrow from existing studies and adapting them to consider changes in climate rather than variations of weather (Akong’a *et al.,* in Parry *et al*., 1998; Gadgil *et al*., 1988).

2.9.7.4 Cost and benefits

This method employs strategies of evaluating ranges from formal economic techniques such as cost-benefit analysis to descriptive or qualitative assessments. Cost-benefit analysis is often employed to assess the most efficient allocation of resources. This is achieved through the balancing or optimization of various costs and benefits anticipated in undertaking a new project, implementing a new policy, accounting for the reallocation of resources likely to be brought about by external influences such as climate change. The approach makes explicit the expectation that a change in resource allocation is likely to yield benefits as well as costs, a useful counterpoint to many climate impacts studies, where negative impacts have tended to receive the greatest attention.

2.9.7.5 Macroeconomic models

These include models of a regional, national, or global agricultural economy. For climate change purposes, the models allocate domestic and foreign consumption and regional production based on given disturbances of crop production, water supply, and demand for irrigation derived from biophysical techniques. Population growth and improvements in technology are set exogenously. The models measure the potential magnitude of climate change impacts on the economic welfare of both producers and consumers of agricultural goods. Predicted changes in production and prices from agricultural sector models can then be used in general equilibrium models of the larger economy (Adams *et al.,* 1990; Fischer *et al.,* 2002) as well as for incorporating financial considerations and market-based adaptations.

Results from these models, however, may only be partial indicators of social welfare, and not representative of all social systems, households, and individuals. For example, smallholder farmers may not be appropriately represented in models that are based on producer and consumer theory. Studies and models based on market-oriented economies assume profit and utility maximizing behavior. They are also relatively complex and require a lot of data and may be difficult, time-consuming, or expensive to apply.

2.9.7.6 The econometric approach

The methodology uses the household-level socioeconomic survey as data to analyze the level of vulnerability of different social groups. There are three different methodologies used to assess vulnerability. These include vulnerability as uninsured exposure to risk (VER), vulnerability as a low expected utility (VEU) and vulnerability as expected poverty (VEP) (Hoddinot & Quisumbing, 2003). All three methods construct a measure of welfare loss attributed to shocks.

- **Vulnerability as uninsured exposure to risk**

This method is based on ex post facto assessment of the extent to which a negative shock causes welfare loss (Hoddinot & Quisumbing, 2003). Impact of shocks is assessed using panel data to quantify the change in induced consumption. Skoufias (2003) employed this approach to analyze the impact of shocks on Russia. In the absence of risk management tools, shocks impose welfare loss that is materialized through a reduction in consumption. The amount of loss incurred due to shocks equals the amount paid as insurance to keep a household as well as offset any shocks occurred. The limitation of this method is that, in the absence of panel data, estimates of impacts, especially from cross-sectional data are often biased and thus inconclusive (Skoufias, 2003).

- **Vulnerability as a low expected utility**

Ligon and Schechter (2003) defined vulnerability as the difference between utility derived from some level of certainty-equivalent consumption at, and above which the household would not be considered vulnerable, and the expected utility of consumption. The method was applied to a panel data set from Bulgaria in 1994. The results showed that poverty and risk play roughly equal roles in reducing welfare. The limitation of this method is that it is difficult to account for an individual’s risk preference given that individuals are often ill-informed about their preference, especially those in uncertain events (Kanbur, 1987).

- **Vulnerability as expected poverty**

This method looks at an individual’s vulnerability as the prospect of a person becoming poor in the future if currently not poor or the prospect of that person continuing to be poor if currently poor (Christiaensen & Subbarao, 2004). It is argued that pre-existing conditions and forces influence the magnitude and the ability of communities to reduce vulnerability to climate change impacts. Vulnerability is therefore seen as expected poverty, with consumption or income being used as the welfare indicator. In this conception, the vulnerability is measured by estimating the probability that a given shock, or set of shocks, moves consumption of an individual/household below a given minimum or forces the consumption level to stay below the given minimum requirement if it is already below that level (Chaudhuri *et al*., 2002).

2.9.7.2 Household Food Economy Approach (HEA)

This method is used to indicate the likely effect of crop failure or other shocks on future food supply (Seaman *et al.,* 2000; Seaman *et al.,*2014). The two main components of the approach are:

- A quantitative description of the economy of a defined population, including all the main factors determining current household income and potential household income under changed conditions, and how these vary between households.
- A system to analyze the relationship between a shock, for example, crop failure from drought or a rise in the price of staple foods and the ability of households to maintain their food and non-food consumption.

The HEA methodology, therefore, aims to provide an understanding of the household economy and its relationship to markets and employment opportunities in a baseline or reference year. This information is used to estimate the effect of a 'shock' on household income and food supply and the likely ability of the household to compensate for this by implementing the various coping strategies available to it (Seaman *et al*., 2000). A similar approach to the HEA is USAID Food Emergency Warning System (FEWS) program (Luers *et al*., 2003).

USAID food emergency warning system (FEWS) program

FEWS NET was developed in 1985 by the US Agency for International Development (USAID) after devastating famines in East and West Africa. Currently, it works in more than 36 of the world's most food-insecure countries. FEWS focuses on acute food insecurity, sudden and/or short-term household food deficits caused by shocks. FEWS program uses indices, calculated as averages or weighted averages of selected variables, to measure vulnerability to food insecurity in different regions throughout Africa. These studies focus on compiling data in different areas, such as crop risk (e.g. length and variability of the growing season), income risk (e.g. income variability, average cash crop production) and coping strategies (for example, staple food production, access to infrastructure) (http://www.fews.net/). The FEWS NET produces:

- monthly reports and maps detailing current and projected food insecurity
- timely alerts on emerging or likely crises

- specialized reports on weather and climate, markets and trade, agricultural production, livelihoods, nutrition, and food assistance

2.9.8 Indicator approach

Given that climate vulnerability is a theoretical concept, it cannot be estimated as other physical phenomena such as mass, energy, and temperature (Luers et al. 2003; Tonmoy et al., 2014); it has been argued that the quantification of vulnerability should not be spoken of in terms of 'measurement' (Hinkel 2011). However, because of the need to integrate the knowledge of climate change vulnerability in decision making and planning, the processes that cause or enhances vulnerability need to be understood and therefore 'measured' in some sense (Luers et al. 2003). Hence the notion of indicators. Indicator-based vulnerability assessment is one of the most widely used assessment methods. It makes use of variables that serve as operational representations of characteristics, qualities or properties of a system (Gallopín 1996) so as to make the vulnerability concept operational (e.g., Luers et al. 2003; Birkmann 2006; Tonmoy et al. 2014). The advantages of using an indicator-based method for assessments include the ability to merge knowledge from various sciences into a mathematically combined composite index (i.e., combining the multiple dimensions of a phenomenon that cannot be captured by a single indicator). It is more difficult to integrate socio-economic and biophysical competences in other assessment methods (Tonmoy et al., 2014).

This method of quantifying vulnerability is based on selecting relevant indicators from a set of potential indicators and then systematically combining them to point out the levels of vulnerability. Analyzing the extent of vulnerability can be done at various levels such as a local scale (Tesso, Emana, & Ketema, 2012; Sukiyono,2017; Adger, 1999; Leon-Vasquez *et al.,* 2003; Morrow, 1999); national (O'Brien *et al.,* 2004); regional (Leichenko & O'Brien, 2001; Vincent 2004); and global scales (Brooks *et al*., 2005; Moss *et al.,* 2001; Weis et al.,2016).In calculating the level of vulnerability using the indicator approach at any given scale, the first method which can be used assumes that all indicators of vulnerability have equal importance and thus giving them equal weights (Cutter *et al.,* 2000). The second method assigns different weights to selected indicators so as to avoid the uncertainty of equal weighting given the diversity of indicators used. In line with the second method, many methodological approaches have been suggested to make up for the weight differences of indicators. Some of these approaches include: use of expert judgment (Kaly & Pratt, 2000;

Kaly *et al*., 1999); principal component analysis (Easter, 1999; Cutter *et al.,* 2003); correlation with past disaster events (Brooks *et al.,* 2005); and use of fuzzy logic (Eakin & Tapia, 2008).

Even though there are attempts in giving weights, their appropriateness is still dubious; because there is no standard weighting method against which each method is tested for precision. The shortcoming of the indicator approach is highlighted by Luers *et al.,* (2003) who are of the opinion that while the indicator approach is valuable for monitoring trends and exploring conceptual frameworks, indices are limited in their application. This is because of considerable subjectivity in the selection of variables and their relative weights, by the availability of data at various scales, and by the difficulty of testing or validating the different metrics. Furthermore, the indicator approach often leads to a lack of correspondence between the conceptual definition of vulnerability and the metrics.

However, indicators could be seen as 'weak' models in which relationships with vulnerability are known or assumed but cannot be characterized with accuracy. Concurrently, the indicator-based methodology for building and assessing vulnerability has been criticized: for hiding the complexity of the phenomenon as indicated by Adger (2006) and regarding the selection, weighting and aggregation of indicators (e.g., Eriksen & Kelly 2007; Vincent 2007 cited in Islam et al.,2014; Barnett et al., 2008; Binder et al., 2010).

Various reviewers (e.g., Adger et al. 2004; Binder et al. 2010; Hinkel 2011; Tonmoy et.al. 2014; Becker et al., 2015, 2017) have looked at the different steps involved in building a vulnerability index. It shows that previously applied methodological approaches to building vulnerability indices vary considerably in their indicator-selection, variable transformation, scaling, weighting, and summarizing methods (Tate 2012). Knowledge of vulnerability indices' robustness to various methodological choices is lacking, but ought to be increased to avoid planning based on methodologically fragile indices (Tate 2012). Nevertheless, since the complexities of socio-ecological systems and anthropogenic processes are difficult to model mechanistically, the aggregation of indicators becomes a reasonable option for quantitatively assessing vulnerability (Tonmoy et al. 2014). Cutter et al. (2003), Birkmann (2007), Hinkel (2011), and Rød et al., (2012) exemplify scholars arguing that indicator-based assessments can serve as a good starting point for the discussion and analysis of vulnerability, especially if geographic visualization approaches are applied (Rød et al., 2015). Generally, GIS and its outputs of geographic visualization allow the exploration of vulnerability assessment methodology since it involves complex spatial and temporal aspects of continuously changing multidimensional phenomena (Harrower et al. 2000). Since vulnerability to climate change is an example of such a phenomenon, the construction and presentation of multidimensional aspects of vulnerability can advantageously be represented in geospatial displays (MacEachren et al., 2004a). Moreover, communicating the complexity of vulnerability is arguably crucial in order to increase the ability to reduce vulnerability (Preston et al. 2011).Indicators are quantifiable constructs that provide information either on matters of wider importance than that which is actually measured or on a process or trend that otherwise might not be apparent (Hammond *et al.*, 1995). Vulnerability is a relative measure and does not exist as something that can be observed or measured in isolation from context. Hence, in developing and using indicators, one needs to be aware of several technical issues, including their sensitivity to change, standardizing indicators for comparison, reliability of the data, mapping of indicators, and coverage of relevant dimensions of vulnerability (Gall, 2007; Cutter *et al*., 2009).

In measuring vulnerability (*V*) three components are typically involved: exposure to climate change (***E***), sensitivity to its effects (***S***) and adaptive capacity (***AC***) for coping with the effects. Attempts are usually made to quantify each of these components, typically by identifying appropriate indicators for each of the components and then combining the indicators into indices. Subsequently, the components are combined into an integrated index of vulnerability. Indicators of exposure and sensitivity are most often from the biophysical realm while others such as those describing adaptive capacity are drawn from socio-economic statistical sources (such as Yohe &Tol, 2002; Adger *et al*., 2004; Schröter *et al*., 2005; Metzger & Schröter, 2005; Eakin & Luers, 2006; Gbetibouo, Ringler & Hassan, 2010;cf. Iglesias, Quiroga & Diz, 2011). Therefore, vulnerability can be measured as biophysical vulnerability and or social vulnerability.

Biophysical vulnerability is the susceptibility of the natural environment to the effects of natural hazards as a result of its exposure (Brooks, 2003; Smit *et al*., 2005). O'Brien *et al*., (2004), are of the opinion that the biophysical vulnerability perspective regards vulnerability to be a fairly stagnant view of the impacts of climate change. Hence, vulnerability assessment studies are based on a linear relationship between hazard and impact as consequences of climate change. The trend of assessing impacts based on physical vulnerability has been highlighted in the IPCC processes (McCarthy *et al*., 2001; Vincent, 2005).

Furthermore, biophysical vulnerability is influenced by the proximity of elements to the natural hazard, rapidity of onset, duration, areal extent and the probability (risk) with which a hazard of specific magnitude and frequency occurs (Cutter, 2005). On the other hand, social vulnerability assesses the sensitivity of a population to natural hazards as well as its ability to respond to and recover from their impacts (Cutter *et al*., 2008). It is the product of social inequalities, such as those social factors that influence or shape the susceptibility of communities to harm and that govern their capacity to respond (Cutter *et al*., 2003). Social vulnerability assessments in disaster research analyze the most vulnerable groups in society and observe different types of vulnerabilities between and within geographical units (Downing & Patwardhan, 2003; Azad *et al*., 2013).The increase in research initiatives on the development of quantitative indicators of climate change and adaptation to climate-related hazards at different scales of analysis (Leichenko & O'Brien, 2002; Hahn *et al*., 2009; Khajuria & Ravindranath; 2012; Vincent & Cull, 2014) are influenced by both the biophysical and social vulnerability. Within the natural hazard research, vulnerability indices have been developed at national and sub-national levels and this approach has been applied in countries such as the USA (Wu *et al*., 2002; Yarnal, 2007); the United Kingdom (UK) (Tapsell *et al*., 2002); Spain (Weichselgartner, 2002); Latin America (Cardona, 2005); Australia (Dwyer *et al*., 2004); the Philippines (Acosta-Michlik, 2005); Germany (Fekete, 2009; Fekete, 2012); Pakistan (Khan & Salman, 2012), or generally for regions worldwide (Mustafa *et al*., 2011; Ramieri *et al*., 2011).

Relevant literature shows some principal components of social vulnerability indicators as shown in Table 2.3. Aspects such as a community's literacy level, employment status, income levels, housing ownership, age and gender distributions, religious beliefs, kinship levels and informal social support networks are some of the examples of social vulnerability components (Tierney *et al*., 2001; Cutter, 2001; Cutter *et al*., 2003; Wood *et al*., 2010). Other indicators include employment (type and stability), income, savings and education levels (Morrow, 1999; Dwyer *et al*., 2004; Cutter, 2006; Zahran *et al*., 2008). An assessment of pertinent literature demonstrates that social vulnerability is high for low income and low-status persons, females, the elderly, young children, the rural poor and those dependent on extraction economies, large families, single parent families, female-headed households, and special needs populations (Morrow, 2008; Fekete, 2010). Extensive research exists on single indicators such as gender, income or education, as well as multidimensional indicators such as urbanization and culture Gender is an indicator of vulnerability due to unequal access to resources between men and women (Dwyer *et al*., 2004; Wisner *et al*., 2004). Females are associated with poverty and inequality. Within the African context, the poor population consists mainly of female-headed households (Frankenberger *et al*., 2003). Gender inequality is subject to increasing unequal distribution of resources among males and females, contributing to increased vulnerability of female-headed households to shocks and hazards. Gender inequality also contributes to insecurity and lack of opportunities or empowerment, resulting in a lower quality of life for female-headed households (Anderson, 2000; Babugura, 2005). In addition, the relationship between indicators and social vulnerability is sometimes based on functional relationships with specific outcomes such as agricultural productivity (Polsky, 2004), environmental inequality (Pulido, 2000) or hazard related mortality (Adger *et al*., 2005).

Table 2.3: List of dimensions contributing to social vulnerability to natural hazards.

Social vulnerability dimension	Author
Income	Morrow (1999), Cutter *et al*. (2003), Adger *et al*. (2004), Burton *et al*. (1993), Cutter *et al*. (2000), Devereux (2006), Leichenko (2002), Cutter and Finch (2008), Cutter and Morath (2013)
Gender	Cutter *et al*. (2003), Fothergill (1996), Vincent (2004), Cutter and Finch (2008), Dunno (2010), Cutter and Morath (2013)
Race, ethnicity	Cutter *et al*. (2003), Pulido (2000), Fothergill *et al*. (1999), Cutter and Finch (2008), Cutter and Morath (2013)
Age	Cutter *et al*. (2003), Cutter *et al*. (2000), Cutter and Finch (2008), Crooks (2009), Cutter and Morath (2013)
Unemployment, dependence on social services	Cutter *et al*. (2003), Adger *et al*. (2004), Heinz Centre for Science, Economics and the Environment (2000), Cutter and Finch (2008), Cutter and Morath (2013)
Housing conditions	Cutter *et al*. (2003), Heinz Centre for Science, Economics and the Environment (2000), Cutter *et al*. (2000), Cutter and Finch (2008), Cutter and Morath (2013)
Infrastructure	Cutter et al. (2003), Adger *et al*. (2004), Heinz Centre for Science, Economics and the Environment (2000), Cutter and Finch (2008), Cutter and Morath (2013)
Family structure, social networks	Cutter *et al*. (2003), Heinz Centre for Science, Economics and the Environment (2000), Cutter and Finch (2008), Cutter and Morath (2013)
Education	Cutter *et al*. (2003), Adger *et al*. (2004), Heinz Centre for Science, Economics and the Environment (2000), Cutter and Finch (2008), Cutter and Morath (2013)
Culture	Cutter *et al*. (2003),
Place (rural/urban dichotomy)	Cutter *et al*. (2003), Adger *et al*. (2004), Cutter *et al*. (2000), Cutter and Finch (2008), Cutter and Morath (2013)
Population growth	Cutter *et al*. (2003), Adger *et al*. (2004), Heinz Centre for Science,

	Economics and the Environment (2000), Cutter *et al*. (2000)
Special needs population (marginalized, disabled, elderly, under 5)	Cutter *et al*. (2003), Adger *et al*. (2004), Blaikie *et al*. (1994), Cutter and Finch (2008), Cutter and Morath (2013)
Commercial and industrial development	Cutter *et al*. (2003), Heinz Centre for Science, Economics and the Environment (2000), Cutter and Finch (2008), Borden *et al*. (2007).
Built environment	Cutter *et al*. (2003), Cutter and Finch (2008)

Identifying and constructing appropriate indicators for vulnerability assessments is highly challenging (Downing *et al.,* 2001; OECD, 2008). While there is a consensus on indicators to measure the impact of climate change, there seems to be no agreed metrics to describe vulnerability such as of crop yields or agricultural income. This can be attributed to the fact that vulnerability is a relative measure rather than something that can be expressed in absolute terms (Adger, 2006; Füssel and Klein, 2006; Eriksen and Kelly, 2007; Füssel, 2009; Hinkel, 2011). Consequently, it is argued that: (i) an indicator can generally only describe a measure of relative vulnerability (between places or time periods); and (ii) individual indicators are not able to portray the heterogeneity of vulnerability (especially with regard to socio-economic vulnerability).

Regardless of the general consensus of what influences social vulnerability to natural hazards and what indicators are valid, scientists and professionals disagree on selecting broadly representative indicators. This is not a unique phenomenon in the field of vulnerability science, but a recurring problem associated with the generation of indices in general (UNDP/BCRP, 2004; Dunno, 2011). As a result, there is no generally accepted set of indicators to assess social vulnerability, nor is there empirical evidence for the connectivity or their relative importance in vulnerability assessments. For that reason, Hinkel (2011) argues that a “one size fits all” vulnerability label is not sufficient, given that it disguises the vast amount of different types of problems addressed and methods applied. Therefore, instead of using the term vulnerability as an unspecified proxy, it is important to use an explicit terminology in order to clarify which particular vulnerability problems are addressed and which methodologies are applied (Füssel, 2009; Klein, 2009; Hinkel, 2011).

On their part, Yohe *et al.,* (2006a, 2006b) argue that the global distribution of vulnerability to climate change varies by assumption on indicators. Given that vulnerability is place-based and context-specific, the significance of particular indicators can vary from region to region, depending on the specific socio-economic context. Consequently, at local scales and when systems can be narrowly defined, vulnerability indicators are considered to be a suitable means to identify particularly vulnerable people, regions or sectors (Barnett, Lambert & Fry, 2008; Hinkel, 2011).

2.9.9 Local vulnerability indicators

Pertinent literature on vulnerability indicators postulates that local vulnerability measures should consider scale, dynamics and diversity aspects. This will help to convey the information of diverse natural environments and heterogeneous socio-economic structure at multiple scales, which is lacking in aggregate vulnerability indices. With regards to scale, recent vulnerability studies argue that vulnerability assessment relies on the scale of analysis such that assessment at the local scale becomes critically important. This is not only because of the biophysical and environmental differences of locations, but also socio-economic contextual differences at the local level. Within a country or region, for example, the heterogeneity of socio-economic contexts such as institutions, population, social network, and culture may affect local vulnerability to climate change (Adger, 1999; Carina & Keskitalo, 2008; Engle & Lemos, 2010). When assessing vulnerability, a dynamic point of view is required (Eriksen & Silva, 2009; Frank *et al.,* 2011). Individual perception and accumulated knowledge of climate change learning through the past experiences of households' response to climate change and through their attitudes, values, culture, and norms evolve over time results. A number of studies support this notion and show that individual awareness is one of the critical factors determining the degree of local vulnerability (Knutsson & Ostwald, 2006; Deressa *et al.,* 2009). Studies that focus on micro-levels unit of analysis such as the household or community ecosystem, makes it feasible to capture the diversity of the natural environment of communities and their socio-economic heterogeneity (Adger *et al.,* 2005; Schroter *et al*., 2005; Flint & Luloff, 2005; Ziervogel *et al*., 2006; Acosta-Michlik & Espaldón, 2008).Measuring local vulnerability by different sectors so as to create local vulnerability measures show that some indicators identified in local case studies overlap across sectors. That notwithstanding, many indicators turned out to be sector-specific, distinguishable and exclusive. The utilized indicators and their inter-linkages, which are geared towards reflecting overall vulnerability, are graphically presented in Table 2.5 below.

Table 2.4: Summary of possible local vulnerability indicators in agricultural sectors. Source: Miller et al., (2013).

Component		**Possible indicators**
Exposure		Precipitation variability Temperature variability Extreme events (e.g., drought, flood, cyclone)
Sensitivity	Coastal farm	Saltwater intrusion and destruction of farmland (low lying farm areas; coastal spring destruction and diseases
	Small rural agrarian communities	Mangrove habitats/wet tropic
	Population	Vulnerable age of the population
Adaptive capacity	Economic	Dependency on rain-fed agriculture or resources Income, non-agriculture income Nominal income, real wage, real expenditure, medical expenditure, disposable income Domestic price and world price (or openness) Physical assets (i.e., animals, vehicles, machines, house and land) Diversification of occupation and crops Immigration option
	Social	Community network Collective action (e.g., religion-based activities observed from marriage and funerals)
	Infrastructure	Buildings and road Access to water Irrigation system Public health Transportation system
	Individual knowledge	Awareness of climate-driven risk based on past threats Level of education /cost of education
	Institutional	Government social interventions. (education policy, credit for low-income farmers, immigration policy)

Following the IPCC (2007) definition of vulnerability with regards to agriculture, exposure can be represented by the frequency of climate extremes. In South Africa, one of the key constraints to agriculture is a high climate variability that has historically included numerous droughts (2002/2003; 2015/2016) and floods (2000). In regions with a higher frequency of droughts or floods, crop production is riskier. The larger the changes, the more difficult the regions are expected to have in adjusting to these changes. More importantly, if increased temperature and decreased rainfall are predicted we would expect to see negative impacts on farm production in already hot and water-scarce regions.

Sensitivity, on the other hand, is shaped by both socio-economic and ecological conditions and determines the degree to which a group will be affected by environmental stress (SEI, 2004). Factors that may influence the sensitivity of a farming region are presented below:

I. Irrigation rate

If we compare two agricultural regions that grow the same crops and have similar climates, their exposure to climate variability might be similar, but their sensitivity could be very different. For example, an irrigated system would have low sensitivity to short-term precipitation variability, whereas a rain-fed system would have greater sensitivity to the same exposure.

II. Land degradation index

Land degradation reduces the productive capacity of the land. Contributors to land degradation include natural disasters and human activities. The human activities extend to agricultural production mismanagement, overgrazing, fuelwood consumption, industry, and urbanization. This indicator represents the “combined degradation index,” which considers soil degradation (erosion, salinization, and acidification) and veld or vegetation degradation (loss of cover and changes in species composition, bush encroachment, alien plant invasions, and deforestation). Areas with higher land degradation indices will experience greater negative impacts of climate variability and change

III.Crop diversification index:

Farmers themselves commonly identify diversification as an ineffective strategy for managing business risks; particularly climatic risks (Bahia, 1965; Thomas et al., 2011; Osumanu,2017; Aniah et al.,2019). An agricultural region with more diversified crops will be less sensitive to climatic variations.

IV.Percent small-scale:

Small-scale farmers, generally subsistence farmers, are more sensitive to climate change and variability because they have less capital-intensive technologies and management practices. Thus, a region with a large number of small-scale farmers will be more climate-sensitive than a region with fewer small-scale farmers.

V.Rural population density:

A region with high population density is more sensitive to climate because more people are exposed and therefore the region will need greater humanitarian assistance.

The capacity to adapt is context-specific and varies from place to place and among social groups and individuals over time (IPCC 2001; Smit & Wandel 2006). According to McCarthy et al., (2001) adaptive capacity is considered to be “a function of wealth, technology, education, information, skills, and infrastructure, access to resources, and stability and management capabilities".

In order to resist or recover from the negative effects of a changing environment, the system exploits opportunities by using the assets and entitlements that the individuals, households, or communities can mobilize and manage in the face of hardship. There are close linkages between vulnerability and livelihoods, and building resilience is a question of expanding and sustaining these assets (Moser, 1998; Miller et al.,2010). Vulnerability is therefore closely linked to asset ownership. The more assets people have, the less vulnerable they are; conversely, the greater the erosion of people's assets, the greater their insecurity. Adaptive capacity can described as being dependent on:

I. Social capital.

This is represented by the number of farmers in farm organizations/organized agriculture. This indicator is a proxy for private social networks. Social networks act as an instrument for financial transfers between farmer members. This may help by relaxing the farmer's credit constraints. Furthermore, social networks act as conduits for information about new technology as well as a network to facilitate cooperation to overcome collective action dilemmas, where the adoption of technologies involves externalities (Deressa *et al*., 2008). It is hypothesized that social capital positively influences adaptation to change.

II. Human capital

Human and civic resources are another critical component of coping and adaptive capacity. This category includes literacy, level of education, access to retraining programs, and other factors that determine how flexible individuals may be in adapting to new employment opportunities or shifts in living patterns brought about by climate variability or change. According to Leichenko *et al.,* (2002), increased overall literacy levels reduce vulnerability by increasing people's capabilities and access to information, thereby enhancing their ability to cope with adversities. Proxies include the dependency ratio and literacy rate. The dependency ratio measures the proportion of economically active and inactive individuals in a population; a higher rate of dependency would indicate that economically active individuals had many others to support, and resources for adapting to changes in climate would be more limited. The literacy rate (World Bank, 1998) was also included as a measure of the skills that individuals would have to have in order to adapt.

The sensitivity of human population health to climate conditions can be expected to be highest in developing countries and among the poor in transitional and developed countries. Completed fertility and life expectancy represent a variety of conditions that affect human health, including nutrition, exposure to disease risks, and access to health services. HIV prevalence is used as an indicator under the assumption that areas with higher rates of HIV/AIDS are more vulnerable. Drimie (2002) states unequivocally that HIV/AIDS is "…the major development issue facing Sub-Saharan Africa." The epidemic deepens poverty, reverses human development achievements, worsens gender inequalities, erodes the ability of governments to maintain essential services, and reduces labor productivity.

Closely related to human resources are civic resources, which include associations among individuals, either informal or formal, through kinship relations, civic associations, or other institutions that would lead to feelings of obligation to help those who may be negatively affected by climate.

III. Financial capital

This is represented by farm income; farm holding size; farm assets; the percentage of people below the poverty line; share of agricultural GDP; and access to credit. These indicators provide a general picture of the financial situation of the province. Regions with higher farm income, larger farms, greater farm value assets, and more access to credit are wealthier and are therefore better able to prepare for and respond to adversity. In contrast, regions with a higher dependence on agriculture (higher share of agriculture in total GDP) are assumed to be less economically diversified and thus more susceptible to climatic events and changes (Moss *et al.*, 2001).

IV. Physical capital

This is related to infrastructure and access to markets. The quality of infrastructure is an important measure of the relative adaptive capacity of a region. Regions with better infrastructure are presumed to be better able to adapt to climatic stresses (Moss *et al.,* 2001). Improved infrastructure may reduce transactions costs and strengthen the links between labor and product markets.

Markets may be important for a variety of reasons, including their abilities to spread risk and increase incomes. Zhang *et al.,* (2007), are of the opinion that markets act as a means of linking people both spatially and over time. This, therefore, allows shocks (and risks) to be spread over wider areas and thus makes households less vulnerable to (localized) covariate shocks. Furthermore, pre-existing coping strategies, for instance, the sale of productive assets will be more effective, thereby avoiding the potentially irreversible effects of these actions (Zhang *et al.,* 2007). Additionally, improved infrastructure will encourage the formation of nonfarm enterprises as a source of diversification in the short run and, eventually, a transition out of agriculture. Infrastructure may further act as a facilitator for migration and remittances, which are important ex-ante and ex-post mechanisms for reducing vulnerability (Moss *et al*., 2001).

2.2 Summary

The unprecedented rate at which present-day climate is changing threatens agriculture and food security in many parts of the world. To be able to measure the consequent risk of agriculture to climate change, possible impacts and how to manage such impacts needs to be carried out. Various approaches have been developed to carry out vulnerability assessment using several indicators. Only with appropriate vulnerability assessment methods will proper adaptation approaches and subsequent implementation of such approaches be carried out. The next chapter deals with the various materials and methods that were employed in carrying out this study.

Chapter Three

Materials and Methods

3.1 Introduction

The character of climate change vulnerability is such that it integrates both the social and biophysical dimensions and therefore calls for interdisciplinary approaches to operationalize the vulnerability concept (e.g. Füssel & Klein 2006; Wilhelmi & Hayden 2010). This rationale gives credit to the use of an interdisciplinary approach (perspectives and frameworks) to assess and characterize vulnerability and to synthesize the results of different analytical methods. This thesis made use of interdisciplinary frameworks. The principle of pragmatism was used as a guide given that it supports the integration of feasible and pertinent perspectives and approaches, to gain insight into or solve a research problem (Creswell 2003; Johnson et al., 2007). Since pragmatism offers an epistemological rationale for mixing methods (Johnson et al., 2007), a mixed-methods approach was used to address and achieve the aims and objectives of this research. A mixed-methods approach combines both quantitative and qualitative data analysis in a single study (Creswell, 2003; Lund,2012; Garuth, 2013; Morse, 2016) as shown in Figure 3.1 .

Through this mixed-methods approach, complementary and converging answers are sought, and the outcomes of one analysis are used as inputs in developing and getting results in another as shown by Figure 3.1, following a sequential mixed-methods design (Johnson & Onwuegbuzie 2004; Ivankova et al., 2006).

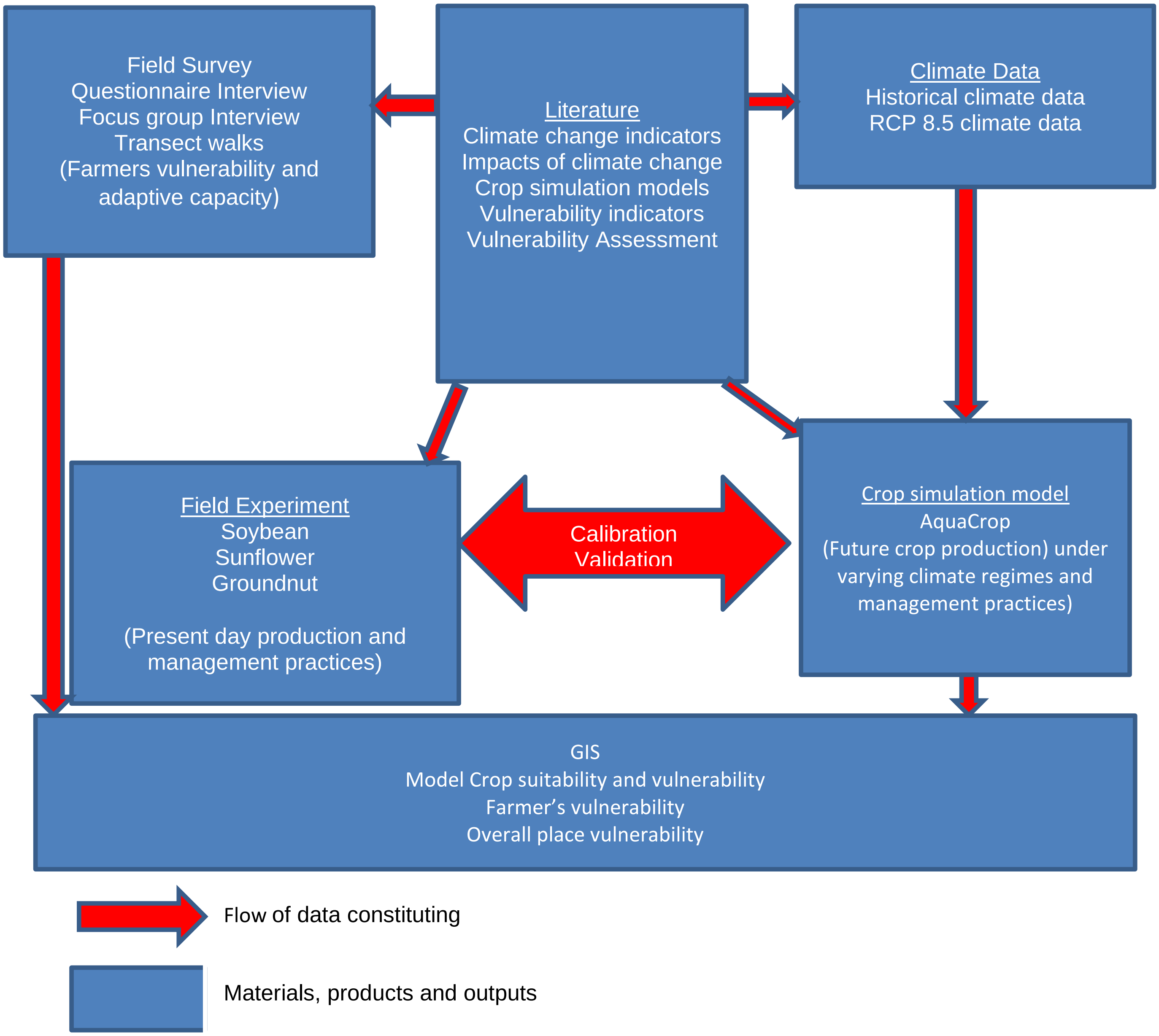

Figure 3.1: Schematic representation of the sequential mixed-methods design employed.

Figure 3.1 shows that the results from the analysis of different literature improved our knowledge of agricultural vulnerability indicators while bridging quantitative and qualitative perspectives, leading to the choice of exposure indicators, field experiment methods and required climate data. These are all fed into crop simulation models which, coupled with results from field survey, are in turn fed into a Geographic Information Software (GIS) to show the vulnerability of the crop and system to future climate change. Even though it can be argued that this sequential method design may create some biased results given that results of one study are fed into another thereby influencing the result of the second study, nevertheless, steps have been taken to ensure that results are not biased. This is done by recording only the results obtained without adjusting to fit any preconceived notion. In addition, this approach is deemed to be pragmatic, and it is relied upon to produce relevant findings. Furthermore, the method has clear benefits in terms of effectiveness and congruence (e.g Tashakkori & Creswell, 2008; Caruth, 2013; Creswell & Plano Clark, 2011). This chapter, therefore, deals with the research design and methodology used for this study. Fieldwork vis: survey and field crop experiments and desktop studies constituted the methods for data collection. Purposive sampling design was used for the selection of farmers. The details of materials and methodology adopted for data collection, analyses and production of necessary maps are discussed in the following paragraphs.

3.2 Data and data sources

This study made use of both primary and secondary data. Primary data included biophysical data, farm management practices and agronomic practices as well as socioeconomic data collected from the field through sampling and observation. Secondary data included climate data, various shapefiles, data on soils as well as data from relevant literature.

3.2.1 Survey and experimental sites

This study was conducted across diverse agroclimatic conditions in two provinces of South Africa, as seen in Figures 3.2 and 3.3. The survey component of the study was carried out in both the Free State and Limpopo Provinces. Field experiments were restricted to Limpopo due to logistical issues as well as the fact that Limpopo has a sufficient number of agroclimatic regions which can be representative of the rest of the summer rainfall areas in South Africa.

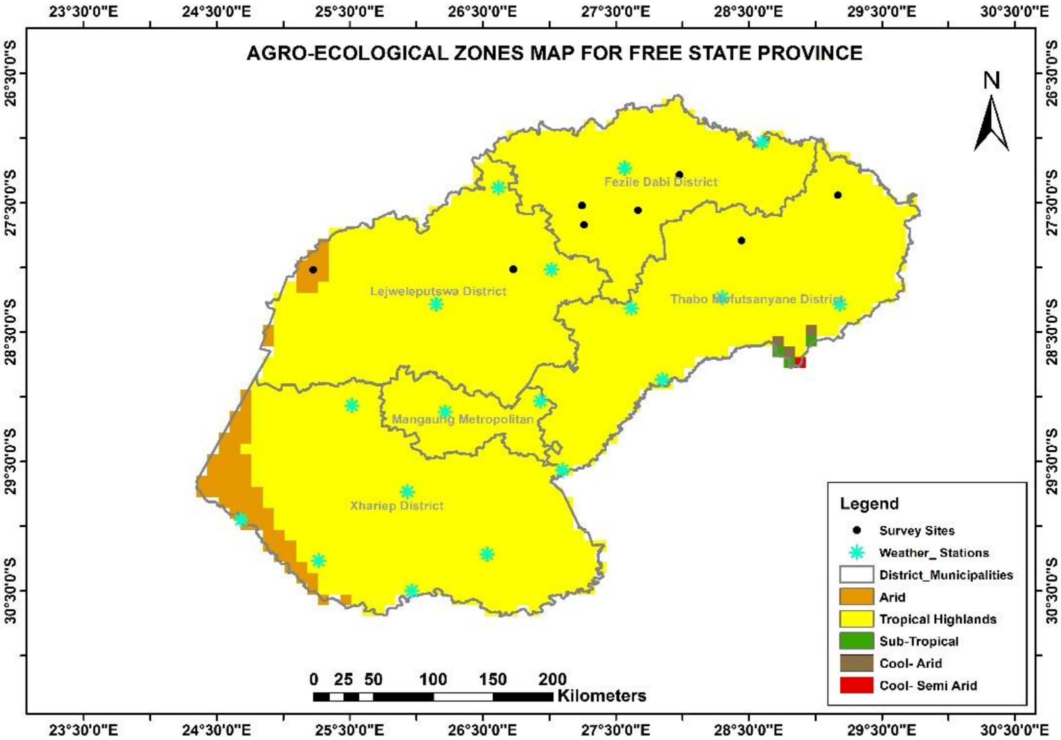

Figure 3.2: Map of the Free State province showing survey sites and climate stations. Source: Calculated from (International Institute for Applied Systems Analysis/ Food and Agricultural Organisation,2012).

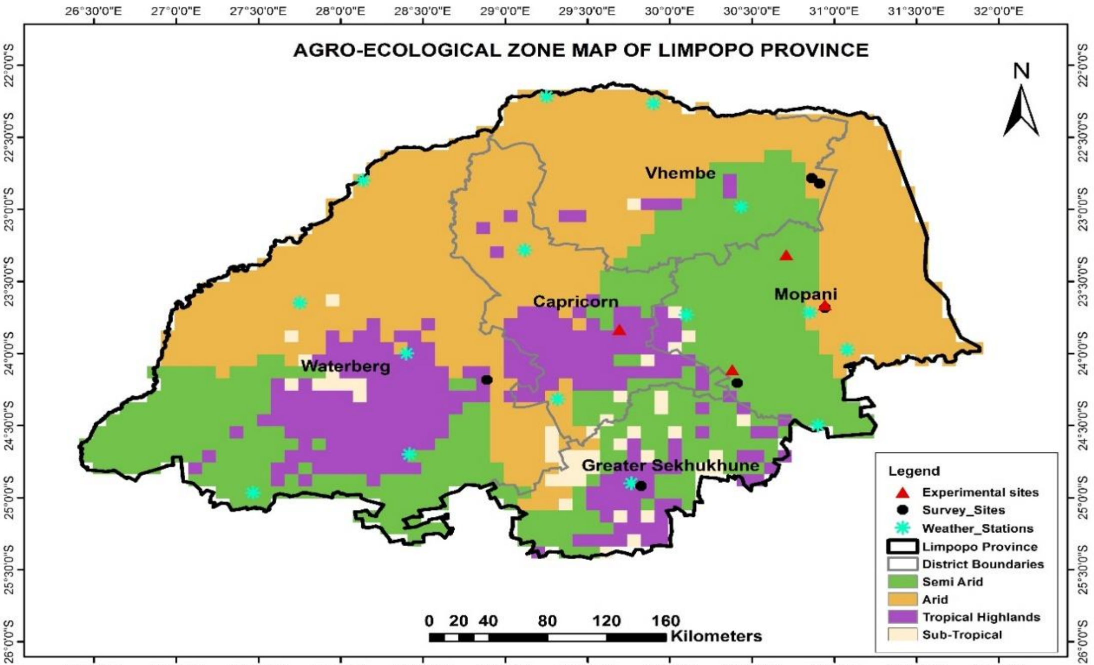

Figure 3.3: Map of Limpopo province showing survey sites and climate stations and experimental sites.
Source: Calculated from GAEZ (International Institute for Applied Systems Analysis/ Food and Agricultural Organisation, 2012).

3.2.1.1 Site classification based on the Agro-ecological Zone model

Agroecological zones (AEZs) as described by Sebastian (2009) are geographical areas exhibiting similar climatic conditions which determine the ability of these geographical areas to support rain-fed agriculture. The data used for this study was the Agro-Ecological Zones for sub-Saharan Africa based on the FAO/IIASA methodology (Harvest Choice/IFPRI 2010). The AEZ approach uses long-term average, spatially interpolated climate data for Africa for the period 1960–1990 (Hijmans et al., 2005; Sebastian, 2009) as well as latitude, elevation, temperature, seasonality, and rainfall amount and distribution during the growing season. The resulting AEZ classifications for Africa have three dimensions: major climate (tropical or subtropical conditions), elevation (warmer lowland or cooler upland production areas), and water availability (ranging from arid zones with less than 70 growing days per year to humid zones where moisture is usually enough to support crop growth for at least nine months per year) (Fischer et al. 2009). Temperature zones are one of the governing factors in the selection of which crops can be cultivated in which areas. The major climate divisions, as defined for the Global Agroecological Zones (GAEZ) project (FAO/IIASA 2002), are calculated based on monthly average minimum and maximum temperature data at a resolution of 0.00833dd (approximately 1x1km) (WorldClim,2009), and SRTM30 elevation data also at a resolution of 0.00833dd (USGS, 2007). Mean monthly temperature adjusted to sea level was calculated for each cell as follows:

$$[(\mathrm{tmin}\_m + \mathrm{tmax}\_m)] / [2 + (0.55 * \mathrm{elevation} / 100)] \tag{3.1}$$

Where: m represents individual months (FAO/IIASA, 2002)

Moisture zones are identified using the length of growing period (LGP) concept which identifies the time in which both moisture and temperature are conducive to crop growth. The moisture zones were defined using LGP data at a resolution of 0.08333dd (approximately 10x10km) (Fischer 2009).The specific moisture zone classes are:

Arid: less than 70 days length of growing period (LGP)

Semi-arid: 70-180 days LGP

Sub-humid: 180-270 days LGP

Humid: >270 days LGP

The data was used in choosing representative zones for the study as seen in Figure 3.2 and 3.3.

3.2.2 Collection of data from literature

A systematic literature review was conducted following the five-step approach of Khan et al., (2003). The steps as employed in this review include the framing of structured questions before the review process; based on specified terms, select the criteria identifying relevant work for the questions, structurally assessing the studies, summarizing the evidence, and interpreting the findings (Khan et al. 2003). An extensive review was conducted to outline different vulnerability assessments techniques used in previous climate change vulnerability assessments for agriculture, vulnerability indicators, as well as different methods on addressing the issue of data limitation in crop simulation and modelling. This process of literature review was conducted to facilitate the selection of methods of analysis that will be implemented when addressing the research objectives.

The structured review questions were as follows:

(i) How is climate change influencing or projected to influence the production of crops in South Africa?
(ii) What challenges and opportunities are highlighted?
(iii) What required adaptation actions (i.e., policies and measures) are mentioned?

The systematic search of the scientific literature was performed on several databases such as in the databases of ‘Scopus’, and ‘Google scholar. Other grey literature was accessed through Google searches. The first screening of search returns identified approximately 200 documents. The titles were the first indication for suitability followed by a perusal of the abstracts for the relevance to the focus of this study. Finally, 80 documents were included in the literature review.

The literature searches and subsequent assessment was structured according to the current and projected future impacts of climate change on agriculture, the climate challenges and/or opportunities recognized in the studies, as well as on possible adaptation strategies or guidelines examined or suggested by them. The material was synthesized to improve knowledge of what climate factors are likely to contribute to agricultural vulnerability in South Africa, as well as establishing an understanding of the adaptation actions necessary to limit the vulnerability and seize possible opportunities.

3.2.3 Collection of soil data, instruments, and analysis

Data were collected from both primary and secondary sources. The collection of soil data and its analysis thereof served two purposes in this study. Firstly, the primary collection of soil data was aimed at providing the necessary soil parameters for the parameterization, calibration, and validation of the crop simulation models.

Secondly, secondary data on soil was obtained from the Soil and Terrain digital database (SOTER) for southern Africa. The essence of secondary soil data analysis in this study was to classify the influence of relevant soil parameters in the production of sunflower, soybean, and groundnut. The soil results also supported the conclusions and recommendations for this study.

3.2.3.1 Pre-plant soil analysis

Prior to the establishment of the field experiments, a simple random sampling was used to collect soil samples with an auger at a depth of 0-90 cm at each location and across two seasons. This was done to ensure that the minimum requirements for model calibrations are met for the crop simulations. Soils were sampled at a depth of 0-15 cm (surface) and 15-30 cm (subsurface) 30-60 cm and 60-90 cm respectively at Syferkuil, Ofcolaco, Punda Maria and Phalaborwa. A total of 10 soil samples per experimental site were collected. A sampling distance of at least 10m was observed between sample points. The depth of sampling ranged from 0 to 90 cm which was acceptable for this study given that soil sampling for agricultural studies are usually taken from 0-15 cm to 0-20 cm deep, which is where a large proportion of the active root zone is. Soils were sent to the lab for various physical and chemical analyses. A composite soil sample was made for analysis of key physical properties and chemical properties which are essential inputs in the AquaCrop simulation model as seen in Table 3.1 below.

Table 3.1: Pre-plant chemical analysis and physical properties of soil at experimental sites 2016/2017 season.

	Location							
Soil pH and Nutrients								
	Syferkuil				**Ofcolaco**			
	0-15 cm	**15-30 cm**	**30-60 cm**	**60-90 cm**	**0-15 cm**	**15-30 cm**	**30-60 cm**	**60-90 cm**
pH	6.4	6.1	5.9	6.4	5.9	5.2	5.4	4.9
				mg kg^{-1}				
Phospherous (P)	16.3	12.6	6.1	3.8	24.2	7.1	8.5	4.1
Potasuim (K)	341.7	265.8	157.1	143.1	231.6	165.9	142.8	78.6
Calcuim (Ca)	758.6	830.1	844.8	1231.5	752.1	652.8	723.8	562.5
Mafnasuim (Mg)	453.3	486.5	501	906.1	298.8	291.2	346.4	154.4
Zinc (Zn)	2.01	1.6	0.6	0.3	3.7	3.1	1.5	0.4
Maganese (Mn)	22.3	20.5	13.4	10.2	10.1	11.2	8.1	4.9
Copper (Cu)	4.2	4.7	3.9	3.3	4.2	3.6	3.8	3.9
Total Nitrogen (N) (%)	0.18	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Organic carbon (%)	0.8	0.7	0.5	0.4	1.0	0.6	0.8	0.8
Physical properties								
Clay (%)	30	31	31	34	24	29	29	31
Silt (%)	7	8	12	10	9	10	11	11
Sand (%)	63	61	57	56	67	61	60	58
Textural Class	Sandy Clay Loam				Sandy Clay Loam			

3.2.4 Field crop experiment

Field experiments were conducted during the summer growing seasons of 2016/2017 and 2017/2018. In the first season, experimental sites were established at the Syferkuil experimental farm located at 23°50’38” S and 29°41’13” E and at Ofcolaco (24°06’41” S and 30°23’26” E). Daily in-crop rainfall (ICR), temperature and solar radiation during the 2016/2017 and 2017/2018 seasons (October – February) are presented in Figures 3.4 – 3.13 for Syferkuil and Ofcolaco.

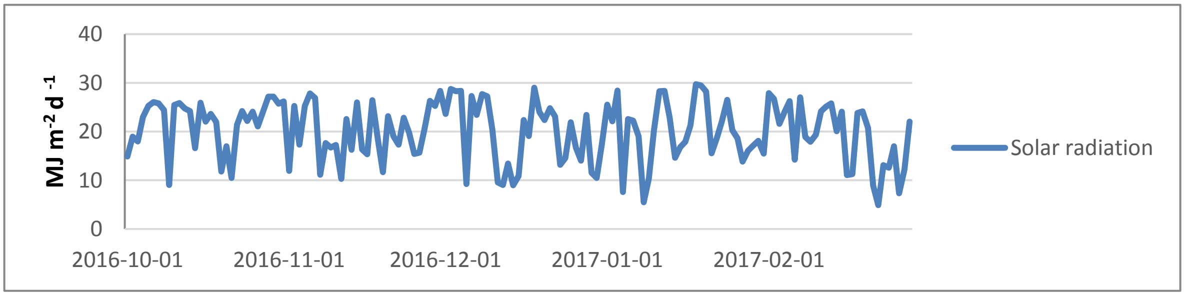

Figure 3.4: Solar radiation during the growing season 2016/2017 at Syferkuil

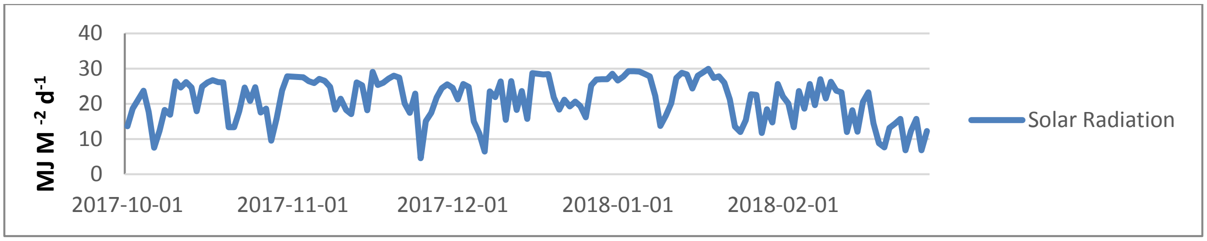

Figure 3.5: Solar radiation during the growing season 2017/2018 at Syferkuil.

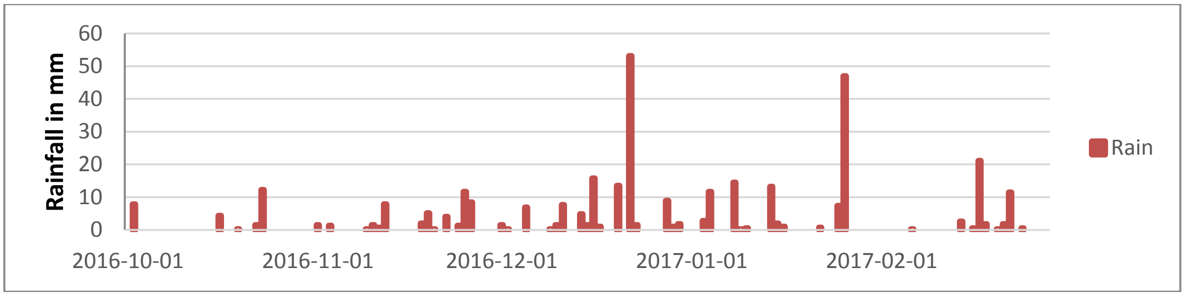

Figure 3.6: Rainfall during the growing season 2016/2017 at Syferkuil.

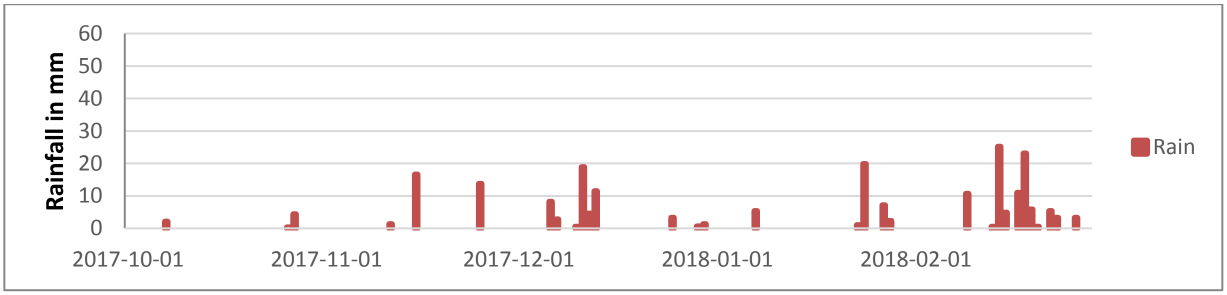

Figure 3.7: Rainfall during the growing season 2017/2018 at Syferkuil.

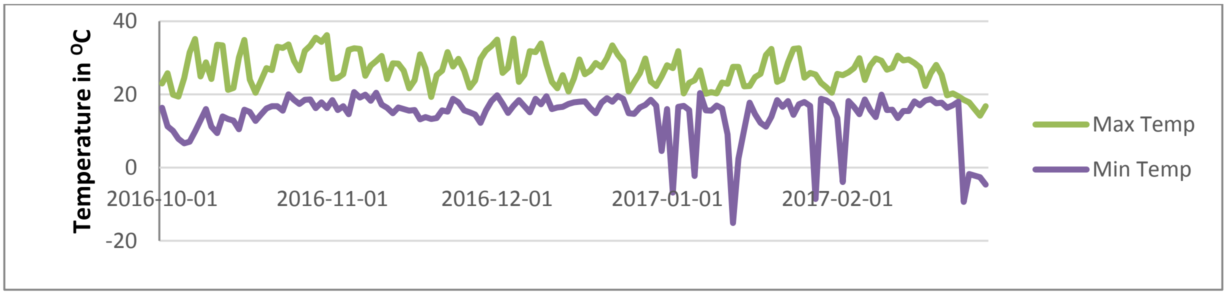

Figure 3.8: Minimum and Maximum temperatures during the growing season 2016/2017 at Syferkuil.

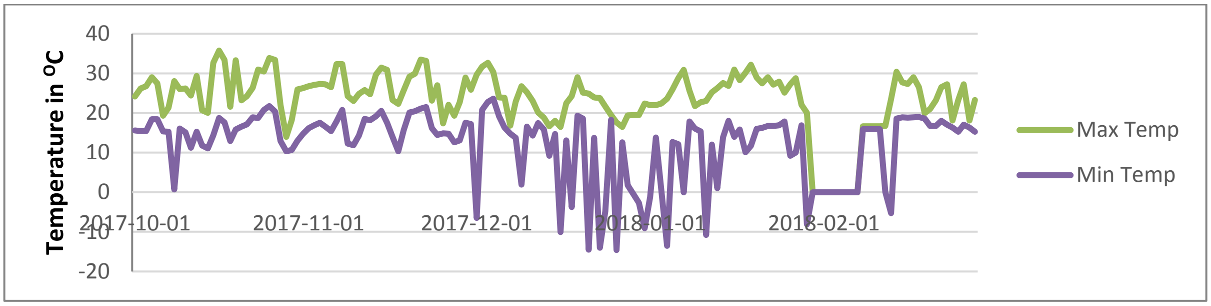

Figure 3.9: Minimum and Maximum temperatures during the growing season at Syferkuil 2017/2018.

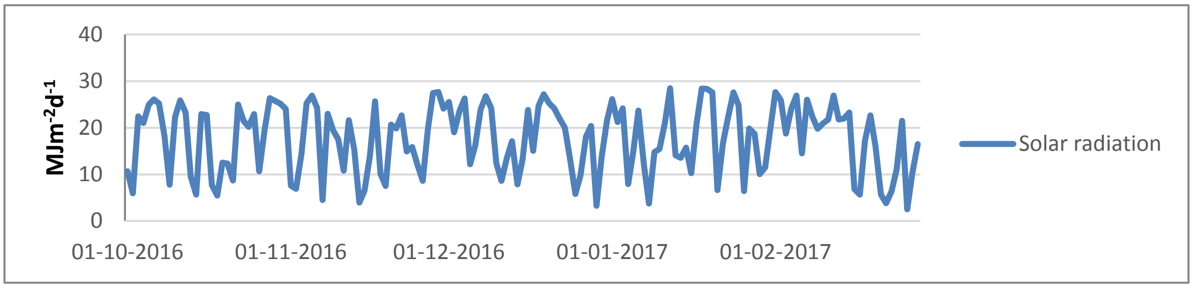

Figure 3.10: Solar radiation during the growing season 2016/2017 at Ofcolaco.

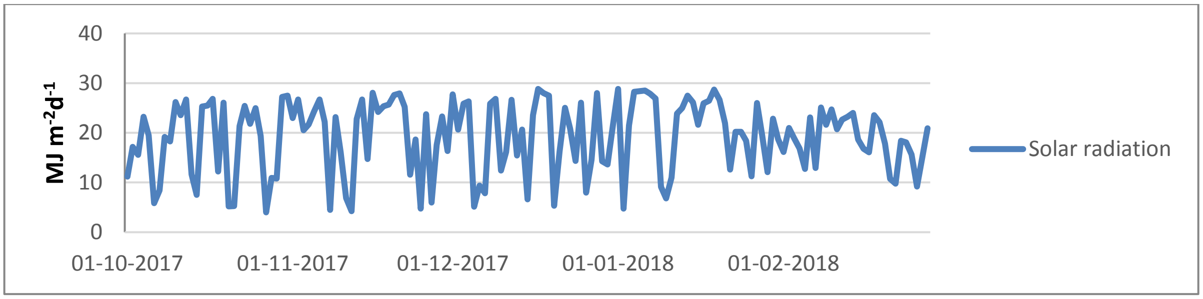

Figure 3.11: Solar radiation during the growing season 2017/2018 at Ofcolaco.

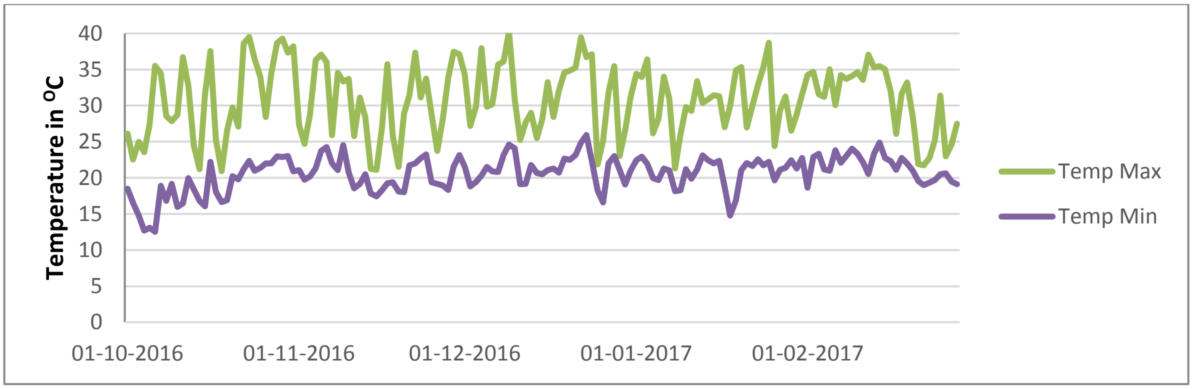

Figure 3.12: Minimum and Maximum temperatures during the growing season 2016/2017 at Ofcolaco.

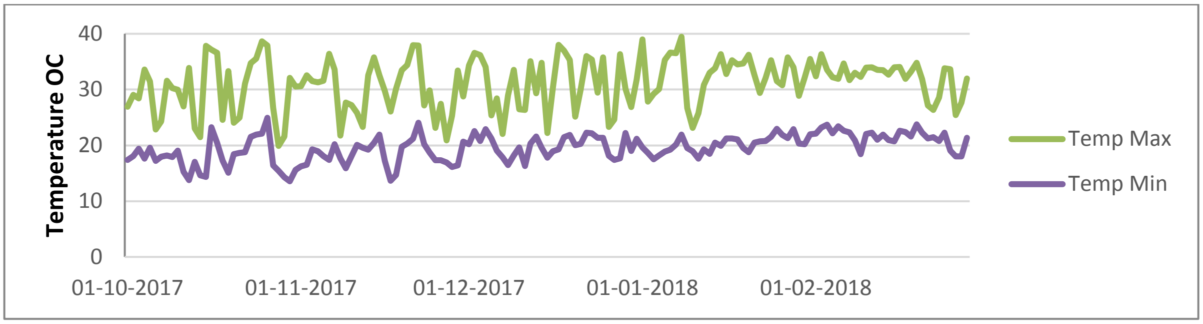

Figure 3.13: Minimum and Maximum temperatures during the growing season 2017/2018 at Ofcolaco.

Seasonal conditions were different between 2016/2017and 2017/2018, particularly in the amount of total ICR: +334 mm in the first season, and 218.56mm in the second season in Syferkuil and 423.18mm in the first season and at Ofcolaco. The late planting during the first season meant that the 2016/2017 season was slightly cooler, and the crop was exposed to lower levels of incoming radiation. Average minimum and maximum temperatures were 14°C and 26.62°C in the first season and 12°C and 23.54°C in the second season at Syferkuil and 20°C and 30.8°C in the first season at Ofcolaco and19.5°C and31.1°C in the Second Season. The average incoming solar radiation was 20°C and 21.5°C respectively in the first and second season at Syferkuil and 17.6 MJ m^{-2} in the first season and 19.2 MJ m^{-2} in the second season at Ofcolaco.

The other experimental site was Punda Maria (22°49’18.” S and 30°54’37” E). Growing season data are shown in Figures 3.14 to 3.16.

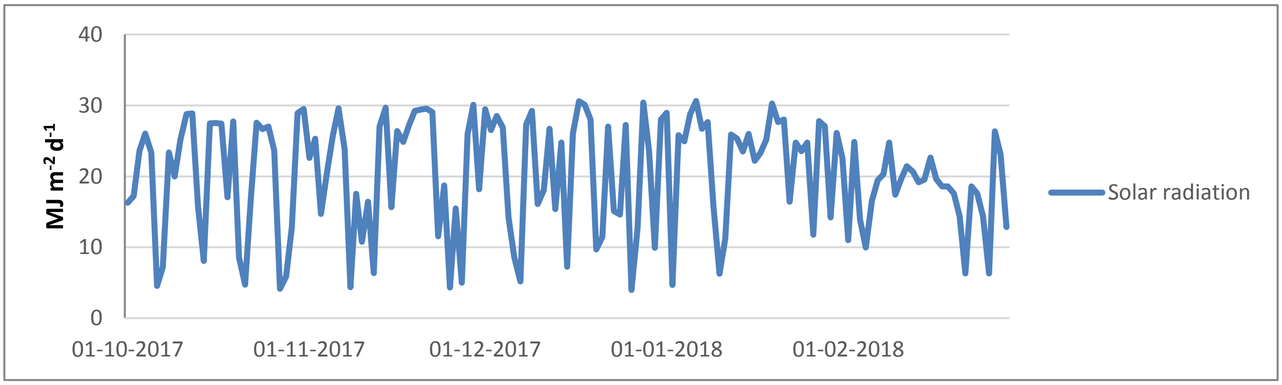

Figure 3.14: Solar radiation during the growing season 2017/2018 at Punda Maria.

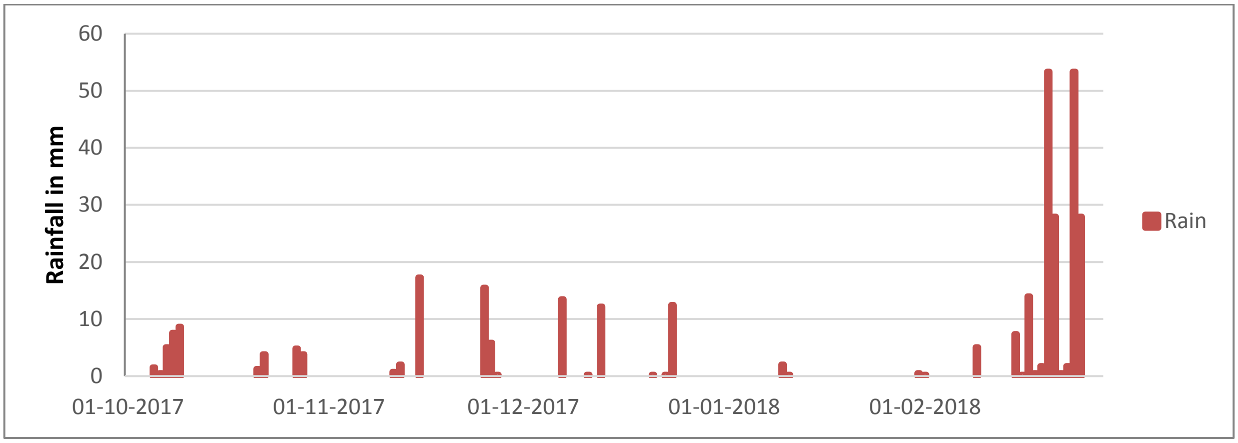

Figure 3.15: Rainfall during the growing season 2017/2018 at Punda Maria.

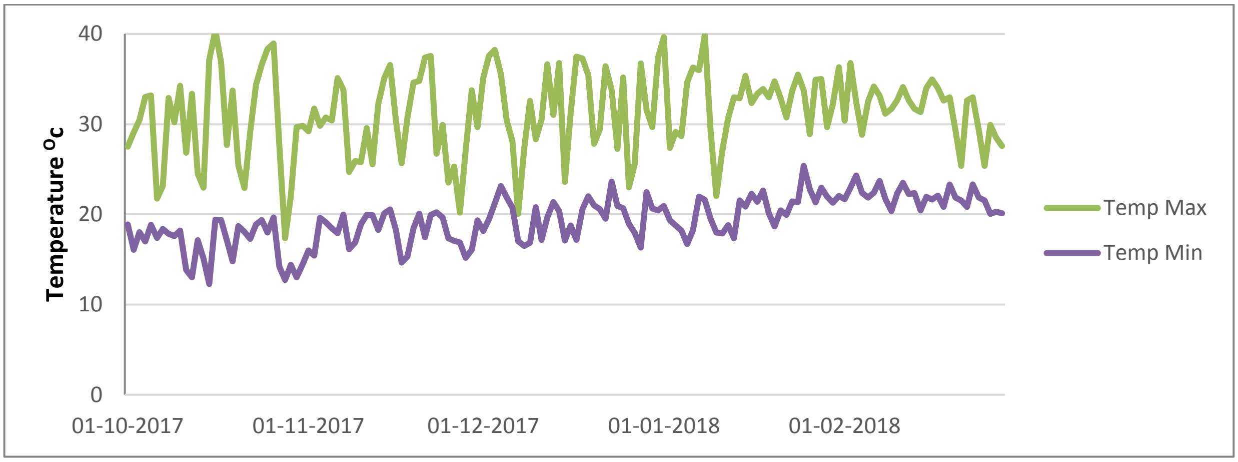

Figure 3.16: Minimum and Maximum temperatures during the growing season 2017/2018 at Punda Maria.

3.2.4.1 Experimental layout

The soils at the experimental areas were ripped to ensure minimum soil disturbance (See Appendix 3.1). A randomized complete block design in split-plot arrangement with three replications was used. The main plot treatments were tillage practice consisting of minimum-till (MT) practice. The subplot treatment was fertilizer application consisting of 0, 30, 60 kg/ha of P fertilization for soybean and groundnut. The full amount of the fertilizer was applied at planting as superphosphate. For sunflower, the subplot treatment consisted of 0, 75 and 150 kg/ha of Nitrogen (N) which was applied as ammonium sulphate $(NH_4)_2SO_4)$ in split dose, at planting. Each sub-plot measured 3m^{2}x 3m^2. Weeds were manually controlled throughout the growing period with a hand hoe when necessary.

AGSUN 8251 cultivar for sunflower; Soybean Don Mario and groundnut cultivar Kwart, was planted manually following production guidelines for sunflower, soybean, and groundnut (DAFF,2010). The experiments were conducted for the two consecutive seasons.

The timing for key field operations was recorded including dates of different physiological stages. The above ground matter from the previous season was cleared during field preparations. Planting and fertilizer application were only applied if more than 20 mm of rain was received and further rainfall was predicted within the next seven days afterward in the first season. In the second season, sprinkler irrigation had to be used only at planting given that the above conditions were not met; an average of 50 mm was applied across the field. The supplementary irrigation was used only to enable seed establishment.

3.2.4.2 Collection and analysis of crop data

Crop data was collected based on the necessary data for crop simulation which included site information, planting date, fertilizer treatments, days to emergence, days to 50% flowering, days to maturity/ harvesting and yield. Measurements of these variables are shown below.

Emergence: measured in days after planting and scored when at least 90% of the hypocotyl (seedlings) within an experiment appears above ground (Vigil et.al. 1997).

Days to flowering: scored when 50% of the plants within an experimental unit have flowered.

Biomass: above ground biomass from five plants from each experimental unit was sampled for biomass analysis. The samples were oven dried at the temperature of 60^{o}C to constant mass. An Analytical scale was used to weigh the dried samples.

Grain yield: The grain yield was taken from plants at harvest maturity from 1.5 m ×1.5 m in all locations and in both seasons. Grain yield was determined by threshing all the pods from the harvested samples drying the seeds at 60% to constant weight. The number of seeds per pod was counted from ten randomly selected plants samples per harvest area and the weight of 100 seed was taken.

Harvest index (HI): The harvest index was calculated by dividing the grain yield by the sum total of the above-ground dry matter and grain yield.

3.2.5 Climate data and projected climate change scenarios

Projected climate change data that was biased corrected was obtained from the Climate System Analysis Group (CSAG) at the University of Cape Town for point scale for Syferkuil, Ofcolaco and Punda Maria. Data at a point scale was obtained using a statistical downscaling technique (Hewitson & Crane, 2006) to obtain daily precipitation and temperature for time-periods 1961-2100 periods, and for Representative Concentration Pathways (RCP) 8.5. Climate data for the whole country was download from the IPCC website.

3.2.5.1 Selection of representative emission pathways

In the IPCC AR5 (Stocker et al., 2013b), Representative Concentration Pathways (RCPs) replaced the SRES emission scenarios and were used as the basis of the climate projections presented in AR5.In this thesis, the RCP 8.5 which describes a future with emissions continuing to rise throughout the 21st century (Meinshausen et al., 2011; Stocker et al., 2013a; Stocker et al., 2013b) was chosen as the basis for vulnerability assessment. The main scenario drivers of the RCP 8.5 (demographic, economic and technological trend) are based upon the revised and extended storyline of the IPCC A2 scenario published in Riahi et al. (2007). Many scenario assumptions and outcomes of the RCP8.5 are thus derived directly from the A2 scenario (Riahi et al. 2007), which was selected from the literature to serve as the basis for the RCP8.5 (for an overview of RCPs, see van Vuuren et al. (2011a). Given that RCP 8.5 is similar to the A2 emission scenario which has been widely used in impact analysis (Ziervogel et al., 2014), and most plausible based on prevailing mitigation efforts this was chosen as the scenario for this study.

3.2.5.2 Choice of GCMS

The initial selection of the GCM model was based on the availability of the most recent empirically downscaled daily GCM climate values for the selected points. Secondly, choosing the single 'best' GCM is problematic as future scenarios are all linked to the representation of physical and dynamical processes within that specific model – this may create the impression of a narrowly determined future, which may not fully span the range of potential future change. A better approach in any impact and adaptation assessment is to use the largest number of possible GCMs (excluding those that can be shown to be unsuitable) and that future change is expressed either as a range of future changes or as a summary statistic (e.g. percentiles) of the distribution of projected changes, with some measure or recognition of the spread of possible future climates also provided (Davis-Reddy & Vincent,2017). In this study, 8 GCMs (BCC-CSM1, BNU-ESM, canESM2, CNRM-CM5, FGOALS-s2, GFDL-ESM2G, MIROC5, MIROC-ESM,) were selected from those used in the IPCC 5th Assessment Report. Only downscaled GCMs were used and hence removing the need for resampling. This reduces the selection error as downscaled GCM runs have local climate adjustment as opposed to regional or global GCM runs.

3.2.5.3 Solar radiation calculation

This research employed the temperature difference method for the calculation of incoming solar radiation (R_S) since the climate data from downscaled models did not have solar radiation. The temperature difference method is recommended for locations where it is not appropriate to import radiation data from a regional station, either because homogeneous climate conditions do not occur, or because data for the region are lacking (Allen et al., 1998). The difference between the maximum and minimum air temperature is related to the degree of cloud cover in a location. Clear-sky conditions result in high temperatures during the day (Tmax) because the atmosphere is transparent to the incoming solar radiation, and in low temperatures, during the night (Tmin) because less outgoing longwave radiation is absorbed by the atmosphere. On the other hand, in overcast conditions, Tmax is relatively smaller because a significant part of the incoming solar radiation never reaches the earth's surface and is absorbed and reflected by the clouds. Similarly, Tmin will be relatively higher since the cloud cover acts as a blanket and decreases the net outgoing longwave radiation. Therefore, the difference between the maximum and minimum air temperature (Tmax - Tmin) can be used as an indicator of the fraction of extraterrestrial radiation that reaches the earth's surface. This principle has been utilized by Hargreaves and Samani to develop estimates of crop reference evapotranspiration (ET_0) using only air temperature data. The Hargreaves' radiation formula, adjusted and validated at several weather stations in a variety of climate conditions, becomes:

$$R_s = k_{Rs}\sqrt{(T_{max} - T_{min})}R_a \quad (3.2)$$

Where:

Rs = incoming solar radiation

Ra = extraterrestrial radiation [MJ m^{-2} d^{-1}],

T_{max}= maximum air temperature [°C],

T_{min} = minimum air temperature [°C],

k_{Rs} adjustment coefficient (0.16. 0.19) [°C-0.5].

The square root of the temperature difference is closely related to the existing daily solar radiation in a given location. The adjustment coefficient k_{Rs} is empirical and differs for 'interior' or 'coastal' regions:

- As far as 'interior' locations are concerned, where land mass dominates and air masses are not strongly influenced by a large water body, $k_{Rs} \cong 0.16$;
- Where 'coastal' locations are concerned, situated on or adjacent to the coast of a large land mass and where air masses are influenced by a nearby water body, kRs ≅ 0.19.

The fraction of extraterrestrial radiation that reaches the earth's surface, R_s/R_a, ranges from about 0.25 on a day with dense cloud cover to about 0.75 on a cloudless day with a clear sky. R_s predicted by Equation 3.3 are limited to ≤ $R_{so\ where}$ Rso is calculated as:

$$R_{so=}\ (a_s + b_s\ )R_a \qquad (3.3)$$

Where:
R_{so} = clear-sky solar radiation [MJ m^{-2} day^{-1}],
a_s+$b_{s\,=}$ fraction of extraterrestrial radiation reaching the earth on clear-sky days (n = N).

But for cases when calibrated values for a_s and b_s are not available, R_{so} is calculated as follows:

$$R_{so=}\ (.75 + 2\ 10^{-5}\ z)R_a$$

Where:
z = station elevation above sea level [m];

Relationship between the fraction of extraterrestrial radiation that reaches the earth's surface, Rs/Ra, and the air temperature difference Tmax - Tmin for interior (kRs = 0.16) and coastal (kRs = 0.19) regions.

The relationship between the fraction of extraterrestrial radiation that reaches the earth's surface, R_s/R_a, and the air temperature difference T_{max} - T_{min} for interior (k_{Rs} = 0.16) and coastal (k_{Rs} = 0.19) regions. (Allen et al., 1998).

3.2.5.4 Reference evapotranspiration

The required reference evapotranspiration (ET_0) expressed by the reference grass evapotranspiration for future climate projections were calculated with the ET_0 Calculator software (Raes, 2012). The software makes use of the FAO Penman-Monteith equation developed by Allen *et al.* (1998).

3.2.6 Survey instruments, sampling and data collection

Instruments used in this study included questionnaire, focus group interviews and transect walk.

The selected sites are representative of the major agroclimatic regions of South Africa according to the AEZ classification (Sebastian, 2009) which were arid, semi-arid and tropical highlands across the five districts of the Limpopo Province and the Free State Province (Figure 3.1 and 3.2). The criteria used in the selection of farmers comprised the following:

a. They should be located in the area;
b. They should be engaged in the cultivation of either sunflower, soybean or groundnut or any combination of the three crops;
c. They should be subsistence and smallholder farmers.

In the survey, key informants and respective Departments were contacted. They, through extension officers provided farmers in the areas cultivating one or all the selected crops. The farmers were invited for the questionnaire administration, one on one interview, focus group discussions and transect walks for selected farmers. Farms for transect walks were selected based on the willingness and availability of the farmers on the day of the scheduled interviews. This was done to reduce the logistical costs involved both in terms of time (both for the farmer and researcher) and resources.

3.2.6.1 Questionnaire Administration

The questionnaires (Appendix 3.2) were administered to farmers across the three agro-ecological zones of Limpopo and in the Free State Province. The benefits, objectives, and importance of the study were communicated to farmers at the gathering. Questionnaires were administered after farmers gave their consent to participate in the study. Structured and semi-structured questions were administered in the questionnaire. The questionnaire comprised the following sections: baseline farm characteristics information, household information and income sources, agricultural production and management practices, through to farmer perceptions to climate (i.e. change and variability), adaptations and barriers to adaptation. Individual farmers were asked to provide information on their farming practices; which of the selected crops (groundnut, soybean, sunflower) were farmed; their observations on the major changes in weather and how these patterns have affected their farming decisions; adaptation to climate change and the support systems available to them to cope with the climatic and none-climatic challenges; and adaptation measures they have used to deal with changes in climate as well as the effectiveness of these adaptation measures.

A total of 600 farmers were sampled in Limpopo, and 250 in the Free State province. Given that the questionnaires were administered with a team that was conversant with the objectives of the questionnaire, spoke the native language, all farmers present were able to understand and respond to all the questions with ease.

3.2.6.2 Farmer Interview

Qualitative data was collected through one-on-one interviews discussions with smallholder farmers which focused on the reasons why certain crop production decisions were taken, their awareness of climate change; interventions and support systems; how do they perceive these interventions and if they find them useful. In this study, the one-on-one interviews provided the researcher with an opportunity to further explore the issues that could not be easily unpacked or explained through the questionnaires.

3.2.6.3 Focus Group Discussions

Focus group discussions were held with the farmers and relevant issues and questions on socio-economic elements and adaptation were raised and answers solicited from the participants according to their agricultural experiences. Questions from the questionnaire were used to explore agricultural production and smallholder farmers’ adaptation strategies towards climatic and non-climatic shocks. Essentially, issues raised included their socioeconomic (occupations and sources of income), and available social infrastructures. This also provided room for the participants to ask questions about the study.

3.2.6.4 Secondary data sources for survey

Data on population structure, composition, education, income levels were obtained from national census archives. This information was useful in the calculation of social vulnerability and adaptive capacity.

3.2.6.5 Data analysis and presentation of survey results

The total number of questionnaires collected from the field was 825. The data from all the questionnaires were captured into Microsoft Excel. Subsequently, the data were coded, and variables labeled properly. Various data analyses including descriptive statistics such as summary tables, factor analysis, and comparative analysis were done and represented in tabular and graphical forms.

3.2.7 Crop simulation calibration

The AquaCrop model was used in simulating the effects of projected climate on the production of sunflower, soybean, and groundnuts.

3.2.7.1 Model inputs

The AquaCrop model has been extensively described in Raes et al., (2008) and Steduto (2009). Model inputs are described in detail below:

Climate datasets: Climate data needed as inputs for both models need to be in a daily time step. Minimum climate data required are rainfall, minimum temperature, maximum temperature, and solar radiation. These data sets for Syferkuil, Ofcolaco, Punda Maria and Phalaborwa were obtained from the CSAG group Cape Town for future climate projections. Historical data was obtained from the Agricultural Research Council. Solar radiation for the projected climate was obtained as described in 3.2.5.1 above.

Soil data/analyses: The soil at each experimental site was analyzed as per parameters for AquaCrop. Results from soil samples (3.2.3.1) like Nitrogen, organic carbon, available phosphorus, Cation exchange capacity, electric conductivity, soil pH, soil texture and soil moisture at field capacity are some of the soil inputs used for the soil module.

Crop parameters: Minimum crop parameters with regards to phenology and growth rates were collected from all experimental sites. Data collected included planting date, emergence, flowering, maturity, and harvesting dates. Calibrated parameters included thermal time from emergence to the end of juvenile stages, from the juvenile stage to floral initiation, from flag leaf stage to flowering, from flowering to physiological maturity, and from flowering to the start of effective grain filling. Potential kernel number per ear, grain growth rate, canopy height, and stem weights were collated, as required in AquaCrop sunflower, soybean and groundnut initialization files.

Management practices and model initial conditions: The response of sole cropping of sunflower, soybean, and groundnut to different levels of fertilizer and water (or rainfall) supply, under minimum tillage practices, were simulated using the treatment data from field experiments conducted at Syferkuil and Ofcolaco for the season 2016/2017 and 2017/2018 and at Phalaborwa and Punda Maria 2017/2018. Detailed specifications of the initial conditions of the model, including sowing characteristics, plant population, type and rate of fertilizer used in the studies are presented below. Table 3.2 shows the fertilizer rate and planting management for crops.

Table 3.2: Fertilizer application rate for field experiment.

Location Date			**Crop**	**Fertilizer application**
	Inter	Intra	Plant Density/Ha	Cultivar
Spacing: Soybean	75cm	10	35000	Don Mario
Sunflower	90cm	30	35000	AGSUN 8251
Groundnut	30cm	60	150000	kwarts
Syferkuil 2016/2017			Sunflower	0 Nkg/ha 75 Nkg/ha 150 Nkg/ha
Syferkuil 2016/2017			Soybean	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Syferkuil 2016/2017			Groundnut	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Syferkuil 2017/2018			Sunflower	0 Nkg/ha 75 Nkg/ha 150 Nkg/ha
Syferkuil 2017/2018			Soybean	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Syferkuil 2017/2018			Groundnut	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Ofcolaco 2016/2017			Sunflower	0 Nkg/ha 75 Nkg/ha 150 Nkg/ha
Ofcolaco 2016/2017			Soybean	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Ofcolaco 2016/2017			Groundnut	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Ofcolaco 2017/2018			Sunflower	0 Nkg/ha 75 Nkg/ha 150 Nkg/ha
Ofcolaco 2017/2018			Soybean	0Pkg/ha 30 Pkg/ha

		60 Pkg/ha
Ofcolaco 2017/2018	Groundnut	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Punda Maria 2017/2018	Sunflower	0 Nkg/ha 75 Nkg/ha 150 Nkg/ha
Punda Maria 2017/2018	Soybean	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Punda Maria 2017/2018	Groundnut	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Phalaborwa 2017/2018	Sunflower	0 Nkg/ha 75 Nkg/ha 150 Nkg/ha
Phalaborwa 2017/2018	Soybean	0Pkg/ha 30 Pkg/ha 60 Pkg/ha
Phalaborwa 2017/2018	Groundnut	0Pkg/ha 30 Pkg/ha 60 Pkg/ha

3.2.7.2 Parameterization of data set in AquaCrop

The parameterization of the sunflower, soybean and groundnut cultivars in AquaCrop was done following two approaches:

Firstly, the existing cultivars in AquaCrop-soybean, AquaCrop sunflower and dry bean (adapted for groundnut cultivar) were calibrated using 2016/17 cropping season input datasets, that is, climate records, soil data, and management practices, at the Syferkuil and Ofcolaco experimental sites. Comparisons were made between the simulated and observed soybean, sunflower and groundnut cultivars, based on four parameters viz days-to-emergence, days-to-flowering, days to maturity/harvesting and grain yields.

Secondly, the minimum dataset from the field experiment conducted in the 2016/17 season was used to calibrate the coefficients of the identified simulated cultivar which best represents the observed cultivar in AquaCrop.

Soil-water holding capacity properties of the Syferkuil Research Farm, and the values used in specifying the AquaCrop model simulation at initialization of cropping season are shown in Table 3.3.

Table 3.3: Syferkuil parameter for crop model.

Layer number	**1**	**2**	**3**	**4**	**5**
Soil layer depth (cm)	15	15	15	15	15
Water content at air dry (mm/mm) a	0.035	0.096	0.133	0.141	0.149
Crop lower limit (mm/mm)	0.069	0.137	0.141	0.157	0.149
Drained upper limit (mm/mm) *	0.268	0.268	0.319	0.286	0.286
Saturated water content (mm/mm)	0.408	0.408	0.413	0.401	0.393
SWCON	0.500	0.500	0.500	0.500	0.500
Bulk density (g/ cm3) *	1.57	1.57	1.51	1.51	1.51
Soil texture	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam	Sandy clay loam
Organic carbon (%) *	0.501	0.501	0.390	0.395	0.228
pH*	7.73	7.73	8.32	8.32	8.32

*Data obtained from study by Whitbread and Ayisi (2004) at the same location

Table 3.4: Punda Maria parameters for crop model.

Layer number	1	2
Soil layer depth (cm)	300	900
Water content at air dry (mm/mm) *	0.058	0.078
Crop lower limit (mm/mm)	0.117	0.087
Drained upper limit (mm/mm) *	0.239	0.188
Saturated water content (mm/mm) *	0.406	0.469
SWCON	0.500	0.500
Bulk density (g/ cm3)	1.48	1.30
Soil texture	Loam	Loam
Organic carbon (%)	0.902	0.902
pH*	6.42	6.42

Table 3.5: Ofcolaco parameters for crop model.

	0-15 cm	15-30 cm	30-60 cm	60-90 cm
pH (KCl)	5.9	5.2	5.4	4.9
P	24.2	7.1	8.5	4.1
K	231.6	165.9	142.8	78.6
Ca	752.1	652.8	723.8	562.5
Mg	298.8	291.2	346.4	154.4
Zn	3.7	3.1	1.5	0.4
Mn	10.1	11.2	8.1	4.9
Cu	4.2	3.6	3.8	3.9
	0.04	0.04	0.04	0.04
Total N (%)				
Organic carbon (%)	1	0.6	0.8	0.8
Physical properties				
Clay (%)	24	29	29	31
Silt (%)	9	10	11	11
Sand (%)	67	61	60	58

3.2.7.3 AquaCrop Validation:

AquaCrop model has been widely used and validated for various crop and soils (e.g. Akumaga et al., 2017; Mabhaudhi et al., 2014; Vanuytrecht et al., 2014; Abedinpour, et al., 2012; Stricevic, et al., 2011). Such studies wherein the AquaCrop model was validated for the biophysical conditions of the region gives confidence in the model's ability to capture the agroclimatic processes. Following the AquaCrop model calibration to simulate field tested climate-management practices, the model was validated to determine the confidence level in the calibrated model to simulate the experimental field conditions and treatments using the data from the 2017/2018 season across the experimental sites.

3.2.7.4 Measures of model performance

The predictive capacity of the models was tested by calculating the root mean square error (RMSE), relative root mean square error (RRMSE), and coefficient of determination (R^2), between the observed and predicted values of sunflower, soybean, and groundnut for grain yields. The model evaluation analysis was conducted using both graphical and statistical methods. The statistical analysis used followed methods described by Willmott et al. (2009) and Willmott et al. (2011).

The RMSE was used to test the goodness of fit between observed and simulated data and is a good overall measure of model performance (Willmott et al., 2009). It provides information about the actual size of errors produced by the model. It is calculated as:

$$\text{RMSE}= \left[\frac{1}{IJ}\sum_{j=1}^{j}\sum_{i=1}^{1}\left(P_j^i - O_j^i\right) 2\right]^{.05} \qquad (3.4)$$

Where: n = number of observations;

P_j^i = individual predicted quantity at site i and time j;

O_j^i = observed values of the study variables at site i and time j;

$\sum_j^j = \text{the}$ summations over all sites (I) and over time periods (J).

According Jamieson et al., (1991) a simulation is considered excellent when the normalized RMSE is less than 10%, good if the normalized RMSE is greater than 10% and less than 20%, fair if normalized RMSE is greater than 20 and less than 30%, and poor if the normalized RMSE is greater than 30%

R^2 is used to interpret the portion of the variation of the predict and (proportional to SST) that is "described" or "accounted for" by the regression (SSR) (Wilks, 1995; Mendenhall & Sincich, 2003). For a perfect regression, SSR = SST and SSE = 0, so that R^2 = 1. R^2 is calculated by:

$$R^2 = \frac{\mathrm{SSR}}{\mathrm{SST}} = 1 - \frac{\mathrm{SSE}}{\mathrm{SST}} \qquad (3.5)$$

Where:

SSR is the regression sum of squares

SST is the total sum of squared deviations of the predicted values around their mean,

SSE is the sum of squared differences between the residuals/errors and their means (Wilks, 1995).

Overall, the model evaluation exercise showed that APSIM is able to reproduce the overall effects of management on groundnut productivity and different sites and seasons in a reasonable range. This, in conjunction with other literature confirming the capability of this model to successfully simulate cropping systems in southern Africa (Baudron et al., 2015; Rurinda et al., 2015; Whitbread et al., 2010) might serve as basis to use the model in simulation experiment whereby: O_i and P_i are the paired observed and predicted data and n is the number of observations.

3.2.8 Long term simulations

The validated AquaCrop model was used to simulate the following scenarios using projected climate data. The simulated scenarios included a factorial combination of the following:

- 3 levels of fertilizer for each crop (sunflower, soybean, and groundnut)'
- 2 crop arrangements (additive and replacement);
- 3 cropping systems (intercropping, sole cropping, crop rotation); and

3.2.8.1 Simulation of sunflower, soybean and groundnut yield using AquaCrop

Conservative parameters such as normalized water productivity coefficient (WP), harvest index reference value (HI_0), canopy decline coefficient (CDC) and, crop transpiration (Tr) (calculated by multiplying the evaporating power of the atmosphere with the crop coefficient (KcTr) and by considering water stresses (Ks) and temperature stress (KsTr)) were used as they are. The model, instead of using the leaf area index (LAI) as the basis to calculate transpiration and to separate soil evaporation from transpiration, it uses canopy ground cover. Hence biomass is calculated as the product of transpiration and a water productivity parameter as denoted by equation 3.6:

$$\mathbf{B = WP \times \sum Tr} \tag{3.6}$$

Where:

B = aboveground biomass (ton/ha);

WP = water productivity (biomass per unit of cumulative transpiration), and

Tr = crop transpiration in mm

Crop yield is calculated as the product of above-ground dry biomass and harvest index (HI) as shown in 3.7:

$$\mathbf{Y = B \times HI} \tag{3.7}$$

Where:

Y = crop yield,

HI = harvest index.

For crop yield estimates for future years, CO_2 files from Representative Concentration Pathways (RCPs) ‘RCP8-5.CO2’ available in the database of AquaCrop were used.

3.2.8.2 Analyzing long term simulation

For each growing season rainfall scenario and climate projection, the simulated sunflower, soybean, and groundnut yield under different management decisions were subjected to analysis using the stepwise linear regression method.

3.2.9 Geographic Information systems methodology and analysis

GIS was used to integrate biophysical and socioeconomic data into a spatial data framework for further analysis:

3.2.9.1 Data types needed for GIS analysis

Required data sets for GIS analysis included the following:

- Soil sample data
- Climatic data (Rainfall and Temperature)
- Socioeconomic data
- Crop growth requirements for sunflower, soybean, and groundnut
- DEM
- GAEZ

Data for the indicating variables were obtained in various formats such as NetCDF, raster dataset as well as attribute data from statistical databases and for various spatial resolutions from various institutions (e.g. CSAG, NCAR). The highest possible spatial resolution was the point scale. The data for all indicating variables were thus processed at variable levels depending on the availability of data.

Some of the climate change scenario data were obtained in NetDCF format, which can be opened in ArcGIS using a tool to create a feature or raster layer. However, due to the inherent constraints of the NetCDF data, the procedure was limited to the creation of feature point layers only. The point layers were further interpolated using nearest neighbour interpolation, which in turn was used to characterize vulnerability indices for various biophysical parameters thereby creating vulnerability composites.

3.2.9.2 Spatial analysis and mapping

Cartographic representations provided the geographic contexts in which to recognize spatial patterns and relationships as well as the relative vulnerability scores agro-climatic zones. Various spatial operations such as vector to raster conversion, reclassification, and weighted overlay were performed at this stage using the ArcMap 10.3 software and its geoprocessing tools in the Arc Toolbox. A "Weighted Overlay Operation" was adopted using GIS techniques for identification of areas of the various crop suitability/vulnerability depending on several thematic layers and based on the principle of Multi-Criteria evaluation. The vulnerability composite indices from the different methods were presented in various maps. Again, given that cartographic representations facilitate the recognition of spatial patterns and relationships, it was possible, from these visuals, to analyze the various vulnerability distributions provided by the different composite index methods.

In this study, to assess the vulnerability of crops to a changing climate, two management levels were taken into consideration and defined as:

Low-level inputs/traditional management: Under the low input/traditional management, the assumption here is that the farming system is largely subsistence based and not necessarily market-oriented. This level was used in analyzing the production of groundnut in South Africa and their response to future climate change. Under this regime, production is based on the use of traditional cultivars (if improved cultivars are used, they are treated in the same way as local cultivars), labour-intensive techniques, and minimal to no application of nutrients, no use of chemicals for pest and disease control and minimum conservation measures.

Intermediate-level inputs/improved management: In the case of the intermediate regime, the assumption is that there is an improvement in input and management. The farming system is partly market-oriented. Management objectives here are production for subsistence as well as commercial sale. Production is based on improved varieties, on manual labor with hand tools and/or animal traction and some mechanization. It is medium labor intensive, uses some fertilizer application and chemical for pest, disease and weed control, adequate fallows and some conservation measures. Suitability is indicated as very high when the calculated suitability index ranks >85, high when the index is >70; good at >50; medium at >40; moderate at >25; marginal at >10; very marginal at >0 and not suitable at when the index equals zero.

3.2.9.3 Map reclassification

The various raster maps (3.3.1) were reclassified spatial using the analyst tools in Arc Toolbox. A scale of 1 to 5 was adopted to indicate the level of vulnerability. Value 5 represented extremely vulnerable while value 1 represented not vulnerable. The scaling of the criteria was done in line with the level of contribution of the factors to the growth of sunflower, soybean, and groundnut from literature.

3.2.9.4 Crop requirements for weighting

Parameters for sunflower, soybean and groundnut cultivation in South Africa have been well documented in various production guidelines from the Agricultural Research Council South Africa and Department of Agriculture (e.g. DAFF, 2010). The climatic and soil requirements of the three crops are presented in Table 3.6.

Table 3.6: Environmental requirements for the cultivation of sunflower, soybean, and groundnut.
Source: DAFF (2010).

Crops	Rank	Classes	Soil Ph	Rainfall(mm)	Temperature (^{O}c)	SlopeDegree (^{0})	Clay (%)	Texture	Water holding Capacity (mm)
Sunflower	5	Highly Vulnerable	> 7.5	< 200; > 1100	> 30	<1.0	> 65	> 3	< 20
	4	Moderately Vulnerable	7-7.5	200 - 300	24 - 30	1 - 2	50 - 60	2.5-3	20-40
	3	Vulnerable	4.5 - 5.5	300 - 400	22- 24	2 - 3	40 - 50	2.2-2.5	40-60
	2	Marginally	5.5 - 6	400 - 500	16 - 21	3- 4	30 - 40	2-2.2	60-80
	1	Less Vulnerable	6 - 7.5	500 - 1000	14 -16	> 4	40	1-2	80
Soybean	5	Highly Vulnerable	> 6.5	< 200; > 1100	> 40	<1.0	> 60	> 2.5	< 40
	4	Moderately Vulnerable	1- 4	200 - 300	38 - 40	1 - 2	50 - 60	2 -2.5	40-60
	3	Vulnerable	4 - 4.5	300 - 400	34 - 38	2 - 3	40 - 50	1.5 -2	60-80
	2	Marginally	4.5 - 5	400 - 500	30 - 34	3- 4	30 - 40		80-100
	1	Less Vulnerable	5 - 6.5	500 - 900	5 - 30	> 4	< 20	1- 1.2	100
Groundnut	5	Highly Vulnerable	> 8	< 100 ; > 1100	>18; > 40	<1.0	> 60	> 2.5	< 40
	4	Moderately Ulnerable	6.7- 7	100 - 300	38 - 40	1 - 2	50 - 60	2 -2.5	40-60
	3	Vulnerable	5 - 6.5	300 - 400	34 - 38	2 - 3	40 - 50	1.5 -2	60-80
	2	Marginally	4.5 - 5	400 - 500	30 - 34	3- 4	30 - 40		80-100
	1	Less Vulnerable	3.5- 4.5	500 - 900	18 - 30	> 4	< 20	1- 1.2	100

3.2.9.5 Crop suitability mapping

Crop suitability maps were created from composite maps in ArcMap 10.3 using the weighted overlay geoprocessing. Weights were assigned to each of the parameters (Table 3.6) using five classes. The various layers were classified from highly vulnerable to less vulnerable. Vulnerability maps were created for sunflower, soybean, and groundnut.

3.2.10 Methodology for calculating exposure/ risk

Exposure and risk are calculated following methods in Mysaik et al (2018). Following the proposed method, climate indices are computed at the grid-scale and point scale for the implicit spatial and chosen temporal domains by using the simulated daily meteorological variables: (i) maximum near-surface air temperature (TX), (ii) minimum near-surface air temperature (TN) and (iii) near-surface precipitation (PR). These are considered as proxies of the relevant hazards associated with climate extremes such as drought, heat and cold waves, floods, flash floods, landslides, soil erosion and water scarcity (Mysaik et al.,2018). Furthermore, these indices of exposure /risk are calculated at point scale using CLimPAct2, indices of drought, unusual high rains and heat waves are calculated.

3.2.11 Methodology for calculating crop sensitivity

To determine the sensitivity of crop harvest to rainfall perturbations, a crop yield sensitivity index was calculated using methods adapted from Simelton et al. (2009;2012). Yield data for sunflower, soybean, and groundnut for all summer rainfall areas in South Africa were obtained for the period 1992-2018. Yields were detrended to reduce the influence of increased agricultural technology in order to highlight inter-annual yield variation as a result of rainfall (Easterling et al., 1996). To determine the crop yield sensitivity index, a linear trend for each yield for each region between 1992 and 2018 was calculated. The equation for this trend line was used to calculate the expected yield in each year as a linear model of the time series of the actual yield. The expected yield was divided by the actual yield for each year to generate a crop yield sensitivity index as seen in equation 3.9 below.

$$\text{Crop yield sensitivity index} = \frac{\text{Expected Yield}}{\text{Actual Yield}} \qquad (3.9)$$

3.2.12 Methodology for calculating adaptive capacity

Proxy indicators of adaptive capacity such as human capital (represented by literacy rates (%)) and financial capital (represented by poverty rates) are considered to be appropriate by a wide range of literature (e.g. Brooks et al., 2005; Gbetibouo et al., 2010). Following these methods, adaptive capacity is calculated by weighting all socioeconomic variable.

$$\text{Adaptive Capacity} = [(\text{Literacy Rate}/100)] + [(100\text{-Poverty Rate})/100)] \qquad (3.10)$$

3.2.13 Methodology for calculating vulnerability

Vulnerability is calculated in two phases following methods in Simelton et al (2009, 2012). Firstly, crop vulnerability is calculated using the formula:

$$\text{Crop drought vulnerability index} = \frac{\text{crop yield sensitivity index}}{\text{exposure index}} \qquad (3.10)$$

The overall mean vulnerability of the region was estimated using equation 3.11

Vulnerability = [(crop yield sensitivity index + exposure index) – adaptive capacity] (3.11).

3.2.14 Methodology for decision support systems

Following the procedures highlighted by the World Bank (2014) where the screening process for adaptation measures or options is considered as a practical decision-making framework essential for the development of the national climate change action plan (World Bank, 2014), scenarios for decision support systems for optimum production will be guided by the following :

- Efficiency: the optimal outputs achieved relative to the resources allocated?
- Effectiveness: will the option meet the objectives?
- Equity: will the option benefit vulnerable groups and communities?
- Urgency: how soon does the option need to be implemented?
- Flexibility: is the option flexible, does it allow for adjustments and incremental implementation and reiteration depending on the level and degree of CC?
- Robustness: is the option robust under a range of future climate projections?
- Practicality: can the option be implemented on relevant timescales?
- Legitimacy: is the option politically, culturally and socially acceptable?
- Synergy/Coherence with other strategic objectives: does the option offer co-benefits

Figure 3.17 shows an illustration of the screening structure with “no regret” or “win-win option being one that delivers benefits. The process will guide the development of a decision support system for production under a changing climate for soybean, sunflower and groundnut

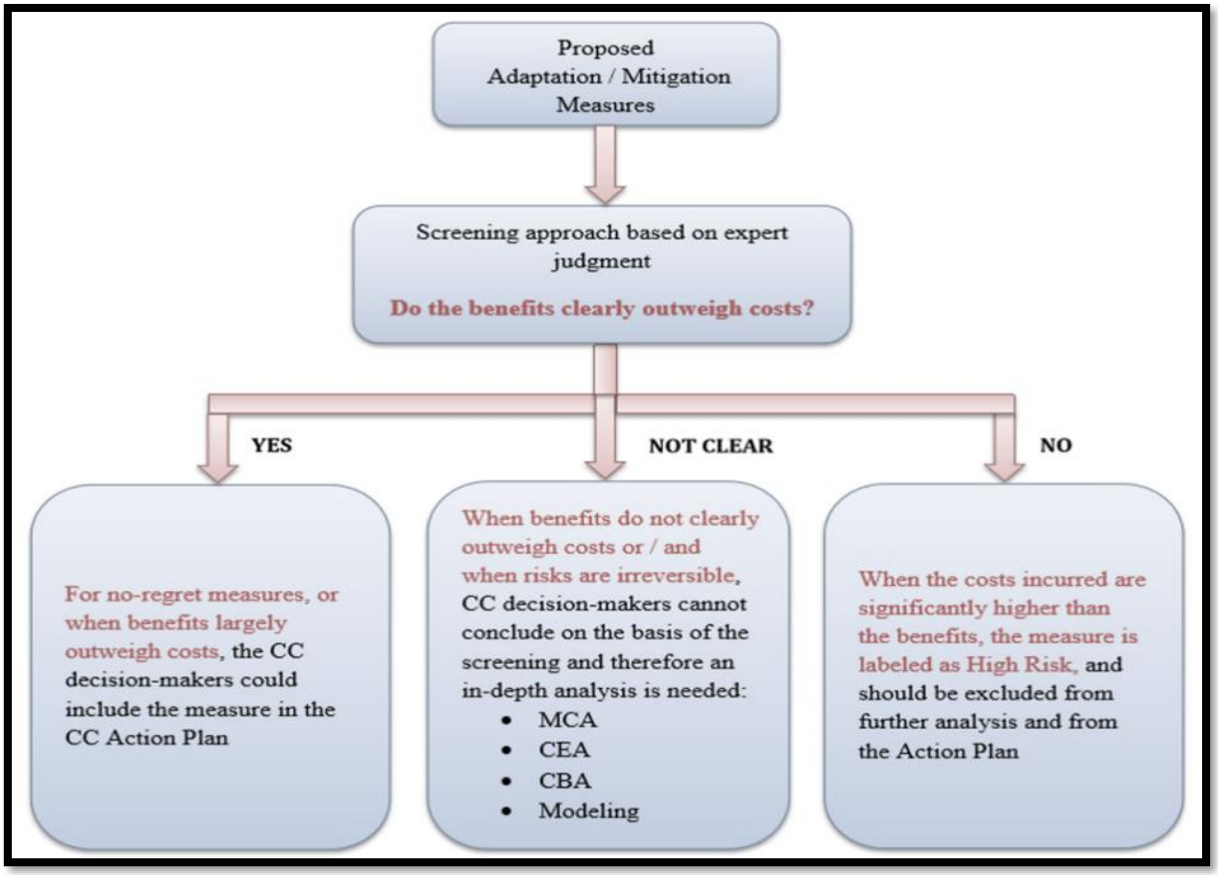

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Figure 3.17: The screening approach for adaptation and mitigation (World Bank, 2014).

3.3 Limitations

The limitations of the analysis involved, for example, data limitation on historical yield data for crop models; socioeconomic data being available only on the county level; and the poor historical data availability for socioeconomic variables, rainfall, and farm management practices.

3.4 Summary

The research design of this thesis cuts across several disciplines and it is problem oriented. In problem-oriented research, it is the societal problems that determine the research, which in the long run provides knowledge for stakeholders and decision-makers (Kueffer et al., 2012). The underlying problems of this thesis are the risk and vulnerability of dryland agriculture to a changing climate, and adaptation thereof. However, the specific problem tackled is the need to understand how vulnerable the dryland agriculture is, how this vulnerability is felt, and how it can be represented by means of assessments to explain the characteristics and processes of the phenomenon which can be fed into adaptation options, thereby helping to reduce vulnerability. It has commonly been emphasized that research into complex socio-ecological problems require interdisciplinary approaches (e.g. Petts et al., 2008). The aim of using a mixed methods research here was to gain more knowledge on the several dimensions of risk and vulnerability in South Africa. The results of both qualitative and quantitative analyses achieved here are considered very relevant and important for a thorough assessment of risk and vulnerability, which would probably not have been this comprehensive if a “traditional’ approach were applied. This will be because of the challenges posed by the integration of both social and biophysical dimensions in climate vulnerability. This process of triangulation from the initial review of relevant literature, to field experiment, survey, to crop simulation and modelling, participatory approach, GIS and statistical analyses show the inherent opportunities and challenges involved in analyzing risk and vulnerability from different analytical perspectives.

Chapter Four

Results

4.1 Introduction

This chapter presents the results from the various data collection methods discussed in the previous chapter. The first results presented are for the agronomic and socioeconomic survey carried out across the agro-ecological zones (AEZ) of Limpopo (humid, semi-arid and arid zones).

The second results presented are for the agronomic and socioeconomic survey carried out across the agro-ecological zones of and Free State. The total numbers of respondents were 600 in Limpopo and 200 in the Free State Province (spread across the various agroecological zones). Given the data collection (see chapter 3) all survey questions were answered by the respondents giving it a hundred percent response rate. Results from the questionnaire provided information on the demographical characteristics, agronomic practices, factors influencing crop production, constraints on agronomic practices and crop production caused by climate change and variability, coping and adaptation strategies to climate variability and change and income generated from farming activities in the various agroecological regions. These will throw an insight into the vulnerability of the farmers in terms of socioeconomic and agronomic dynamics. Where results across are similar, they are represented as a province in order to indicate uniformity. Where there are differences they are presented as per AEZ.

The third results are in relation to the suitability of crop production in relation to the physical characteristics developed in Chapter 3. The aim here is to show which areas are suitable to selected crop cultivation in relation to parameters which are important for the selected crop growth and development.

The fourth section of the results deals with projected climates of the selected sites in each agroecological region of Limpopo. Reason for climate analysis done only for Limpopo was because this was more convenient for the experiments that were carried out.

The fifth result section presents the results of the field experiments carried out in the Limpopo Province.

The sixth results are for the crop simulation models done for selected crops under projected climate change scenarios for various climate change models under RCP 8.5 scenario.

4.2 Agronomic practices and socioeconomic survey of farmers and potential impacts on agricultural production in the Limpopo Province and the Free State Provinces

4.2.1 Limpopo Province

4.2.1.1 Farmers Background information In Limpopo Province

A general background to farmers demographic is presented in Table 4.1 below with the aim of identifying gender and the age group of respondents involved in farming activities. This will throw light on the ability to maximize their resources as shown below.

Table 4.1: Demographic characteristics of farmers in Limpopo.

Age Group	Male	Female	Grand Total	% per age group
18-36	21	21	42	7
37-46	19	27	46	8*
47-56	37	85	122	20*
57-66	63	106	169	28
67-76	57	74	131	22*
77-86	29	25	54	9
87-96	15	21	36	6.
Grand Total	241	359	600	100

*Figures rounded up

It was observed that the most active age group in farming were elderly respondents between the ages of 57- 66 (28.17%), followed by the ages 67-76 (21.83%) and only 7.67% of the age group 37-46 years.

4.2.1.2 Farm sizes In Limpopo province

Farm sizes in the Limpopo are shown in Table 4.2. Most of the farmers had an average farm size of 1.77(ha). These ties in with similar findings by Jaeger (2010) who highlighted that subsistence farmers had access to an average of 2 ha or less of land for their agricultural production. This might be because they do not have the financial resources to get more land; are not financially viable to get access to loans. The bigger pieces of land were own by smallholder farmers.

Table 4.2: Sampled Farm Sizes in Limpopo Province.

Farm size(ha)	Count of farmers	% of farmers
1 - 2	233	39*
3 - 5	184	31*
6 - 9	88	15*
10 - 29	60	10
30 - 59	25	4*
≥60	10	2*
	600	100

*Figures rounded up

4.2.1.3 Water management techniques during the production of sunflower, soybean, and groundnut in Limpopo

All the farmers apply one water management technique or the other (Table 4.3). It is worth noting here that the farmers themselves were not aware of the implications of their practices in relation to water management. For example, they do not know that deep weeding was water conservation techniques where only the crops were allowed to use available water resources instead of competing with weeds.

Table 4.3: Water harvesting technique employed in Limpopo and the Free State Provinces.

	Limpopo
Water harvesting technique	% of Water harvesting technique employed
Cover crops	25.61
Contour ploughing	0.13
Ridging	12.04
Deep weeding	49.94
Pot holding	0.38
Mulching	9.22
Furrow Drainage	2.69
If other Specify	0
Grand total	100

The most water management technique employed is deep weeding (49.94%), followed by cover crops (25.61%).

4.2.1.4 Production System and Agronomic Practices in Limpopo

The climatic conditions and various socio-economic factors prevalent in these communities shape the agronomic decisions and agronomic practices carried out by farmers as shown by the following results.

4.2.1.5 Farming experience in Limpopo

With regards to years of farming experience, Table 4.4 shows that most of the farmers (10.83% in Limpopo) had 37- 47years of farming experience. This is followed by 10.67% with 1-6 years and 10.17% with 7-11 years of farming experience. Most of the farmers (53.1%) had 27 years and above of farming experience.

Table 4.4: Farming Experience of farmers in Limpopo and Free State Provinces.

Years of farming	Count of farmers Limpopo	% Limpopo
1-6	64	10.67
7-11	61	10.17
12-16	55	9.17
17-21	57	9.50
22-26	44	7.33
27-31	59	9.83
32-36	49	8.17
37-41	65	10.83
42-46	36	6.00
47-51	30	5.00
52-56	26	4.33
57-61	22	3.67
62-66	16	2.67
67-71	16	2.67
Grand Total	600	100

Given that a significant number of the farmers were within the age groups nearing retirement (if they were involved in another profession) or retired, it can be assumed that farming was a coping strategy for most of the people with low income. This can also explain why Table 4.3 shows that 11% of the farmers with farming experience of 1-6 years and yet the age group of most of the farmers is above 60 years. This could be an indication that they just entered the farming sector after their retirement from secular jobs. Agriculture hence serves as a buffering system for the retired people.

4.2.1.6 Percentage of farmers cultivating selected crops in Limpopo

An analysis was made of the food crops cultivated inclusive of groundnuts, soybean, and sunflower as shown by Figure 4.1. In Limpopo out of the farmers surveyed, 284 (47%) cultivated groundnuts; 70(12%) cultivated groundnut and soybean; 86 (14%) cultivated groundnut and sunflower; 100(17%) cultivated sunflower and 60 (10%) cultivated soybean. None of the farmers cultivated all three crops. In order of predominance, the other crops cultivated by the farmers include maize, cowpea, sorghum, vegetables inclusive of indigenous vegetables.

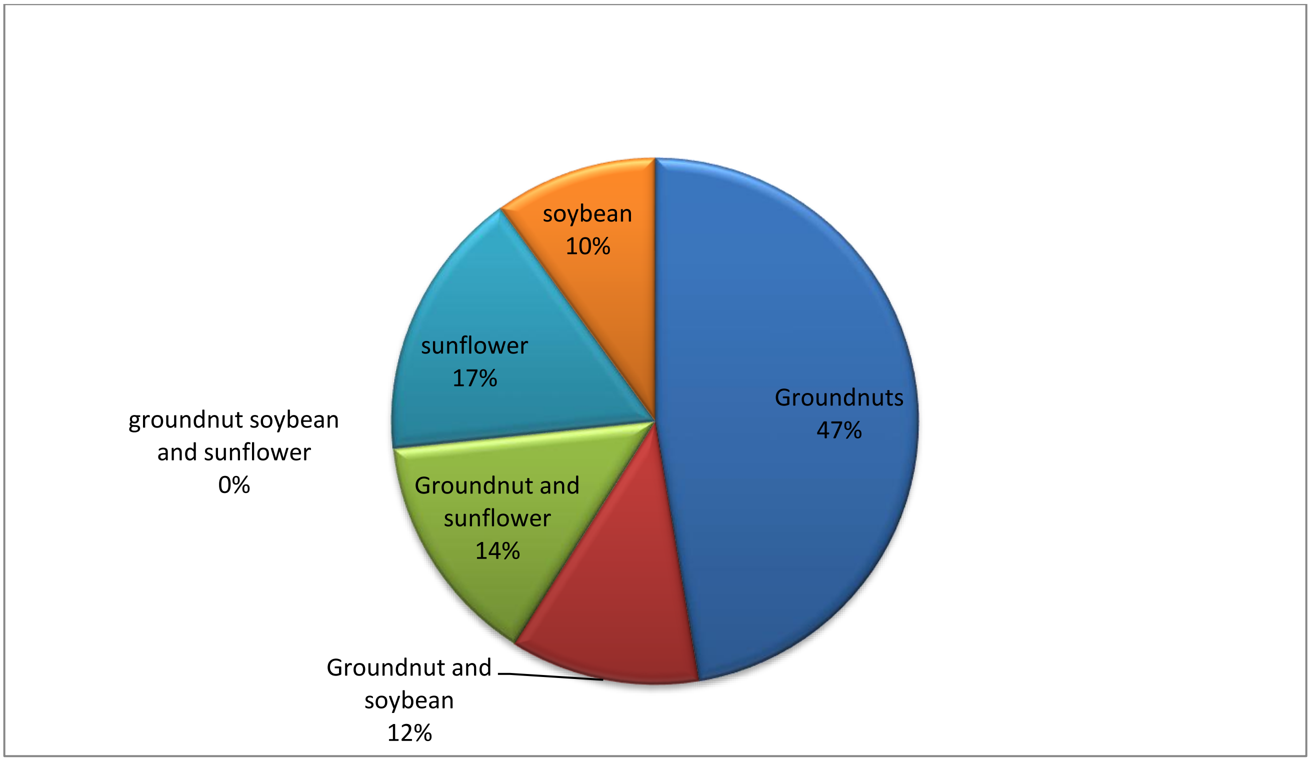


Figure 4.1: Percentage of surveyed farmers cultivating groundnut, soybean, and sunflower in Limpopo Province.

4.2.1.7 Crop agronomic practices in the Limpopo

The tillage practices carried out by the farmers are shown in Table 4.5 below. Results from the table show that the predominant practice in the area is hand digging of the entire field practiced by 26.67% of the farmers interviewed. This is followed by 23.33% of farmers carrying out ridge tillage. It is worth noting that some form of conservation agricultural practices is being employed by the farmers such as no-tillage (3.33%) and mulch tillage

(17%). Looking at the farmers involved in no-tillage, a few of them were conversant with conservation practices, while others just did it because they saw their neighbor doing it.

Table 4.5: Tillage Practices in the three AEZ of Limpopo.

Tillage practice	Total Number of farmers in the Humid	Total Number of farmers in the Semi-Arid	Total Number of farmers in the Arid	Total Count	%
No-tillage	10	4	6	20	3.33
Mulch tillage:	32	30	40	102	17
Strip or zonal tillage:	45	46	41	132	22.
Ridge till (conventional tillage)	40	47	47	134	22.33
Reduced or minimum tillage:	14	18	10	42	7
Hand digging of the entire field	54	53	53	160	26.67
Planting basins	5	2	3	10	1.67
If other specify	0	0	0	0	0
Grand Total	200	200	200	600	100

4.2.1.8 Crop variety, planting densities and planting dates in the Limpopo

Table 4.6 shows that 68.6 % of the farmers growing groundnut, 90% soybean and 75% sunflower could not remember the names of the cultivar they had planted.

Table 4.6: Cultivar choice of Farmers in Limpopo.

Groundnut variety	**% Groundnuts**	**Soybean Variety**	**% Soybean**	**Sunflower Variety**	**% Sunflower**
Akwa (254)	11.6	Don Mario	10	Agsun	25
Anel (254)	16.24				
Nyanda (1173)	.50				
Kangwane Red (254)	1.0				
Rambo (254)	1.52				
Unknown	68.5	Unknown	90		75
Grand Total	100		100		100

4.2.1.9 Planting density and dates for sunflower, soybean, and groundnut in Limpopo

With regards to planting density and row spacing, 90% of the farmers in Limpopo used random planting for groundnuts, 40% for soybeans and 30% for sunflower.

Table 4.7 shows that 65.25% of the farmers who planted groundnuts planted within the planting window as stipulated by the groundnut production guidelines of the Department of Agriculture (2010). The rest planted outside of the window. These decisions would probably have been influenced by the climate. On the other hand, 66% of the farmers planted within the specified planting dates given by DAFF (2010) as production guideline for soybean production and 59.27% planted sunflower within the specified planting window.

Table 4.7: Crop planting dates in Limpopo for 2016/2017 planting season.

Planting date	% groundnut	% soybeans	% sunflower
September	5	0	
October	10	19	20
November	55	56	50
December	10	11	9
other	20	15	21
Grand Total	100	100	100

4.2.1.9.1 Fertilizer application, timing, and rates of application for sunflower, soybean, and groundnut in Limpopo

The basis for fertilizer application before planting results from the potential benefit of residual fertilization from the previous season's crops. This is not based on production guidelines for either of the crops shown below in Table 4.8. It was found that of all the crops, 79% of the farmers applied some form fertilizer before planting, 16% during planting and the rest didn't use any form of fertilizer whatsoever in Limpopo.

Table 4.8: Time frames for fertilizer application in Limpopo during 2016/2017 season.

Application	**Groundnut (% of farmers)**	**Soybean (% of farmers)**	**sunflower (% of farmers)**
Before planting	79	22	25
During planting	16	73	70
Days after planting	0	0	0
During flowering	0	0	0
Do not apply	5.5	5	5
Grand Total	100	100	100

With regards to groundnut, most farmers in Limpopo did not apply chemical fertilizers to this crop. Instead the crop benefits from the application of fertilizers to other crops such as maize. That notwithstanding the farmers were aware they needed to increase the fertility of their land by employing a cheaper and more available source of fertilizer to their land as seen in Table 4.7. Table 4.9showed that most farmers used organic sources of fertilization rather than the mineral fertilizers.

Table 4.9: Fertilizer application and the rate of application In Limpopo.

Fertilizer	**% applied to Groundnut**	**% applied to Soybeans**	**% applied to Sunflower**	**Average Rate of Application (kg/ha) Groundnut**	**Average Rate of application (kg/ha) Soybean**	**The average rate of application in kg(ha) sunflower**
Chemical fertilizer	5	10	10	5	12	15
Kraal manure	35.75	45.5	45.5	240	240	240
Leaf litter	3.5			50	50	50
Crop residue	50	50	50	600	500	500
Crop residue /kraal manure	10.75	4.5	4.5	260	260	260
Grand Total	100	100	100			

As shown in Table 4.9, the most preferred means of fertilizer was crop residue which is applied to the field following the season harvest. The rate of application was estimated at 600kg/ha for groundnut, 500kg/ha for soybean and 500kg/ha for sunflower. This was closely followed by the kraal manure with a rate of application estimated at 240kg/ha for groundnut, soybean, and sunflower.

4.2.1.10 Herbicides, pesticides, fungicide use in the production of sunflower, soybean, and groundnut in Limpopo

Forty percent of the farmers used a combo of herbicides and pesticides on their farms in Limpopo. None of the farmers applied any form of fungicide on their farms.

4.2.1.11 Weed control during the production of sunflower, soybean, and groundnut in Limpopo

All the farmers practised weed control on their farms. As to the degree of effectiveness of weed control, the results show that 31% of the farmers in Limpopo had very effective weeding results while 66.75% say their methods are somewhat effective and 2.25% not effective at all (Table 4.10).

Table 4.10: Effectiveness of weed control management in Limpopo.

Degree of Effectiveness	**Humid**	**Semi-arid**	**Arid**	**% of farmers**
Very effective	11	10	10	31
Somewhat effective	22	22.25	22.50	66.75
Not effective at all	1	.65	.6	2.25
Grand Total				**100**

Table 4.11 focused on the frequency of weeding by the farmers. The results show that most of the farmers weeded their farms once, followed by twice and very few weeded thrice for all three crops.

Table 4.11: Number of times crops were weeded in the 2016/2017 season-Limpopo.

Number of times	**% Groundnut**	**% Soybean**	**% sunflower**
Once	84.5	84.5	75
Twice	8.5	11.1	23.57
Thrice	7	4.4	1.43
Grand Total	**100**	**100**	**100**

With respect to the method of weeding, most of the farmers in Limpopo said they used the hand hoe for weeding. This response ties in with the results in Table 4.10 and 4.11 where weed control was found to be somewhat effective, and most of the farmers weed once. Using the hand hoe for weed control is cumbersome and extremely tiresome and given the age distribution of these farmers (Table 4.1), it is understandable why weeding is mostly once in a season (Table 4.11), and not as often as need be. The absence of regular weeding, especially for those farmers who do not practice tillage, contributes to a situation where the crops are in direct competition with weeds. This might lead to a decrease in the water levels required for optimum crop growth and production and a resultant decline in yield.

4.2.1.12 Crop production factors influencing investment decisions

The decision to produce either sunflower, groundnut, and sunflower is influenced by either constraining factors or non-constraining factors. The respondents were asked about the factors that influenced their investment decisions in producing groundnuts, soybean, sunflower, and other crops with regards to constraints and no constraints. Their response as seen from Figure 4.2 show that the decisions to produce groundnuts are strongly influenced by constraining factors like cash availability (98%), rainfall (97%), input availability (97%), food security (91%) and temperature (89%).

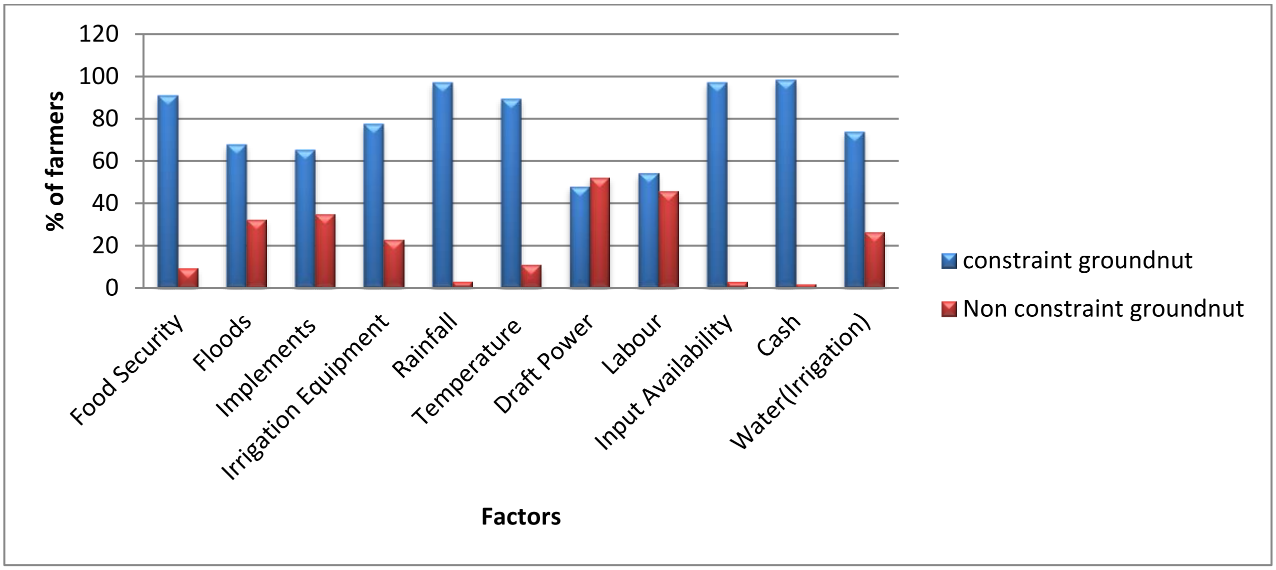


Figure 4.2: Factors influencing groundnut production in Limpopo.

Figure 4.3 shows that the most constraining factors influencing soybean production are input availability, cash availability, rainfall, water (Irrigation), Food Security (43%) and temperature (49%). On the non-constraint side, labor is at 9%. This might be because it is mostly the youths taking the chance to cultivate soybean. The older farmers are not very keen on its cultivation because it does not contribute towards their food security.

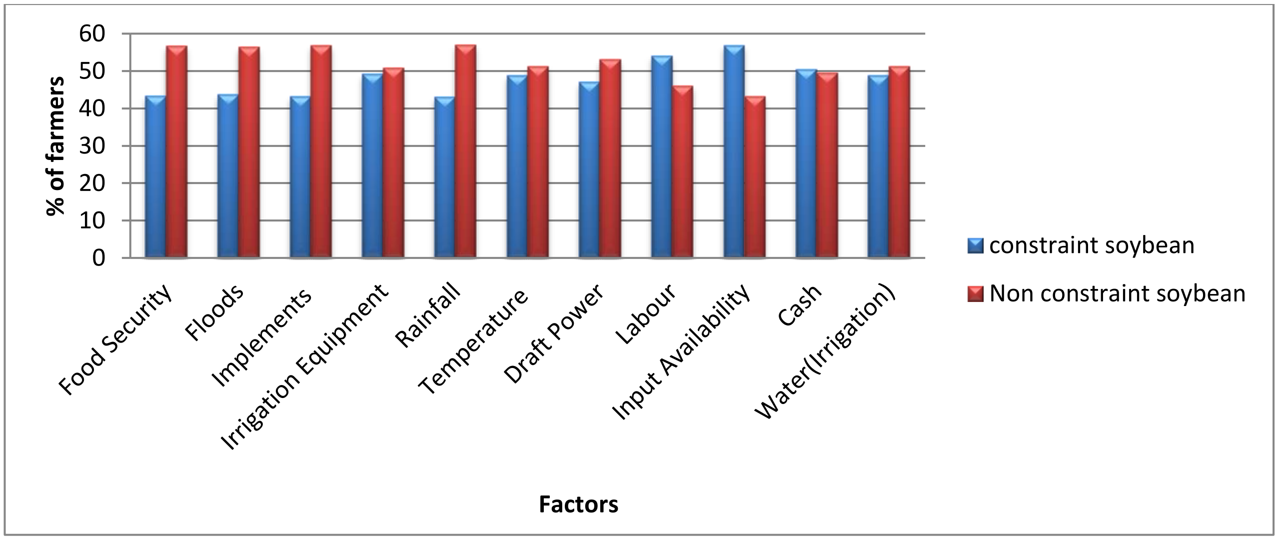


Figure 4.3: Factors influencing soybean production in Limpopo.

Figure 4.4 indicates that sunflower is not on the top of choice for the farmer. Most of the factors that influence production are more of constraining factors of production. The only factor which is not a constraint to sunflower production is water.

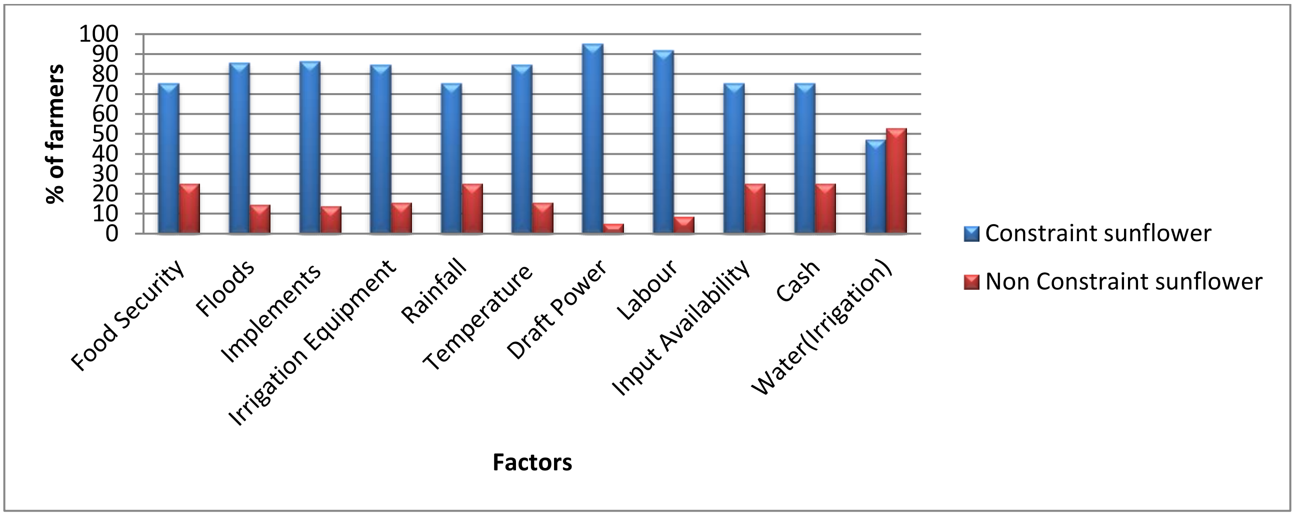


Figure 4.4: Factors influencing sunflower production in Limpopo.

With regards to the other crops produced by the farmers, the factors influencing their investment decision include temperature, irrigation equipment, rainfall, cash and water (Figure 4.5).

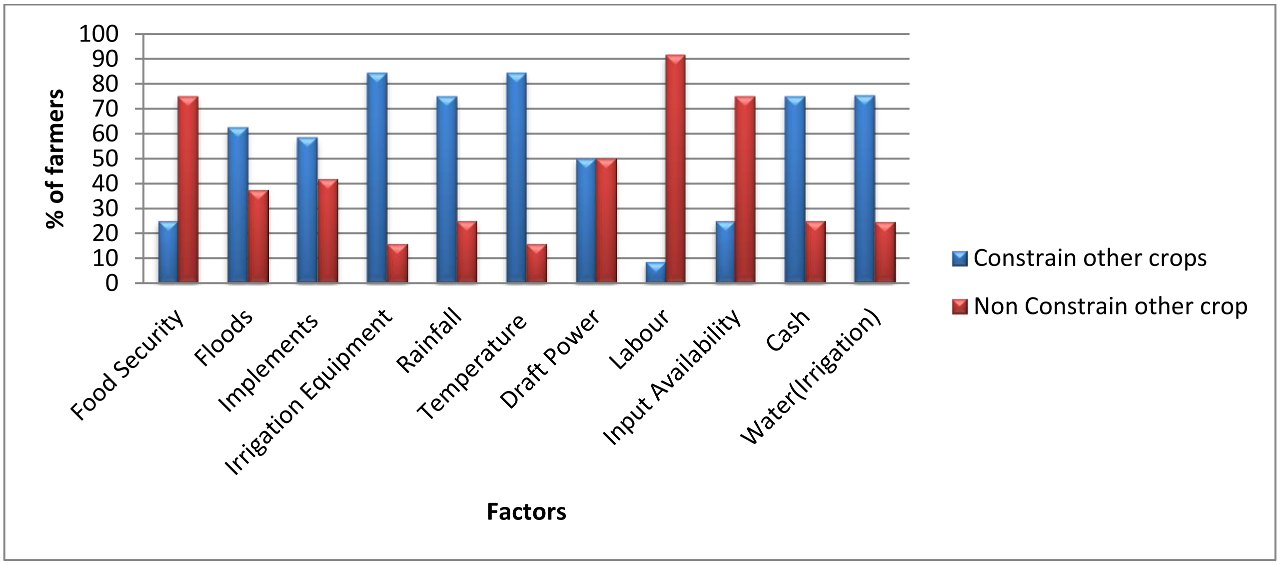


Figure 4.5: Factors influencing the production of other crops in Limpopo.

In order to determine which factors are most important to the farmers when making a crop investment decision, a factor analysis was carried out. The result from Table 4.12 shows that floods, implements, temperature, rainfall, cash, irrigation equipment, and food security are the major factors that influenced the farmers' decision on investment.

Table 4.12: Factor loadings for crop investment decision.

Factor pattern:	**F1**	**F2**	**F3**
Food Security	**0.733**	0.332	-0.593
Floods	**0.927**	0.181	0.329
Implements	**0.899**	0.297	0.321
Irrigation Equipment	**0.815**	-0.358	0.456
Rainfall	**0.864**	-0.460	-0.205
Temperature	**0.889**	-0.431	0.154
Draft Power	0.577	**0.649**	0.496
Labour	0.429	**0.888**	-0.166
Input Availability	0.574	0.381	**-0.725**
Cash	**0.834**	-0.456	-0.310
Water (Irrigation)	0.207	**-0.968**	-0.142
Cronbach's alpha:	**0.899**		

4.2.1.13 Cropping decisions influenced by the climate in Limpopo

The farmers made use of indigenous knowledge to guide their understanding of weather and climate patterns, as well as the decisions they were making about crops and farming practices. This might explain some of the variations observed in the reasons why some farmers were not following the normal planting calendars for crops. Similarly, as reported by Kalanda (2011), African farmers have used indigenous knowledge to back farm management decisions especially those related to climatic conditions. Figure 4.6 shows that planting date, choice of crop and water availability are the crop production decisions influenced by the climate in groundnut production.

Climate influences decisions on planting dates, choice of crop, deep weeding and water for soybean production. With regards to sunflower, the most influential cropping decisions are planting date and water. Planting date, fertilizer application, choice of crop, deep weeding, variety to grow and water are the most affected by climate.

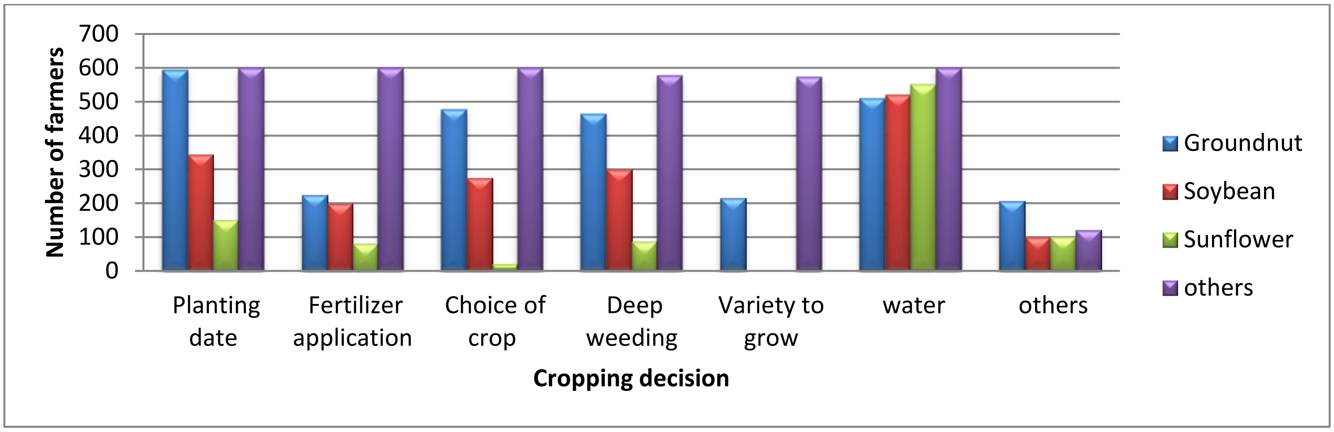


Figure 4.6: Cropping decision as influenced by the climate in Limpopo.

A further analysis to determine which crop production decisions are affected the most by climate is presented in Table 4.13. A factor analysis was carried out to identify the management practices that could be representative of cropping decisions influenced by the climate in the area. From the loadings, deep weeding, choice of crop to grow, fertilizer application, planting date, variety to grow and water is the dominant climatic factors.

Table 4.13: Factor loading for decisions influenced by climate.

Factor pattern:	**F1**	**F2**	**Initial communality**	**Final communality**	**Specific variance**
Planting date	**0.945**	0.328	1.000	**1.000**	**0.000**
Fertilizer application	**0.950**	-0.224	1.000	0.953	0.047
Choice of crop	**0.986**	0.151	1.000	0.995	0.005
Deep weeding	**0.988**	0.128	1.000	0.992	0.008
Variety to grow	**0.928**	-0.291	1.000	0.947	0.053
Water	**0.875**	**-0.871**	1.000	0.972	0.028
Others	0.412	**0.715**	1.000	0.681	0.319
Cronbach's alpha:	**0.917**				

4.2.1.14 Deviations from usual agronomic practices in the farming season 2016/2017 in the Limpopo

Farmers were asked about deviations from their usual agronomic practices in the cropping season 2016/2017. Their responses indicated that 63.82% of the farmers deviated from their usual agronomic practices. The deviations include a range of crops (crop diversification), the range of area planted, crop tillage, tillage practices, and fertilization application. The deviation practices are all in lieu of adaptation. Figure 4.7shows that most of the farmers increased their range of crops.

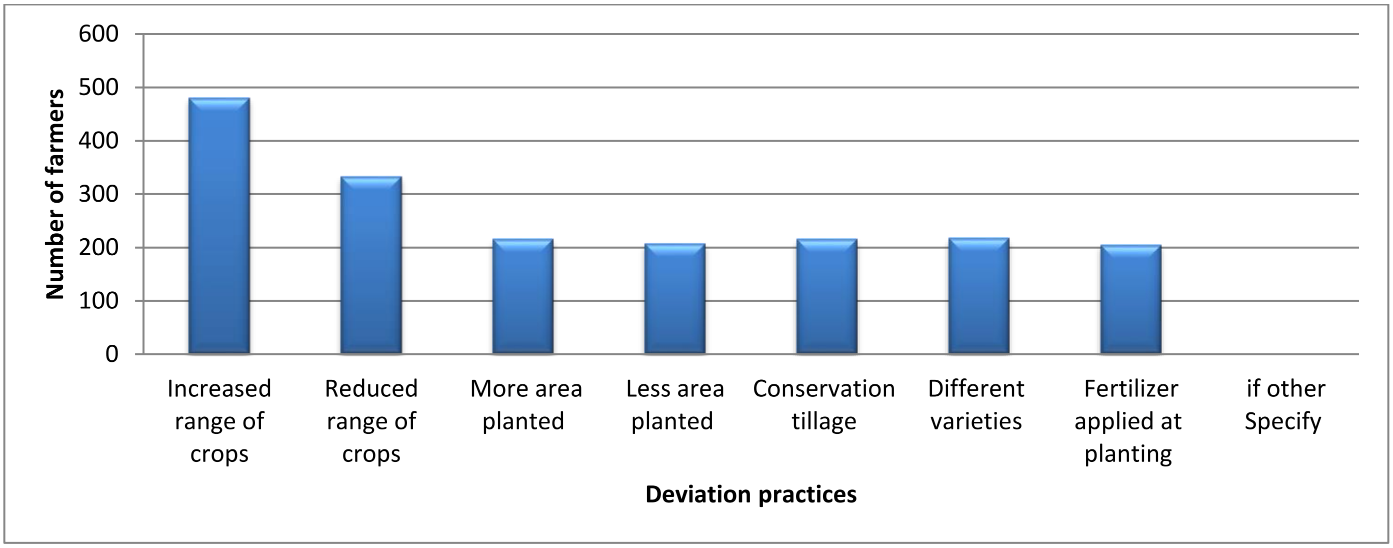


Figure 4.7: Deviations from normal agronomic practices in Limpopo Province.

4.2.1.15 Reasons for deviation apart from climatic influence.

The respondents were asked for reasons to deviations in farming practices apart from climatic factors. The response to this question shows that water for irrigation is the most contributing factor to the deviation, followed by seed availability (Figure 4.8).

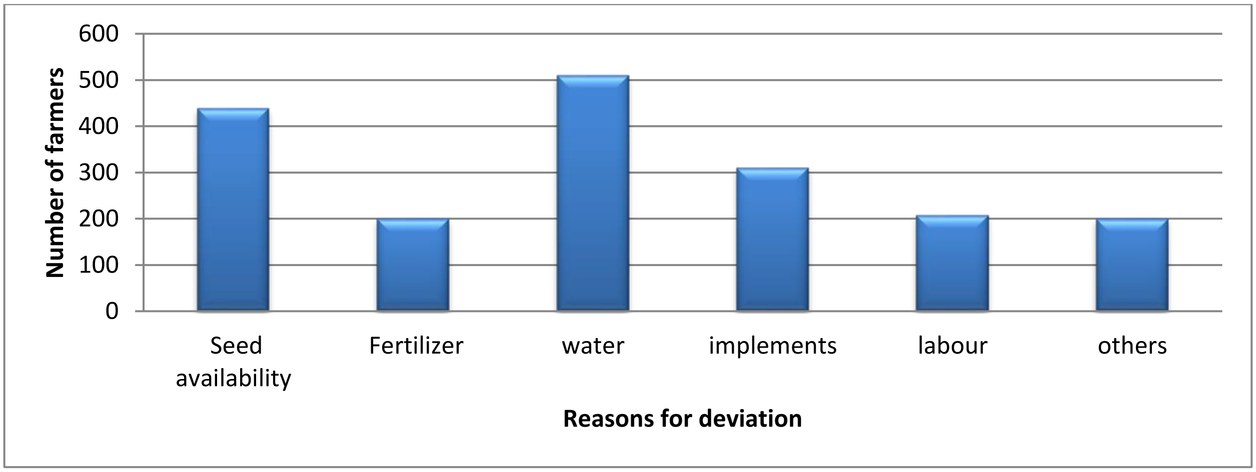


Figure 4.8: Nonclimatic factors causing deviation from normal agronomic practices.

4.2.1.15 Constraints on agronomic practices and crop production caused by climate change and variability in Limpopo

Respondents were asked if they have noticed any changes in the weather patterns since they started farming. All the respondents noticed a change in weather pattern from the time they started farming. Figure 4.9 shows the result of the climate factors which were apparent to the respondents. Late rains and low rainfall were the most obvious changes noted.

Higher than normal rainfall was also noticed. This will tie in with the seasonal floods which have affected the province due to higher than normal rainfall.

All respondent conceded that the changes were apparent from year to year.

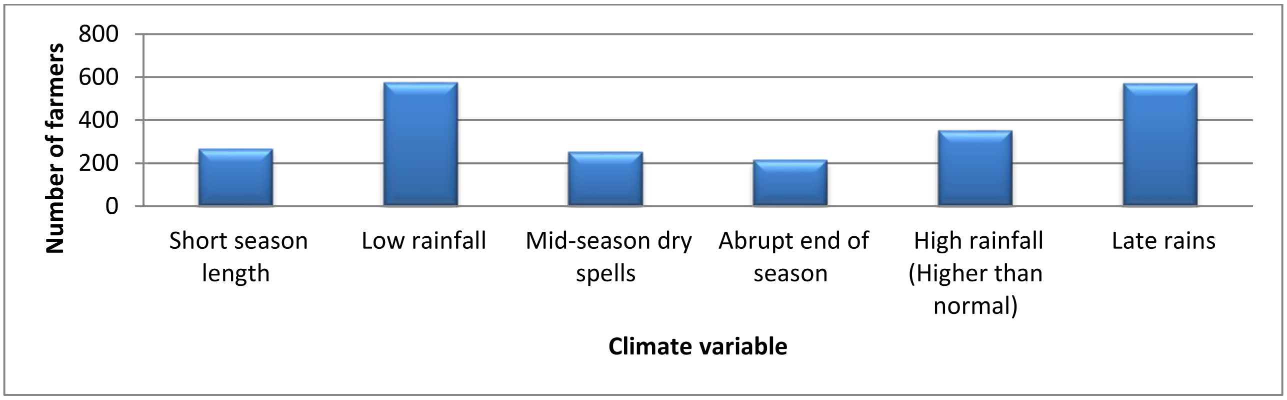


Figure 4.9: Perception of a changing climate by farmers in the Limpopo Province.

4.2.1.16 Effects of climate on farming practices in 2015/2016 farming season Impact of weather on farming activities in Limpopo

All the farmers attested that the changing climate affected their farming activities in the farming season. Results ties in with results shown by Figure 4.10 above where climate has influenced farm management such as area size is utilized for crops, changes in the choice of crop variety.

4.2.1.17 Variability in agronomic practices

With regards to changes in farming activities, the farmers were asked if they had drastically changed their practices. As shown by Figure 4.10, 84.5% of the farmers said they had drastically changed their farming activities from the time they started farming. This response comes from most of the older farmers because of the climate variability experienced in the area.Sixteen percent said they have not drastically changed their farming methods.

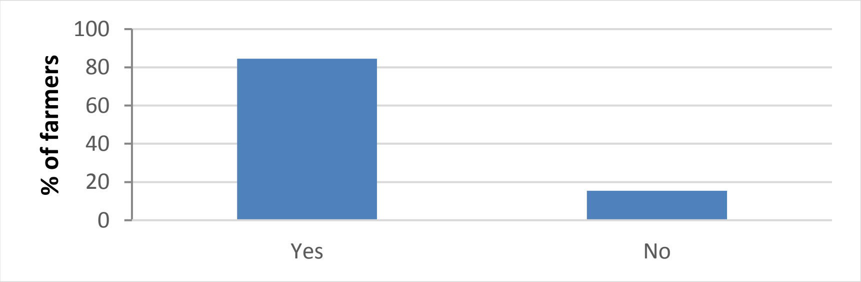


Figure 4.10: Drastic changes employed by farmers in regard to farming practices in Limpopo.

Figure 4.11 shows the response of the farmers in regard to changing their farming activities on a yearly basis. 494 farmers changed their farming activities on a yearly basis while 106 said they don’t change their practice yearly.

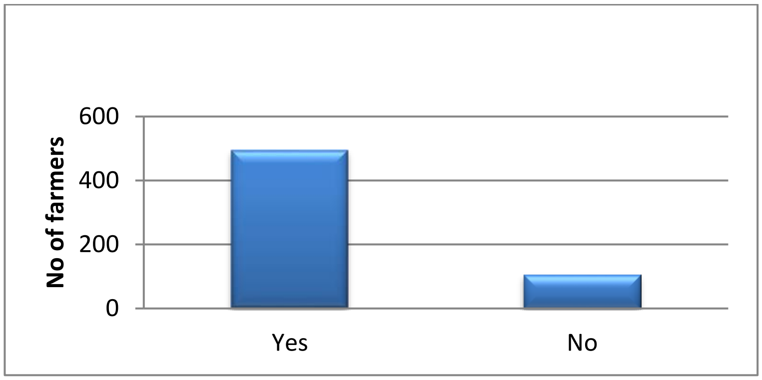


Figure 4.11: Variability in annual farming practices in Limpopo.

4.2.1.18 Climatic thresholds affecting Farmers in Limpopo

Farmers were asked which climatic threshold affected them the most. Results from Figure 4.12 show that most farmers in all three AEZs were affected by droughts followed by floods in the arid regions, waterlogging in the humid and arid and lastly by hail in all three regions.

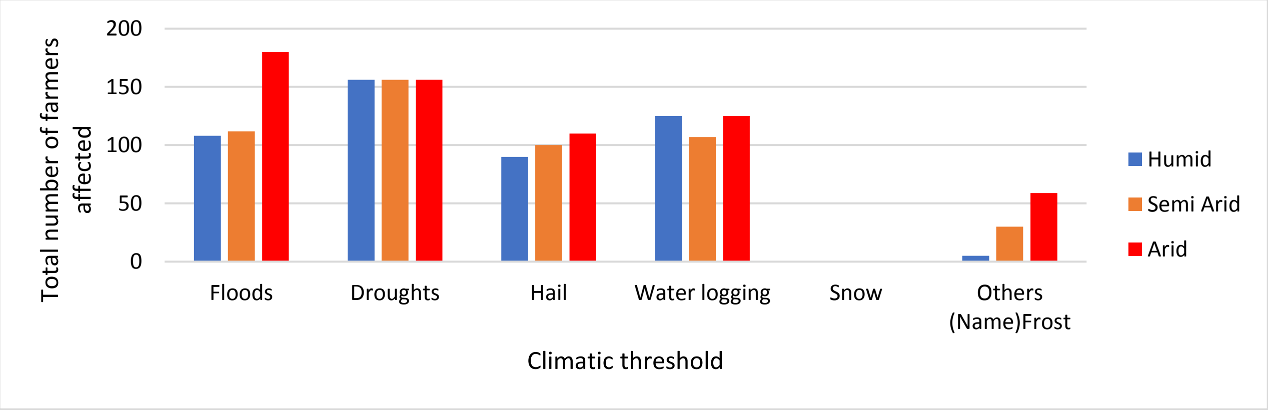


Figure 4.12: Climatic thresholds affecting farmers Limpopo.

4.2.1.19 Coping and adaptation strategies to climate variability/change in Limpopo

Questions were asked to assess the coping and adaptation methods used by the farmers to reduce the effects of climatic extremes caused by the changing climate. It further looks at the socioeconomic conditions of the area and assesses their vulnerability.

4.2.1.20 Coping and adaptation to climate extremes in Limpopo

Farmers were asked if they have ways to deal with the extreme events as experienced in section 4.2.1.16 and 4.2.1.20 above. All farmers said they had ways of dealing with one or more of the extreme events experienced. They further attested that their methods of dealing with such events involved changes in their farming practices and strategies. The practices and strategies included a change in planting dates, change in area and type of crops planted as seen in Table 4.14.

Table 4.14: Adaptation measures employed by surveyed farmers in Limpopo in the face of climatic change

Climatic effects	**Response**
Relatively shorter season	• Change the type of crop planted • Change in planting date
Low rainfall	• Change of planting dates • Mulching • Cover crops • Water harvesting • More than one type of crop planted
Mid-season dry spells	• Change planting dates,
The abrupt end of the season	• Nothing
Late rains	• Change planting dates • Increase areas cultivated • Decrease area cultivated
High than normal rainfall	• Construct water paths from farms for surface runoff
Waterlogging	• Change site, • Plant trees, • Apply absorbents

Figure 4.13 shows the percentages of farmers employing one type of adaptive measure or another across the three agro-ecological zones when faced with climatic challenges.

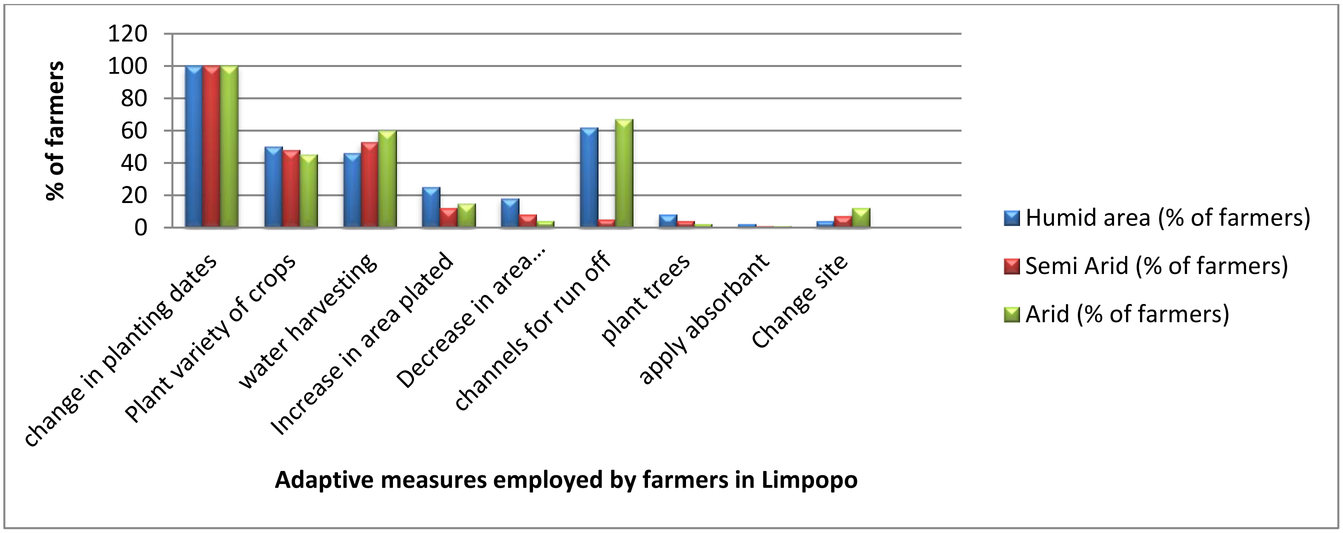


Figure 4.13: Methods used by surveyed farmers in Limpopo to cope with climatic changes across agro-ecological zones.

The most used adaptation method for farmers is changing the planting dates which is employed by all the farmers across the three AEZs. The second which is mostly used in the Arid and Humid zones is the creating of channels for runoff.

4.2.1.21 Other sources of income to farmers in Limpopo

Farmers were asked if they had other sources of income. Results from their responses (Figure 4.14) showed that 500 of them were engaged in other commercial activities. A total of 377 farmers were employed, 418 practice rearing animals while 550 (230 child grant and 320 pension grant) received some sort of grant.

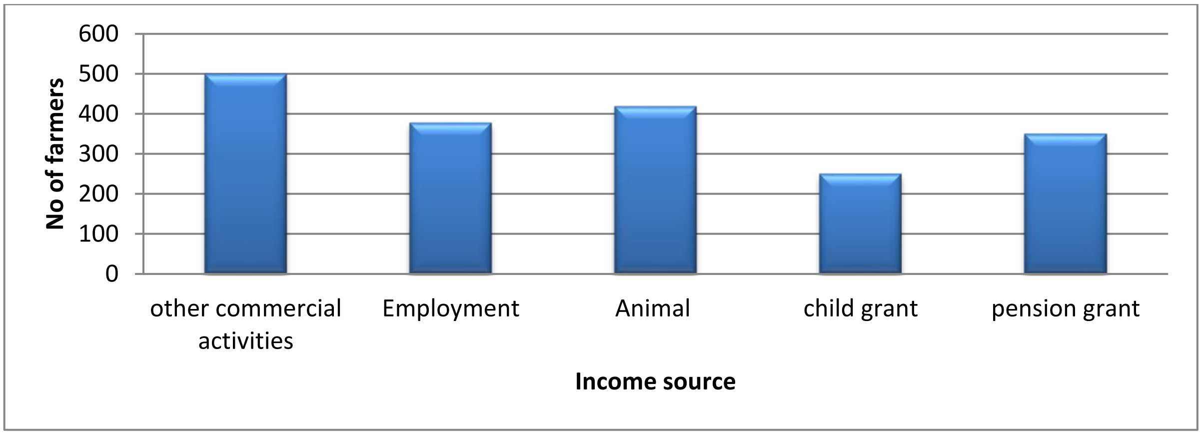


Figure 4.14: Other sources of income to surveyed farmers Limpopo.

4.2.1.22 Household composition in Limpopo

Results from the survey showed that the sampled household of the farmers made up a total male of 1665 and a total of 2010 female. The average household size was estimated at 6.5 persons per household. The age distribution in households is shown in Table 4.15 which reveals that the predominant age group is 16-26 (746) followed by the 0-15 age group.

Table 4.15: Age composition of surveyed households in Limpopo.

Age	**Total -Limpopo**
0-15	690
16-26	746
27-37	571
38 -48	415
49-59	481
60	324

The result of the age distribution showing a young population tie in with the population pyramid of South Africa, which shows an increase in the young.

With regards to marital status, most farmers (296) were married followed by 150 who were single. A total of 105 were widowed while 49 of them were divorced as shown in Figures 4.15.

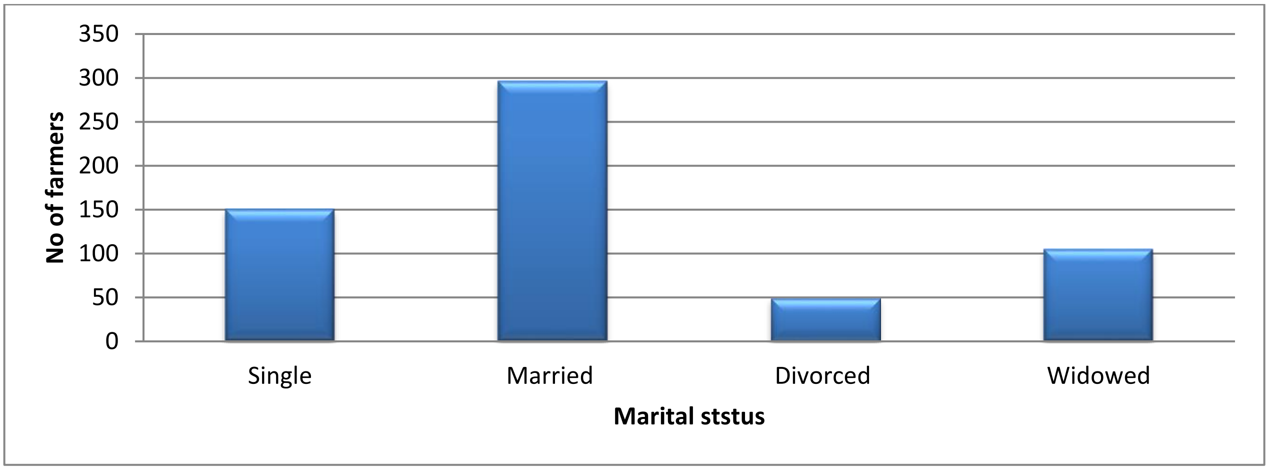


Figure 4.15: Marital status of surveyed farmers In Limpopo.

When asked if the farmers had other dependents living outside their households, 150 of them said yes, while 450 said no. An average of 3 persons living outside the farmers household was being supported by the farmers.From the household characteristic presented above, it can be said that the households are vulnerable given that they are mostly made up of females; they have a high percentage of young children and old people as against the youth; a high percentage of single-parent households (widowed, single, divorced) and the size of their household is large. This factor working together places the household at risk to the ravages of climate change.

4.2.1.23 The predominant livelihood of the surveyed community in Limpopo

All the respondents attested to the fact that agriculture was the predominant activity in their community.

4.2.1.24 Institutional arrangements in place to support farmers in Limpopo

Results from Figure 4.16 shows the kind of support the farmers receive from various governmental and non-governmental institutions to assist them. Most support is received from DAFF followed by NGO's and Agro finance institutions. With regards to support from DAFF, 10% of the farmers got monetary support, 26% got seeds, 22% got machinery and 28% benefited from educational support. NGO's, on the other hand, assisted 43% of the farmers with seeds and 28% with educational support.

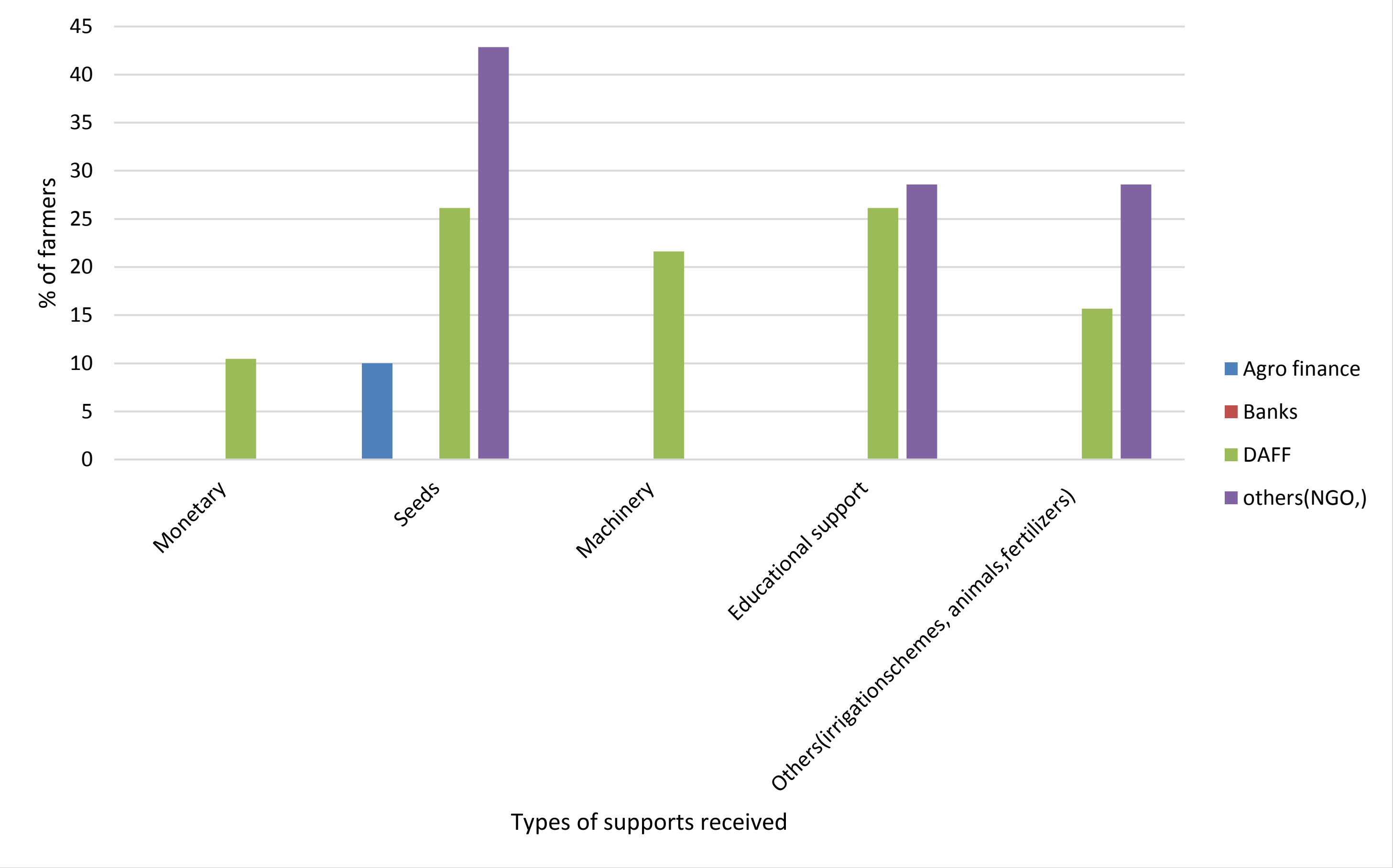
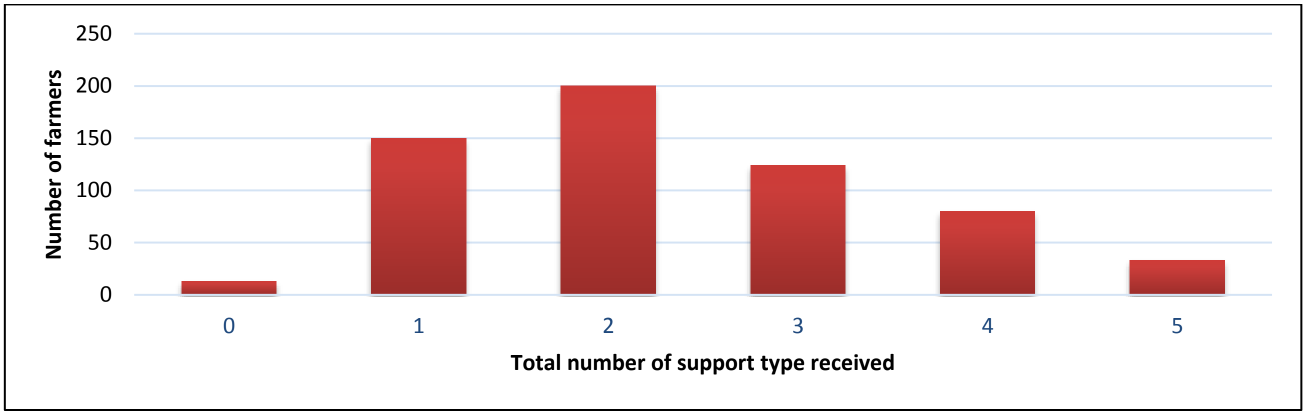


Figure 4.16: Infrastructure and institutional arrangements to support surveyed farmers in Limpopo

With the support given to farmers, some farmers received more than one type of support as seen in Figure 4.17. Most of the farmers received two types of support as seen in Figure 4.18.



Figures 4.17: Number of supports received by farmers in Limpopo.

4.2.1.25 Correlation of support types received per AEZ in Limpopo

A correlation analysis was carried out on the various types of supports received by the farmers. Results from Table 4.16 to 4.18 shows that money correlates with most of the support types in all the zones.

Table 4.16: Correlations amongst support factors in the arid area of Limpopo.

Correlation matrix (Pearson (n)):

Variables	Monetary	Seeds	Machinery	Educational support	Others (irrigation schemes, animals, fertilizers)
Monetary	**1**	0.457	0.584	**0.936**	-0.954
Seeds	0.457	**1**	**0.993**	0.741	-0.168
Machinery	0.584	0.993	**1**	0.995	-0.089
Educational support	0.936	**0.741**	**0.995**	**1**	-0.787
Others (irrigation schemes, animals, fertilizers)	-0.954	-0.168	-0.089	-0.787	**1**

Table 4.17: Correlation between support factors in Semi-Arid area of Limpopo.

Correlation matrix (Pearson (n)):

Variables	Monetary	Seeds	Machinery	Educational support	Others (irrigation schemes, animals, fertilizers)
Monetary	**1**	0.657	0.554	**0.973**	-0.754
Seeds	0.675	**1**	**0.967**	0.841	-0.166
Machinery	0.584	0.967	**1**	0.995	-0.034
Educational support	0.973	**0.841**	**0.995**	**1**	-0.757
Others (irrigation schemes, animals, fertilizers)	-0.754	-0.166	-0.034	-0.757	**1**

Table 4.18: Correlation between support factors in the humid area of Limpopo.

Correlation matrix (Pearson (n)):					
Variables	Monetary	Seeds	Machinery	Educational support	Others (irrigation schemes, animals, fertilizers)
Monetary	**1**	0.574	0.584	**0.936**	-0.832
Seeds	0.574	**1**	**0.989**	0.874	-0.152
Machinery	0.584	0.989	**1**	0.993	-0.069
Educational support	0.936	**0.874**	**0.993**	**1**	-0.751
Others (irrigation schemes, animals, fertilizers)	-0.832	-0.152	-0.069	-0.751	**1**

In looking at the support types that will make a difference in the area, Table 4.19 shows the results of a factor analysis carried out. Money and educational support loaded very high, thereby indicating that they were the most needed type of support needed in the region.

Table 4.19: Factor Analysis of Support received by farmers in Limpopo.

Factor pattern:					
	F1	F2	Initial communality	Final communality	Specific variance
Monetary	**0.901**	0.434	1.000	**1.000**	**0.000**
Seeds	**0.797**	-0.604	1.000	**1.000**	**0.000**
Machinery	**0.746**	-0.665	1.000	**1.000**	**0.000**
Educational support	**0.996**	0.088	1.000	**1.000**	**0.000**
Others (irrigation schemes, animals, fertilizers)	**-0.729**	-0.684	1.000	**1.000**	**0.000**

A test of significance was carried out. Evidence from Appendix 4.1 shows a chi-square, *p = 1* which is greater than α-value. Hence on this basis, the null hypothesis was accepted, and it was established that the samples are statistically different. To reiterate this, the *p-value* for Wilks' G² is compared with the α-value. Given that the *p-value* obtained in the analysis is 0.99 (Appendix 4.1) which is greater than α=0.05, the null hypothesis which states that the means are independent is accepted.

A factor analysis was carried out to determine which of the support was most important for adaptation to climate change. The Kaiser-Meyer-Olkin (KMO) (Appendix 4.2) was used to assess sampling adequacy and evaluation of any correlations, which is acceptable at values > 0.500). The result from Table 2 shows a KMO value of 0.539. This means the sample data could be used to perform a factor analysis. The Cronbach alpha was 0.585, suggesting that the sample is statistically correlated with high reliability.

4.2.1.26 Ease of access to financial institutions by farmers in Limpopo

With respect to how easy it is to farmers to access finance; the results are shown in Figure 4.18. From their responses, cooperatives are the easiest to access whereas banks and microfinance institution are not easily accessible to farmers.

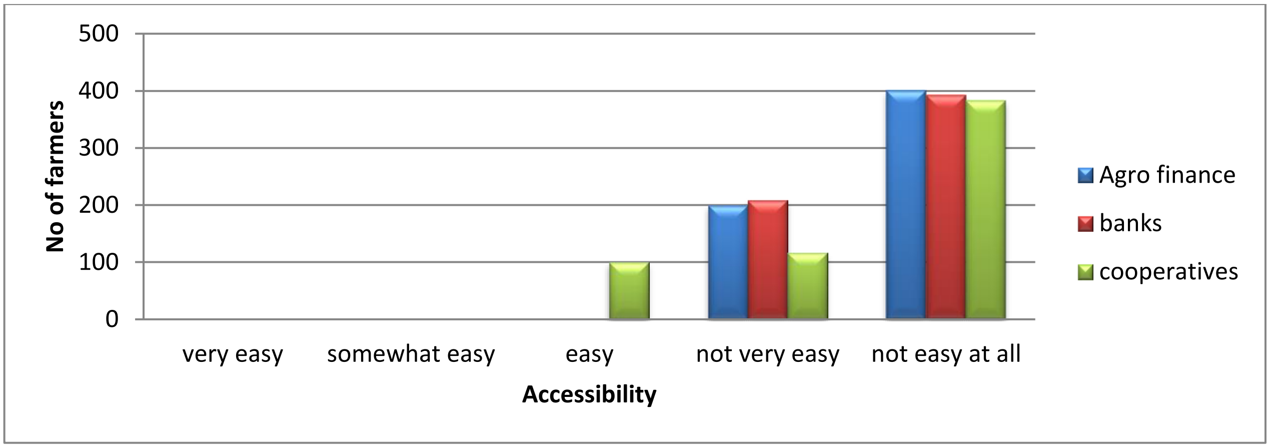


Figure 4.18: Ease of obtaining credit facilities by farmers.

4.2.1.27 Important changes best suited to maintain production under climate change by farmers in Limpopo

Farmers were asked to rank practices in order of importance to continuing production effectively under climate change. The ranking was done in relation to five categories, with 1 being the most important and 5, the least important. Farming practices were categorized into five categories: on farm management, new technologies, conservation agriculture, diversification on and beyond farm and different dating of farming practices.

According to the farmers, for them to be able to produce optimally in the face of the changing climate what needs to be prioritized with regards to farm management will be to feed crop residues to the livestock (Table 4.20). This is followed by applying fertilizers that breaks down and releases nutrients slowly. This might be in the case of floods or erosion, where the fertilizer applied will not all be washed away.

Table 4.20: Changes to be made for optimum production by surveyed farmers under changing climatic conditions in Limpopo.

	Rank	**Apply fertilizers according to fertilizer recommendations**	**Apply a fertilizer that breaks down and releases nutrients slowly**	**Changing crop produced to another**	**Feed crop residues to livestock**	**Count of Changing plant density**
Farm Management	1	108	134	58	320	112
	2	221	62	264	76	244
	3	88	248	138	64	82
	4	103	80	52	75	52
	5	80	76	88	65	110
Conservation Agriculture		adopt no-till production	Adopt ripper tillage	Apply crop residue as a mulch to bare soil		
	1	100	308	347		
	2	250	85	91		
	3	97	62	48		
	4	89	55	58		
	5	64	90	56		
Diversification on and beyond the farm		The shift from farming to non-farming activities	Intercrop with legumes	Intercrop with trees	Changing from crop production to livestock and dairy production	
	1	400	368	281	250	
	2	47	60	91	53	
	3	53	46	120	69	
	4	51	62	56	76	
	5	49	64	52	152	
New Technologies		adopt flood tolerant cultivars	Adopt drought tolerant fast-maturing cultivars	change in farming tools		
	1	182	183	222		
	2	232	205	272		
	3	80	100	120		
	4	66	90	106		
	5	40	22	80		
Different Dating for Farming Practices				Planting Date		
	1			200		

With regards to new technologies, 60% of the farmers chose drought tolerant and fast maturing cultivars to be the most important, followed by 30% for flood tolerant and lastly changing tools for farming with 10%.

Results showed that with regards to conservation agriculture 75% of the farmers chose ripper tillage production as the most important factors to be adopted in the face of climate change, followed by 20% for applying residue as mulch to bare soil and lastly the 5% for the adoption of no-till production.

On diversification on and beyond the farm 30.79% farmers ranked shift from farming to non-farming activities as the most important, followed by 28.33% ranking intercrop with legumes, 21.63% ranked apply crop residue as mulch and 19.25% ranked intercrop with trees as the important changes to be made. On farming dates, all the farmers (100%) ranked it as the most important.

Factor analysis

Taking all the adaptation measures together, a factor analysis was done to see which of the factors are most important to the farmers for adaptation measures. Before the factor analysis was carried out, a Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was carried out and the result is shown in Table 4.21. The KMO value is 0.64 and close to 1 which indicates that the sum of partial correlations is not large relative to the sum of correlations and so factor analysis should yield distinct and reliable factors. According to Hair et al. (2006), a KMO value of 0.5 or more is acceptable and factor analysis can be carried out.

Table 4.21: Kaiser-Meyer Olkin Measure of sampling adequacy of factors of adaptation.

Adaptation measures	Factor
Apply fertilizers according to fertilizer recommendations	0.655
Count of Apply fertilizer that breaks down and releases nutrients slowly	0.839
Changing crop produced to another	0.634
Feed crop residues to livestock	0.530
Count of Changing plant density	0.727
Adopt drought tolerant fast-maturing cultivars	0.639
adopt flood tolerant cultivars	0.518
change in farming tools	0.818
adopt no-till production	0.528
Adopt ripper tillage	0.575
Apply crop residue as a mulch to bare soil	0.627
Intercrop with legumes	0.640
Intercrop with trees	0.812
Changing from crop production to livestock and dairy production	0.472
The shift from farming to non-farming activities	0.634
changing the planting date	0.621
KMO	0.640

Results from Table 4.22 show the output of the factor analysis with the factors in bold being the most important to the farmers. According to the farmers, the most important adaptation measure is applying crop residue as mulch to bare soil whereas the application of fertilizer that breaks down and releases nutrients slowly was the least important for the farmers. Other important adaptation measures reported by the farmers include adopting ripper tillage, intercropping with trees. Furthermore, Table 4.22 shows the Cronbach's alpha at 0.902 indicating a high degree of internal consistency. Streiner (2003) suggested a maximum of 0.90 for alpha.

Table 4.22: Factor analysis for adaptation measures.

Factor pattern:	F1	F2	F3	Initial communality	Final communality	Specific variance
Apply fertilizers according to fertilizer recommendations	0.189	-0.976	0.110	1.000	1.000	0.000
Apply fertilizer that breaks down and releases nutrients slowly	0.010	0.335	-0.915	1.000	0.949	0.051
Changing crop produced to another	-0.106	-0.932	-0.191	1.000	0.916	0.084
Feed crop residues to livestock	0.960	0.277	0.031	0.997	1.000	0.000
Changing plant density	0.227	-0.885	0.128	1.000	0.852	0.148
Adopt drought tolerant fast maturing cultivars	0.695	-0.633	-0.189	1.000	0.920	0.080
Adopt flood tolerant cultivars	0.676	-0.735	-0.048	1.000	1.000	0.000
Change in farming tools	0.676	-0.735	-0.048	1.000	1.000	0.000
Adopt no till production	0.158	-0.987	-0.026	1.000	1.000	0.000
Adopt ripper tillage	0.959	0.254	0.077	1.000	0.991	0.009
Apply crop residue as a mulch to bare soil	0.981	0.188	0.053	1.000	1.000	0.000
Intercrop with legumes	0.951	0.304	0.063	0.996	1.000	0.000
Intercrop with trees	0.941	0.201	-0.271	1.000	1.000	0.000
Changing from crop production to livestock and dairy production	0.748	0.538	0.240	1.000	0.906	0.094
Shift from farming to non-farming activities	0.949	0.317	0.001	0.999	1.000	0.000
Cronbach alpha	0.902					

4.2.1.28 Changes in income and revenue the 2014-2017 farming season in Limpopo

Tables 4.23 to 4.25 show that the cost of production and revenue varies across the years 2014 to 2017. Such variations could be influenced by factors alluded in section 4.2.14 dealing with farmer support and section 4.2.10 on adaptive responses. It is worth noting that some of the farmers did not consider the cost implication of working for themselves, using other resources (e.g. bakkies, tractors borrowed from friends), assistance from friends, technical and expert advice and services from friends and colleagues as factors of production hence did not include it in the total cost of production. Without proper financial management, the farmers will not be able to ascertain if it is worthwhile to continue producing the crops they are producing. They are unable to show the profitability of their production venture and this might also be a cause why small-scale farmers and subsistence farmers find it difficult to access loans.

Table 4.23: Cost of production and revenue from groundnut production in Limpopo the 2014-2018 Farming Season.

		Groundnut Production			
Area	Production Year	The average cost of production (R/ha)	Average yield t/ha	Revenue (R)/ha	Yield per province (t/ha)
Humid	2014/2015	5800	2.2	153600	3
	2015/206	5200	1.9	188600	2.4
	2016/2017	5400	2.9	120600	3.5
Semi-Arid	2014/2015	5000	1.6	153500	3
	2015/206	5650	1.5	188500	2.4
	2016/2017	5850	2.3	120500	3.5
Arid	2014/2015	5000	.790	145000	3
	2015/206	5150	1.09	180000	2.4
	2016/2017	5350	1.69	112000	3.5

Table 4.24: Cost of production and revenue from soybean production in Limpopo for the 2014-2018 Farming Seasons.

		Soybean Production			
Area	Production Year	The average cost of production (R/ha)	Average yield t/ha	Revenue (R)	Yield per province (t/ha)
Humid	2014/2015	5650	1.9	145000	3
	2015/206	4800	1.2	180000	2.4
	2016/2017	5000	1.6	112000	3.5
Semi-Arid	2014/2015	4850	1.13	142500	3
	2015/206	5000	1.03	178500	2.4
	2016/2017	4200	1.83	110750	3.5
Arid	2014/2015	4950	1.11	119758	3
	2015/206	5100	1.01	153258	2.4
	2016/2017	5300	1.11	103258	3.5

Table 4.25: Cost of production and revenue from groundnut production in Limpopo the 2014-2018 Farming Season.

Sunflower Production					
Area	Production Year	The average cost of production	Average yield t/ha	Revenue (R)	Yield per province (t/ha)
Humid	2014/2015	8500	1.90	275000	0.75
	2015/2016	9000	1.89	250000	0.75
	2016/2017	9000	2.37	371000	0.95
Semi-Arid					
	2014/2015	8100	2.00	287000	0.75
	2015/2016	6400	1.00	235000	0.75
	2016/2017	13200	0.98	200000	0.95
Arid					
	2014/2015	10500	1.70	245000	0.75
	2015/2016	9500	0.90	185000	0.75
	2016/2017	14000	1.20	208750	0.95

4.2.1.29 Cost of production and profit margins for predominant crops in Limpopo for the period 2014-2018

Tables 4.26 and 4.27 is the result of the survey, showing results of cost-benefit analysis for producing the most popular summer crops grown in the Limpopo Province. With input as per survey results, Table 4.24 shows it is cheaper to produce sunflower, soybean, and groundnuts. The breakeven yield for sunflower is 1.32 t/ha and should be sold for at least R3549.89 for the farmer to break even. The most expensive system of production is for irrigated maize which needs a breakeven yield of 14.70t/ha and should be sold for at least R2328.97 so as to benefit from economies of scale.

Table 4.26: Cost analysis for selected summer crop production in Limpopo Province.
Source: survey results and grainSA.

Average cost budgets for production of selected summer crops cultivation for the period 2014-2018

Crop	**Maize (lower yield)**	**Maize (higher yield)**	**Maize (medium yield)**	**Sunflower**	**Soybean**	**Grain Sorghum**	**Groundnuts**	**Irr-Maize**
1) INCOME								
Yield target (ton/ha)	2.00	4.00	2.50	2.00	1.20	2.20	2.50	12.75
South African Futures Exchange (SAFEX): Estimated Price	R 2,300	R 2,300	R 2,300	R 5,200	R 4,850	R 2,600	R 9,088	R 2,300
Deductions	R 280	R 280	R 280	R 323	R 63	R 63	R 63	R 280
Net Farm Gate Price	R 2,020	R 2,020	R 2,020	R 4,877	R 4,787	R 2,537	R 9,025	R 2,020
GROSS INCOME (R/ha)	**R 4,040**	**R 8,080**	**R 5,050**	**R 9,754**	**R 5,744**	**R 5,581**	**R 22,561**	**R 25,755**
2) VARIABLE EXPENDITURES								
Seed	R 793.20	R 1,264.16	R 1,087.43	R 498.89	R 513.41	R 418.20	R 1,400.00	R 4,176.56
Fertiliser	R 1,844.00	R 3,296.00	R 2,328.00	R 950.00	R 948.80	R 2,102.10	R 838.80	R 6,495.36
Lime	R 139.86	R139.86	R 139.86			R 139.86		R 139.86
Fuel	R1,120.95	R 1,116.81	R 1,154.08	R 600.00	R 600.00	R 1,115.94	R 700.00	R 1,310.49
Reparation	R 622.60	R 640.99	R 628.73	R576.68	R 646.69	R 619.53	R 769.57	R 567.71
Herbicide	R 471.22	R 471.22	R 444.12	R392.38	R 253.28	R 619.57	R 659.42	R 742.69
Pest control	R 174.29	R 174.29	R 52.60	R 16.59	R 457.07	R 473.70	R 652.60	R 600.84
Input insurance	R 137.87	R 256.04	R177.26				R -	R -
Irrigation cost								R 6,528.38
Grain hedging	R563.70	R783.96	R 640.65			R -	R -	R 2,121.86
Contract Harvesting	R -	R -	R -	R -	R -	R -	R -	R -
Harvest insurance	R197.42	R 366.64	R266.52	R 298.82	R 753.95	R -	R -	R 676.87
Aerial spray	R -	R -	R -	R -	R -	R -	R -	R -

Casual labour	R192.00	R 192.00	R 192.00	R 192.00	R 192.00	R 192.00	R 800.00	R192.00
Drying cost	R -	R -	R -	R -	R -	R -	R -	R -
Packaging and packaging material	R -	R -	R -	R -	R -	R -	R 300.00	R -
Interest on production R/ha	R 359.78	R 500.36	R 408.90	R 275.67	R 317.40	R 335.19	R 371.83	R 1,354.28
Total variable expenditure (R/ha)	**R 6,616.89**	**R 9,202.32**	**R 7,520.15**	**R3,801.03**	**R4,682.60**	**R 6,016.09**	**R6,492.21**	**R 24,906.89**
Total fixed cost (r/ha)	**R 2,634.77**	**R 2,521.01**	**R 2,665.03**	**R 2,652.75**	**R 2,656.68**	**R 2,574.20**	**R 2,784.35**	**R 4,787.50**
Total cost (R/ha)	**R 9,251.66**	**R 11,723.33**	**R 10,185.18**	**R6,453.78**	**R7,339.28**	**R8,590.29**	**R 9,276.56**	**R 29,694.39**
3) gross margin (R/ha)	**-R 2,577**	**-R 1,122**	**-R 2,470**	**R 5,953**	**R 1,062**	**-R 435**	**R 16,069**	**R 848**
4) Nett margin (R/ha)	-R 5,212	-R 3,643	-R 5,135	R 3,300	-R 1,595	-R 3,009	R 13,285	-R 3,939

Table 4.27: Cost-benefit analysis for selected summer crop production in Limpopo Province from the period 2014 to 2018. Source: survey results and grainsSA.

Summary Limpopo average cost budgets and income and for selected summer crops cultivation for the period 2014-2018

	Maize (lower yield)	**Maize (higher yield)**	**Maize (medium yield)**	**Sunflower**	**Soybean**	**Grain Sorghum**	**Groundnuts**	**Irr-Maize**
SAFEX: Estimated Price	R 2,300.00	R 2,300.00	R 2,300.00	R 4,500.00	R 4,850.00	R 2,600.00	R 9,087.50	R 2,300.00
LGO (ton/ha)	2.00	4.00	2.50	2.00	1.20	2.20	2.50	12.75
1) INCOME								
Net Farm Gate Price (R/ha)	R 2,020.00	R 2,020.00	R 2,020.00	R 4,877.00	R 4,787.00	R 2,537.00	R 9,024.50	R 2,020.00
Net Farm Gate Price (R/ton)	R 1,010.00	R 505.00	R 808.00	R 2,438.50	R 3,989.17	R 1,153.18	R 3,609.80	R 158.43
2) EXPENDITURES								
Total variable cost (R/ha)	R 6,616.89	R 9,202.32	R 7,520.15	R 3,801.03	R 4,682.60	R 6,016.09	R 6,492.21	R 24,906.89
Total variable cost (R/ton)	R 3,308.44	R 2,300.58	R 3,008.06	R 1,900.51	R 3,902.17	R 2,734.59	R 2,596.89	R 1,953.48
Total variable & fixed expenditure (R/ha)	R 9,251.66	R 11,723.33	R 10,185.18	R 6,453.78	R 7,339.28	R 8,590.29	R 9,276.56	R 29,694.39
Total variable & fixed expenditure (R/ton)	R 4,625.83	R 2,930.83	R 4,074.07	R 3,226.89	R 6,116.07	R 3,904.68	R 3,710.63	R 2,328.97
3) MARGIN								

Gross margin (R/ha)	R -2,576.89	R -1,122.32	R -2,470.15	R 5,952.97	R 1,061.80	R -434.69	R 16,069.04	R 848.11
Gross margin (R/ton)	R -1,288.44	R -280.58	R -988.06	R 2,976.49	R 884.83	R -197.59	R 6,427.61	R 66.52
Nett margin (R/ha)	R -5,211.66	R -3,643.33	R -5,135.18	R 3,300.22	R -1,594.88	R -3,008.89	R 13,284.69	R -3,939.39
Net margin (R/ton)	R -2,605.83	R -910.83	R -2,054.07	R 1,650.11	R -1,329.07	R -1,367.68	R 5,313.87	R -308.97
BREAK-EVEN & PROFITABILITY (ONLY variable cost)								
Break-even yields (t/ha)	3.28	4.56	3.72	0.78	0.98	2.37	0.72	12.33
Break-even Safex price (t/ha)	3588.44	2580.58	3288.06	2223.51	3965.17	2797.59	2659.89	2233.48
BREAK-EVEN & PROFITABILITY (variable & fixed cost)								
Break-even yields (t/ha)	4.58	5.80	5.04	1.32	1.53	3.39	1.03	14.70
Break-even Safex price (t/ha)	4905.83	3210.83	4354.07	3549.89	6179.07	3967.68	3773.63	2608.97

Table 4.28 shows the cost of production if all farmers were to receive support in terms of seeds, fertilizers, and machinery as shown above. The calculated cost of production will be estimated as seen below on the summary table

Table 4.28: Cost-benefit analysis for selected summer crop production in Limpopo Province with projected government support based on production figures for 2014-2018 seasons.

SUMMARY								
	Maize (lower yield)	**Maize (higher yield)**	**Maize (Bt)**	**Sunflower**	**Soybean**	**Grain Sorghum**	**Groundnuts**	**Irr-Maize**
SAFEX: Estimated Price	R2,300.00	R2,300.00	R 2,300.00	R 4,750.00	R 4,850.00	R 2,600.00	R 9,087.50	R 2,300.00
LGO (ton/ha)	3.50	6.50	4.50	1.50	1.75	3.00	1.50	12.00
1) INCOME								
Net Farm Gate Price (R/ha)	R2,020.00	R 2,020.00	R 2,020.00	R 4,427.00	R 4,787.00	R2,537.00	R9,024.50	R2,020.00
Net Farm Gate Price (R/ton)	R 577.14	R 310.77	R 448.89	R 2,951.33	R 2,735.43	R 845.67	R6,016.33	R 168.33
2) EXPENDITURES								
Total variable cost (R/ha)	R2,718.87	R3,385.49	R 2,810.77	R 2,137.90	R3,068.12	R2,388.41	R 3,553.41	R 12,784.61
Total variable cost (R/ton)	R 776.82	R 520.84	R 624.62	R1,425.27	R 1,753.21	R 796.14	R 2,368.94	R 1,065.38
Total variable & fixed expenditure (R/ha)	R5,353.64	R5,906.50	R5,475.80	R 4,790.65	R 5,724.80	R4,962.61	R 6,337.76	R 17,572.11
Total variable & fixed expenditure (R/ton)	R1,529.61	R 908.69	R1,216.85	R 3,193.77	R 3,271.32	R1,654.20	R 4,225.18	R 1,464.34
3) MARGIN								
Gross margin (R/ha)	R 4,351.13	R9,744.51	R 6,279.23	R 4,502.60	R 5,309.13	R 5,222.59	R 9,983.34	R11,455.39
Gross margin (R/ton)	R1,243.18	R1,499.16	R 1,395.38	R 3,001.73	R 3,033.79	R 1,740.86	R6,655.56	R 954.62
Nett margin (R/ha)	R 1,716.36	R7,223.50	R 3,614.20	R1,849.85	R 2,652.45	R 2,648.39	R 7,198.99	R 6,667.89
Net margin (R/ton)	R 490.39	R ,111.31	R803.15	R 1,233.23	R 1,515.68	R 882.80	R 4,799.32	R 555.66
BREAK-EVEN & PROFITABILITY (ONLY variable cost)								
Break-even yields (t/ha)	1.35	1.68	1.39	0.48	0.64	0.94	0.39	6.33

Break-even Safex price (t/ha)	1056.82	800.84	904.62	1748.27	1816.21	859.14	2431.94	1345.38
BREAK-EVEN & PROFITABILITY (variable & fixed cost)								
Break-even yields (t/ha)	2.65	2.92	2.71	1.08	1.20	1.96	0.70	8.70
Break-even Safex price (t/ha)	1809.61	1188.69	1496.85	3516.77	3334.32	1717.20	4288.18	1744.34

4.2.2 Free State Province

4.2.2.1 Farmers background information in the Free State

Results from Table 4.29 shows that there is a higher percentage of women to men involved in agriculture as seen with the Limpopo province. From the farmers sampled a total of 102 were women as against 98 men.

Table 4.29: Demographic characteristics of farmers in the Free State.

Age Group	Male	Female	Grand Total	% per age group
18-36	19	6	25	12.5
37-46	22	9	31	15.5
47-56	13	22	35	17.5
57-66	21	32	53	26.5
67-76	12	26	38	19
77-86	9	6	15	7.5
87-96	2	1	3	1.5
Grand Total	98	102	200	100

As with Limpopo, the most active age group involved in farming were elderly respondents between the ages of 57- 66 (26.5%) followed by the ages 67-76 (19%) and 15.5% of the age group 37-46 years. Unlike Limpopo, there are more farmers in the category 37-46 years, which might boost productivity in the agricultural sector in the Free State.

4.2.2.2 Farm sizes in the Free State Province

Farm sizes are shown in Table 4.30. Most of the sampled farmers had over 100 ha of land for cultivation. This might mean there are more small-scale farmers in the Free State than in Limpopo. However, ownership of an average of 2 ha of land was seen to be predominant, meaning there was also a high population of subsistence farmers in the area.

Table 4.30: Sampled Farm Sizes in the Free State Province.

Farm size (ha)	Count of farmers	% of farmers
1 - 5	46	23
5 - 10	24	12
10 - 29	22	11
30 - 60	25	12.5
70 - 100	36	18
≥100	47	23.5
Grand Total	200	100

4.2.2.3 Production system and agronomic practices in Free State Provinces

4.2.2.4 Years of farming experience in the Free State Province

Table 4.31 shows that most of the farmers in the Free State have over 37 years of farming experience.

Table 4.31: Farming experience of farmers in Free State Provinces.

Years of farming	Count of farmers Free State	% Free State
1-6	21	10.5
7-11	18	9
12-16	13	6.5
17-21	14	7
22-26	10	5
27-31	16	8
32-36	12	6
37-41	25	12.5
42-46	8	4
47-51	9	4.5
52-56	9	4.5
57-61	12	6
62-66	14	7
67-71	19	9.5
Grand Total	200	100

4.2.2.5 Crops cultivated in the Free state

In the Free State, 35% of the farmers sampled cultivated only Sunflower, 22% soybean, groundnuts 12%, soybean, and sunflower 25% and groundnut and sunflower 6% as shown by Figure 4.19.

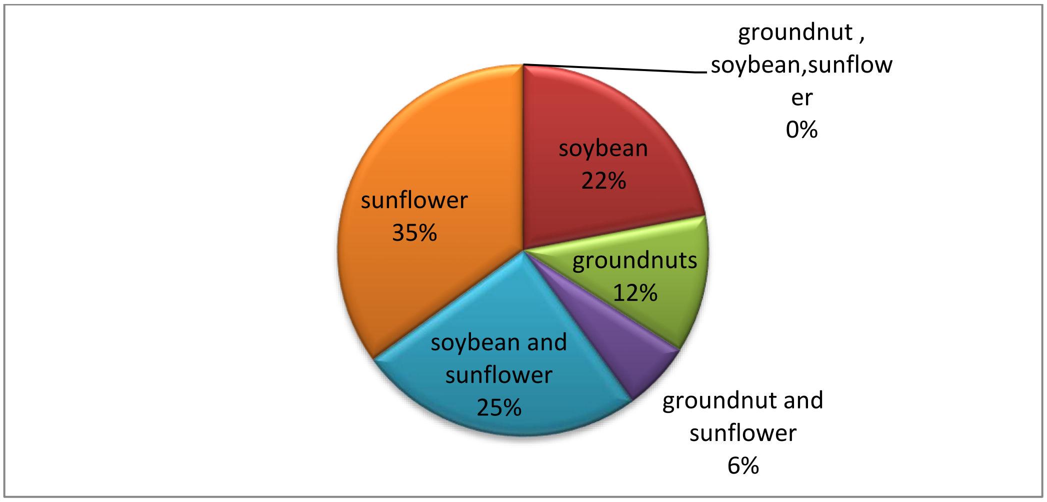


Figure 4.19: Percentage of surveyed farmers cultivating groundnut, soybean, and sunflower in Free State Province.

4.2.2.6 Crop agronomic practices in the Free State Provinces

The tillage practices carried out by the farmers in the Free State are shown in Table 4.29 below. Results from the table show that the predominant practice in the area is mulching and minimum tillage (25%). This is followed by 20% of farmers carrying out hand digging of the entire field. The farmers in the Free State are more involved with conservation practices.

Table 4.32: Tillage Practices in the Free State Province.

Tillage practice	Count of farmers in the Free State	%
No-tillage	20	10
Mulch tillage:	50	25
Strip or zonal tillage:	20	10
Ridge-till:	15	7.5
Reduced or minimum tillage:	50	25
Hand digging of the entire field	40	20
Planting basins	5	2.5
If others specify	0	0
Grand Total	200	100

4.2.2.7 Crop variety, planting densities and planting dates in the Free State Province

Most of the Free State farmers as shown in Table 4.33 were aware of the different cultivars that they planted as well as the characteristics of the cultivars. An average of 1.67% of the farmers didn’t know the cultivar names of any of the three crops they cultivated.

Table 4.33: Cultivar choice of Farmers in Free State.

Groundnut variety	**% Groundnuts**	**Soybean Variety**	**% Soybean**	**Sunflower Variety**	**% Sunflower**
Akwa (254)	18	Don Mario	47	Agsun	45
Anel (254)	18.24				
Nyanda (1173)	18.50				
Kangwane Red (254)	1.0				
Rambo (254)	1.52				
Unknown	3	Unknown	1		1
Others	39.74		52		54
Grand Total	100		100		100

With regards to planting density, 20% of the farmers used random planting. Table 4.34 shows that most of the farmers planted within the specified planting windows for the crops.

Table 4. 34: Crop planting dates in the Free State for 2016/2017 planting season.

Planting date	% groundnut	% soybeans	% sunflower
September	5.25	6	4
October	24	20	17
November	50.5	45	55
December	10.25	9	15.1
other	10	20	8.9
Grand Total	100	100	100

4.2.2.8 Fertilizer application, timing, and rates of application in the Free State

Similar to the farmers in Limpopo, the farmers in the Free State also utilized nonchemical sources of fertilizers. However contrary to the most preferred type of non-chemical fertilizer utilized by Limpopo Farmers which was crop residue, the Free State Farmers preferred crop residue and kraal manure as shown by Table 4.35. The rate of application for crop residue and kraal manure was estimated at 800 kg/ha for groundnut, 750 kg/ha for soybean and 750 kg/ha for sunflower. This was closely followed by the crop residue with a rate of application estimated at 500 kg/ha for groundnut, 600 kg/ha for soybean and 600 kg/ha for sunflower.

Table 4. 35: Nonchemical fertilizer application and the rate of application in the Free State.

Fertilizer	% applied to Groundnut	% applied to Soybeans	% applied to Sunflower	Average Rate of Application kg/ha) Groundnut	Average Rate of application (kg/ha) soybean	The average rate of application in kg(ha) sunflower of a 3:2:1 (25)
Chemical fertilizer	45	60	60	16	35	70
kraal manure	17.4	16.3	17.1	300	400	400
leaf litter	2.2	3.4	3.1	10	10	10
crop residue	39.1	40	39.5	500	600	600
crop residue/kraal manure	41.3	40.3	40.3	800	750	750
Grand Total	100	100	100			

4.2.2.9 Herbicides, pesticides, fungicide uses in the Free State

Thirty percent of the farmers used a combo of herbicides and pesticides on their farms in the Free State. None of the farmers applied any form fungicide on their farms.

4.2.2.10 Weed control practices by farmers in Free State

Table 4.36 shows that farmers in the Free State have better weed management. Fifty-three percent of farmers had very effective weed management while 45 had somewhat effective weed management.

Table 4.36: Effectiveness of weed control management in the Free State.

Degree of Effectiveness	% of farmers
Very effective	53
Somewhat effective	45
Not effective at all	2
Grand Total	**100**

Table 4.37 focused on the frequency of weeding by the farmers. The results show that most of the farmers weeded their farms twice, followed by once and very few weeded thrice for groundnut. Soybean and sunflower were weeded once properly because they used round-up for weed management.

Table 4.37: Number of times crops were weeded in the 2016/2017 season in Free State.

Number of times	% Groundnut	% Soybean	% sunflower
Once	49	60	65
Twice	49.5	40	34
Thrice	.5	0	0
Grand Total	100	100	100

4.2.2.11 Water management techniques utilized by farmers in Free State

All the farmers were using one water management technique or the other. The most employed method is deep weeding, followed by cover crop and mulching as shown in Table 4.38.

Table 4.38: Water harvesting technique employed in Free State.

Water harvesting technique	**Free State**
cover crops	13.53
Contour ploughing	11.5
Ridging	6.32
Deep weeding	52.35
Pot holding	2.5
mulching	12.38
furrow Drainage	1.42
if other Specify	0
Grand total	100

4.2.2.11 Crop production factors influencing investment decisions in the Free State

Sampled farmers in the Free State were asked which factors influenced their investment decisions in producing groundnuts, soybean, sunflower. Their response is shown in Figures 4.20 to 4.22. It can be seen that when decisions on what to produce are made with respect to groundnuts, aspects such rainfall (83%) input temperature (70%) and irrigation equipment (68%) make the farmers not to plant groundnut (Figure 4.21). As can be seen in the soybean and sunflower production constraint, climate plays a great role in planting decisions as with that of groundnut.

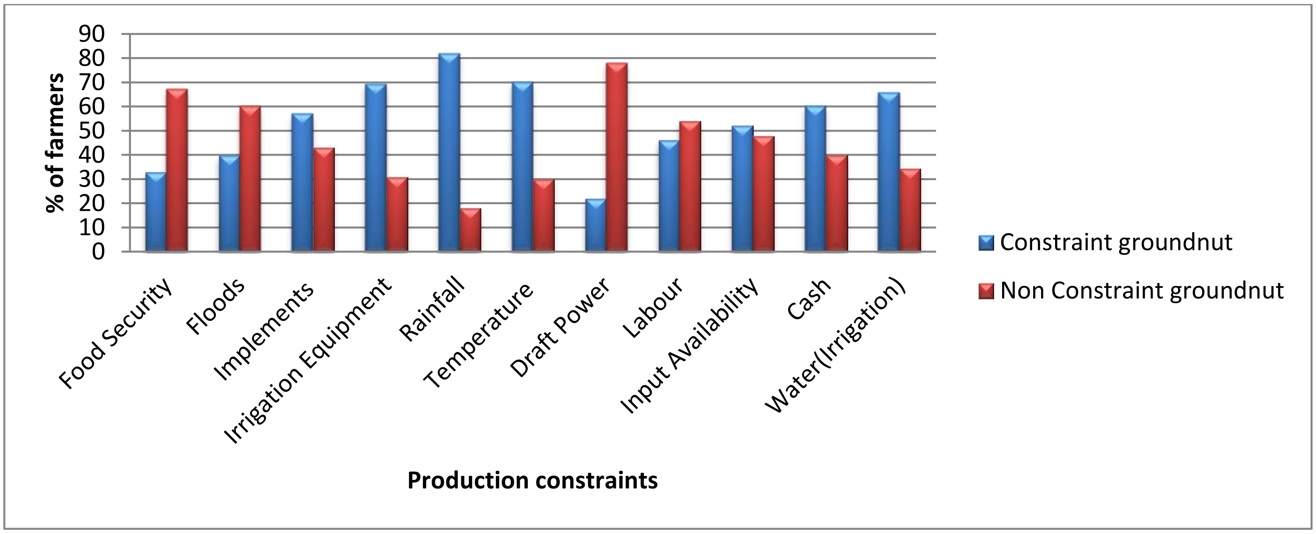


Figure 4.20: Factors influencing groundnut production in Free State.

Figure 4.21 shows that the most constraining factors influencing soybean production are temperature (70%) and input availability (48.83%). On the non-constraint side, labor is at

9%. This might be because it is mostly the youths taking the chance to cultivate soybean. The older farmers are not very keen on its cultivation because it does not contribute towards their food security.

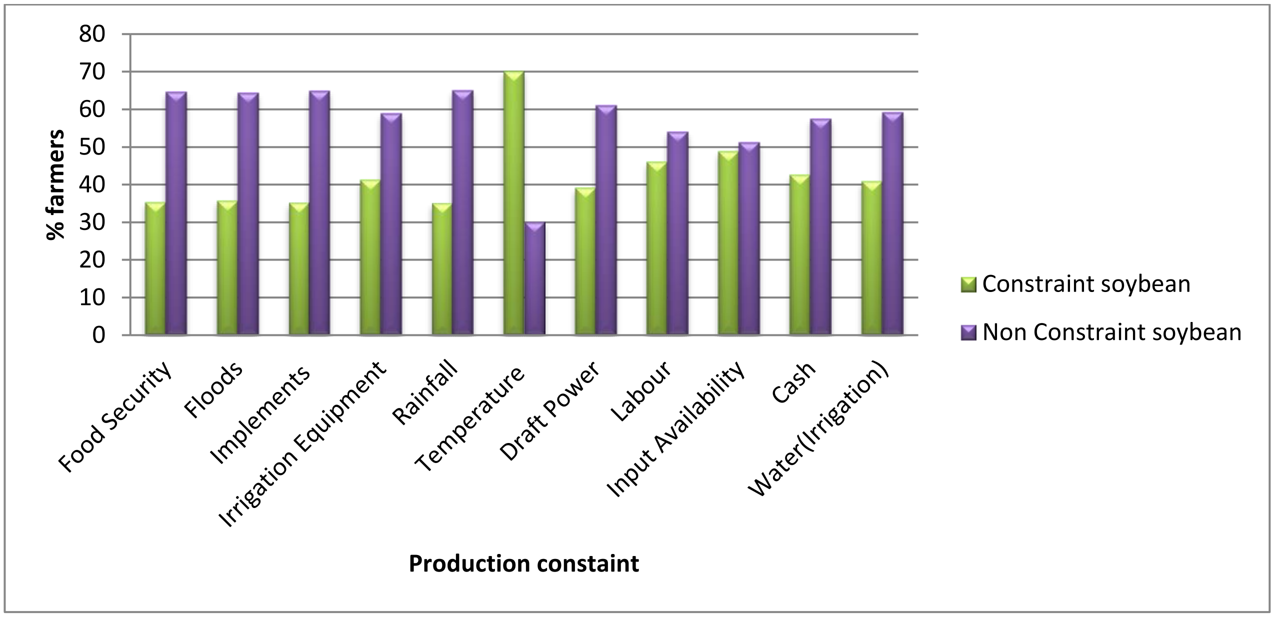


Figure 4.21: Factors influencing soybean production in the Free State.

Figure 4.22 indicates that sunflower is not on the top of choice for the farmer. Most of the factors are constraining factors of production.

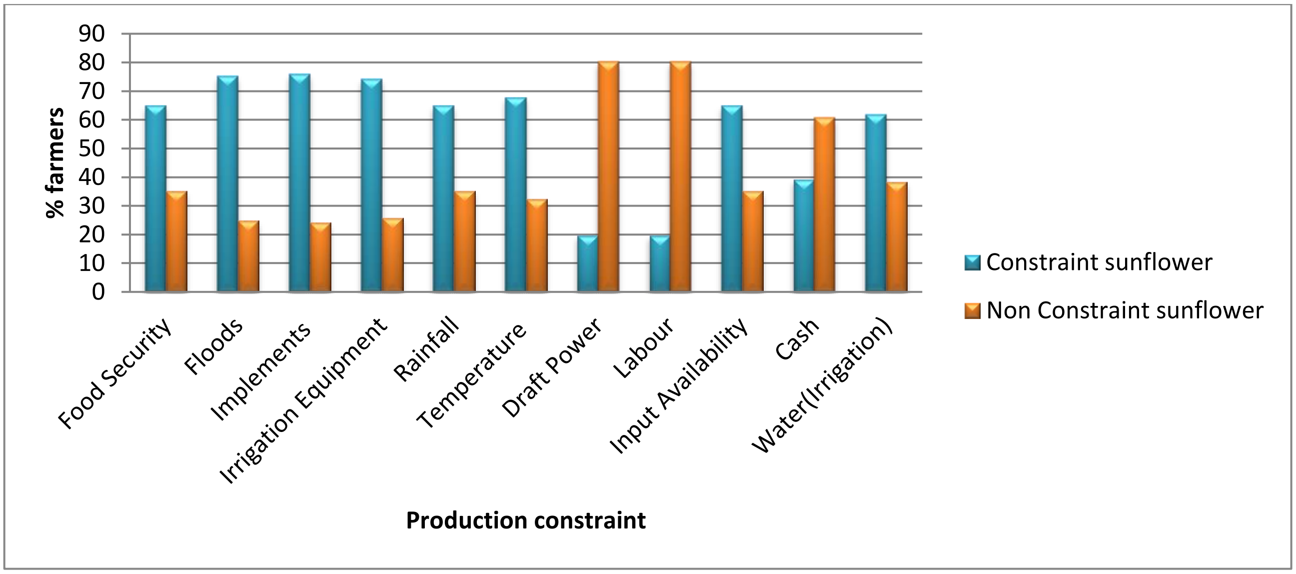


Figure 4.22: Factors influencing sunflower production in Free State.

4.2.2.12 Cropping decisions influenced by the climate in the Free State

With regards to sunflower, the cropping decisions most affected by climate are planting date and water as seen in Figure 4.23. For groundnut planting date followed by water and sunflower water ranks the highest followed by planting dates.

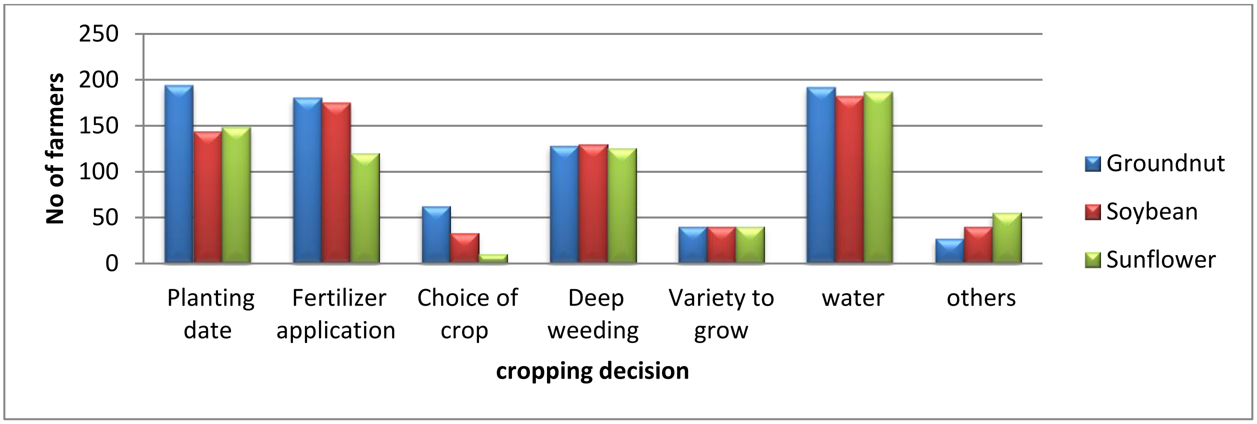


Figure 4.23: Cropping decision influenced by the climate in Free State.

4.2.2.13 Deviations from usual agronomic practices in the farming season 2016/2017 in Free State

Farmers were asked about deviations from their usual agronomic practices in the cropping season 2016/2017. The deviation was regarding the range of crops, the range of area planted, crop tillage, tillage practices, and fertilization application. The deviation practices are all in lieu of adaptation.Figure 4.24 shows that most of the farmers (176) applied fertilizer at planting and also increased their range of crops (150). An average of 55.21429% of farmers deviated from their usual agronomic practices in the farming season 2016/2017.

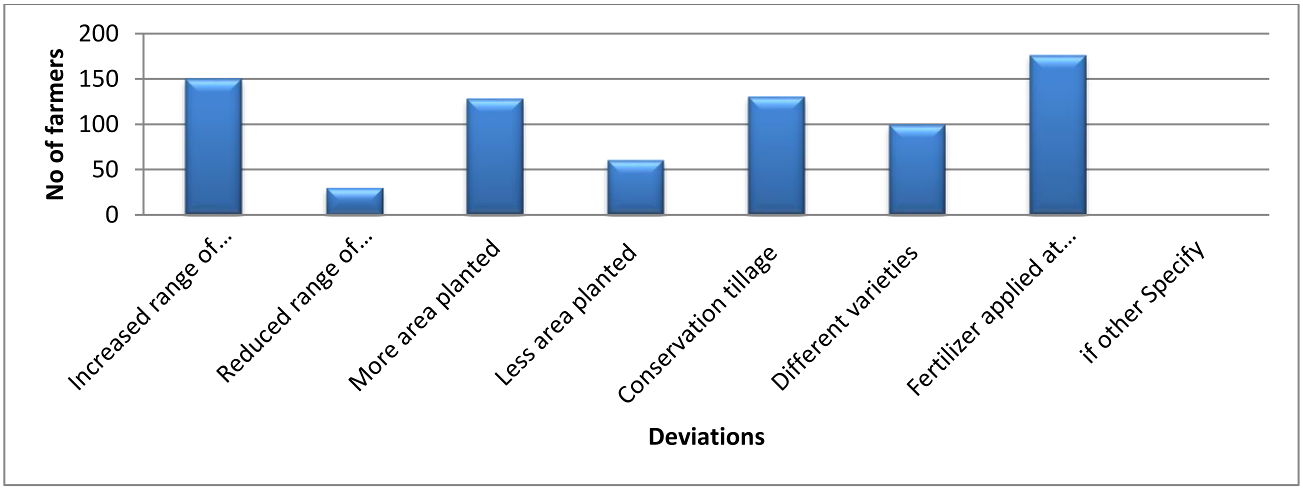


Figure 4.24: Deviations from normal agronomic practices in Free State.

4.2.2.14 Reasons for deviation apart from the climatic influence

The respondents were asked for reasons to deviations in farming practices apart from climatic factors. This was to rule out climate as the only reason why farmers are changing farming practices. Response to this question is shown in Figure 4.25. Results show that water is the most contributing factor to the deviation, followed by seed availability. Results here are like that in Limpopo. Water in this instance refers to the availability of ground sources for supplementary irrigation purposes.

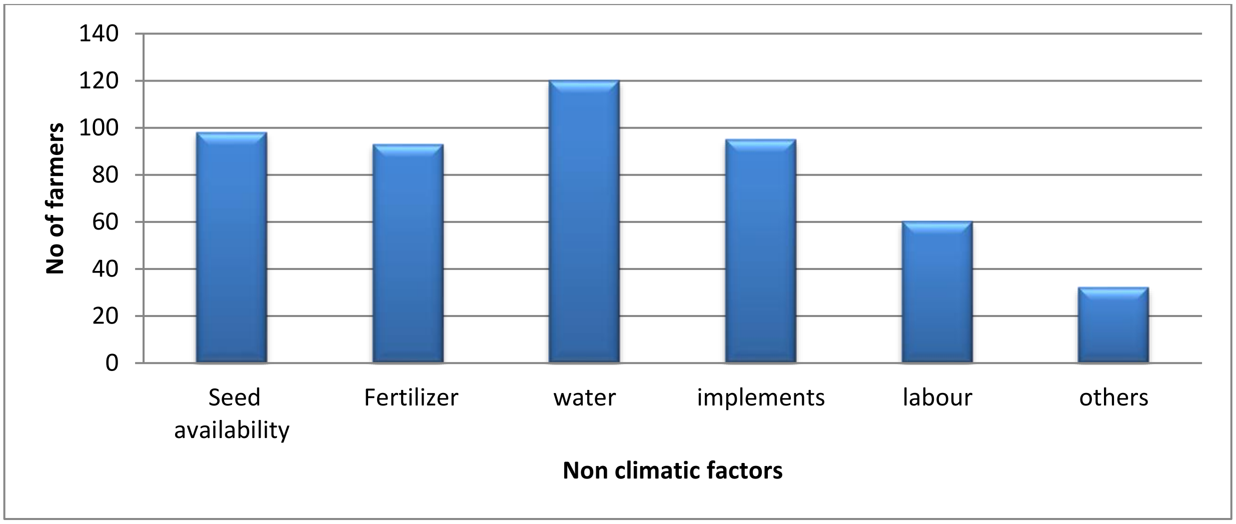


Figure 4.25: Nonclimatic factors causing deviation from normal agronomic practices in the Free State.

4.2.2.15 Constraints on agronomic practices and crop production caused by climate change and variability in Free State

The aim of this was to look at the constraints on agronomic practices and crop production caused by climate change and variability. It also throws light on the perception of the respondents to climate change and variability.

4.2.2.16 Farmer’s perception of Changes in weather patterns in the Free State

Respondents were asked if they have noticed any changes in the weather patterns since they started farming. All respondents noticed a change in weather pattern from the time they started farming. Figure 4.26 shows the result of the climate factors which were apparent to the respondents. Late rains, short season higher than normal rainfall (198 farmers) were the most obvious changes noted. All respondent conceded that these changes were apparent from year to year.

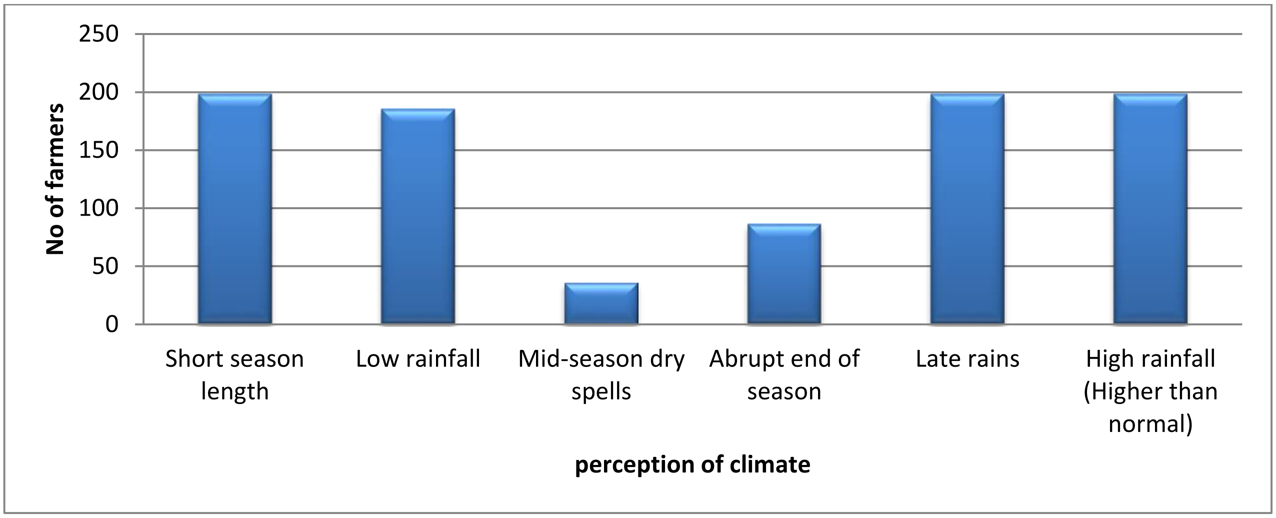


Figure 4.26: Farmer’s perception of a changing climate in Free State.

4.2.2.17 Effects of climate on farming practices in 2015/2016 farming season in the Free State

Due to the climate change and variability experienced by the farmers, they changed some of their farming practices in the 2015/2016 farming season. Figure 4.27 shows the number of farmers who changed farming practices in the 2015/2016 farming season due to climatic influences. With regards to specific crops, the area planted to groundnut and soybean was decreased by 40 and 20 respectively. Figures from Grain SA showed that area planted to groundnut in the Free State decreased drastically from 22500(000ha) in the 2014/2015 to 6500(000ha) in the 2015/2016 farming season. One hundred farmers increased the area planted for sunflower. This also ties in with statistics from Grain SA which shows area planted to sunflower in the Free State increased from 49.4% to 55.5% in the 2014/2015 to 2015/2016 farming season.

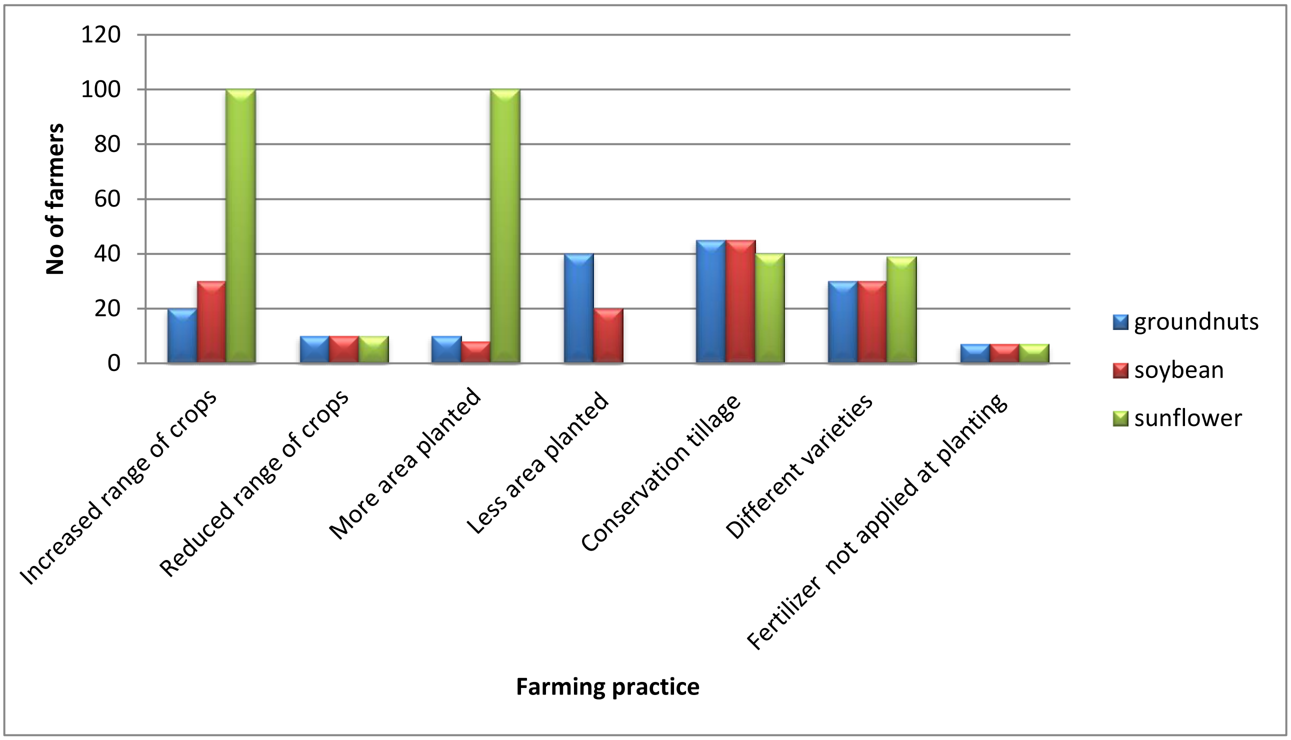


Figure 4.27: Climate influence on farming practices in the Free State.

4.2.2.18 Impact of weather on farming activities in the Free State

All the farmers attested that the changing climate affected their farming activities in the farming season. Results ties in with results shown by Figure 4.28 above.

4.2.2.19 Variability in agronomic practices in the Free State

With regards to changes in farming activities, the farmers were asked if they had drastically changed their practices. As shown by Figure 4.28, 83% of the farmers said they had drastically changed their farming activities from the time they started farming. This response comes from most of the older farmers because of the climate variability experienced in the area. Seventeen percent of the farmers said they have not drastically changed their farming methods.

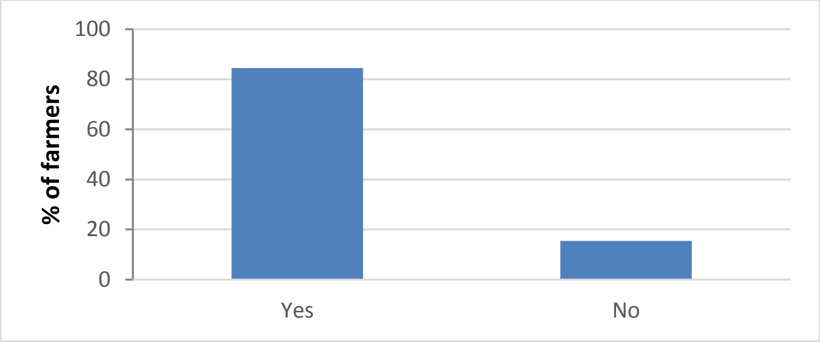


Figure 4.28: Drastic changes in farming practices experience by farmers in the Free State.

Figure 4.29 shows that 101 farmers changed their farming activities on a yearly basis while 99 said they don't change their practice yearly.

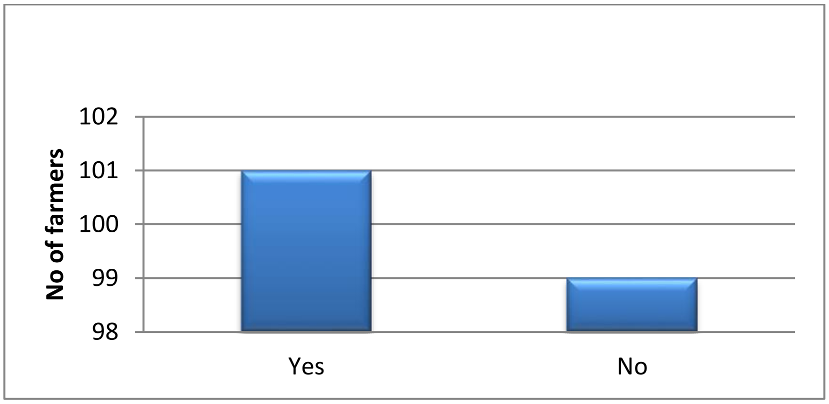


Figure 4.29: Variability in annual farming practices in the Free State province.

4.2.2.20 Climatic thresholds affecting farmers in the Free *State*

Results from Figure 4.30 show that most farmers were affected by droughts (185) followed by hail (63), frost (50) and lastly by floods (343). Waterlogging is not much of a problem here as only 10 farmers say they are affected by it.

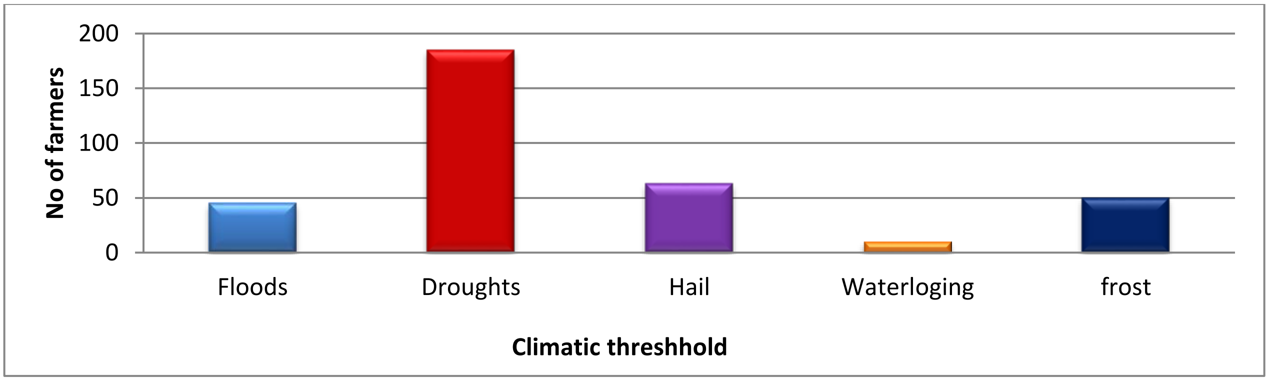


Figure 4.30: Climatic thresholds affecting farmers the most in the Free State.

4.2.2.21 Coping and adaptation strategies to climate variability/change in the Free State

Farmers were asked if they had ways to deal with the extreme events as experienced in 4.2.2.16 above. The response is presented in Table 4.39.

Table 4.39: Coping and adaptation strategies to climate variability/change in the Free State

Climatic effects	Response
Drought	• Change the type of crop planted • Change in planting date • Change cultivar
Floods	• Change of planting dates • Channels created • More than one type of crop planted
Hail	• nothing
Frost	• Change planting dates,

With regards to changes in production output due to the changes in farming practices employed by farmers due to extreme climate events, 86.25% of the farmers said they noticed changes in their production while 14.75% said they did not notice any difference. Farmers, who experienced changes due to their coping strategies, said they also experienced an increase in yield for the crops planted.

4.2.2.22 Other sources of income to farmers in the Free State

The farmers were asked if they had other sources of income. Results showed that they had other sources of income besides grain crop production. Most of the additional income sources came from animal rearing followed by other commercial activities as shown by Figure 4.31.

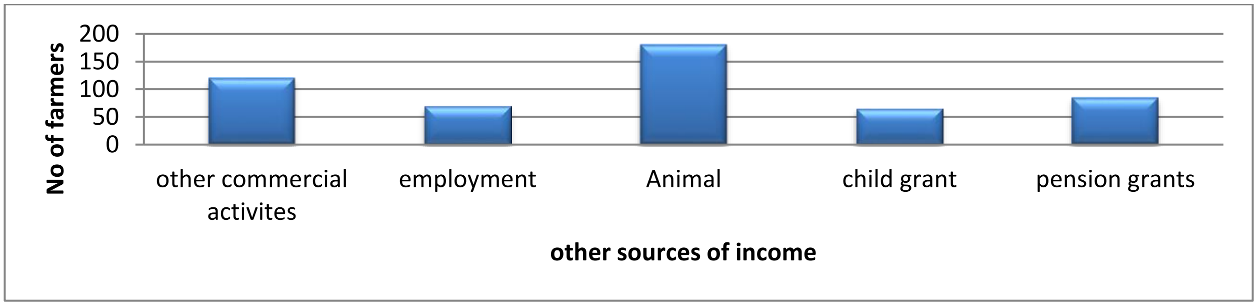


Figure 4.31: Other sources of income to farmers in the Free State.

4.2.2.23 Household composition in the Free State

Results from the survey showed that the sampled household of the farmers made up a total male of 267 and a total of 233 female. The average household size was estimated at 3.2 persons per household. The age distribution in households is shown in Table 4.40. It shows that the predominant age group is the age group 16-26 (50) followed by the 0-15 age group (45).

Table 4.40: Age composition of households in the Free State.

Age	Total Free State
0-15	45
16-26	50
27-37	29
38 -48	30
49-59	24
60	22

The result of the age distribution showing a young population tie in with the population pyramid of South Africa, which shows an increase in the young.

With regards to marital status, most farmers (296) were married followed by 150 who were single. A total of 105 were widowed while 49 of them were divorced.

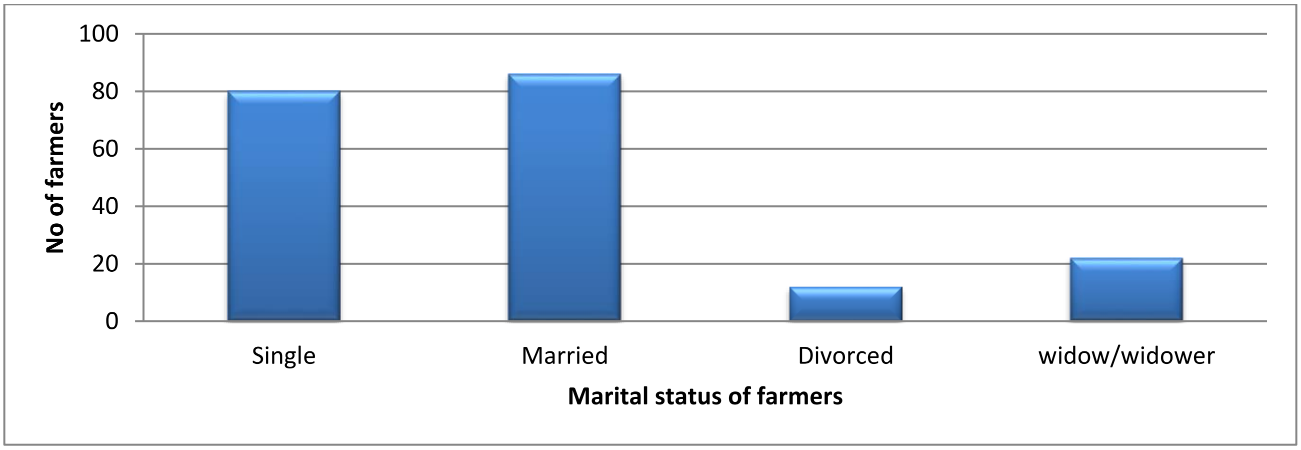


Figure 4.32: Marital status of farmers in the Free State.

When asked if the farmers had other dependents living outside their households, 107 of them said yes. An average of 1.2 persons living out of the farmers household was dependent on the farmers.

From the household characteristic presented above, the households are mostly made up of males; they have a high percentage of young children and old people as against the youth; a high percentage of single-parent households (widowed, single, divorced) (Figure 4.32) and the size of their household is smaller. This factor working together places the household at risk to the ravages of climate but less vulnerable when compared to the household characteristics of Limpopo.

4.2.2.23 The predominant livelihood of the community in the Free State

All the respondents attested to the fact that agriculture was the predominant activity in their community.

4.2.2.24 Institutional support arrangements and access to finance in the Free State

Results from Figure 4.33 shows the kind of support that the farmers receive from governmental and non-governmental institutions to assist them. Most support is received from DAFF followed by NGO's and Argo finance institutions. The most type of support received is in terms of educational support, followed by others (e.g. irrigation schemes, animals, fertilizers).

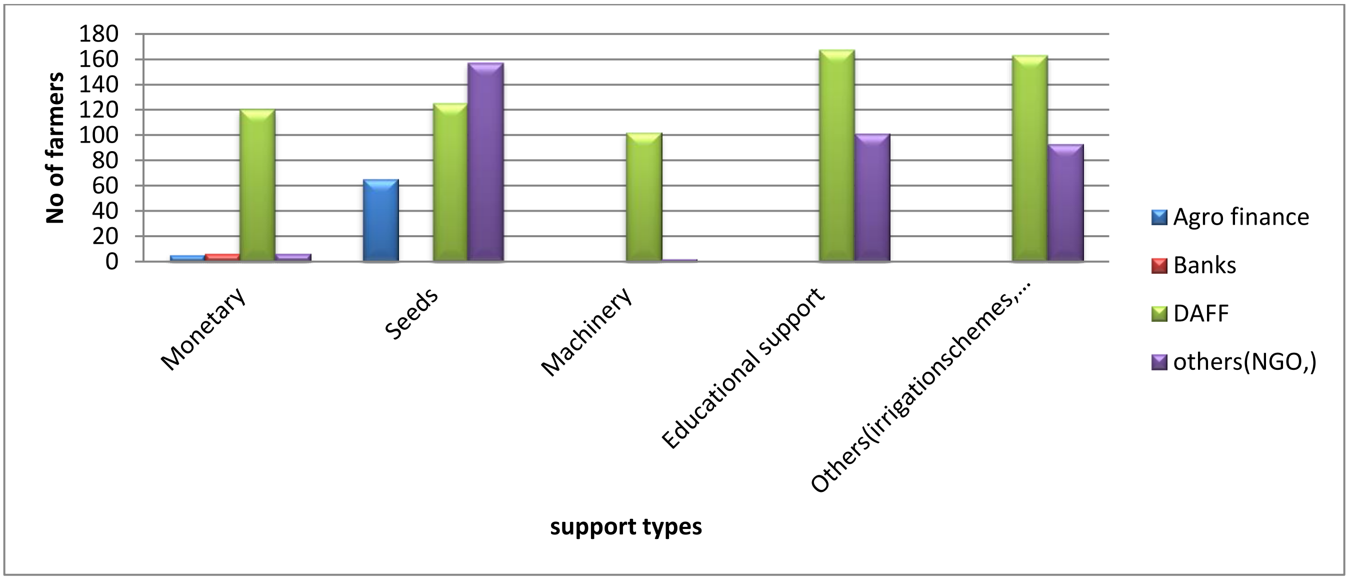


Figure 4.33: Infrastructure and institutional arrangements to support farmers in the Free State Province.

With respect to how easy it is to farmers to access finance; the results are shown by Figure 4.34 show that cooperatives are the easiest to access; banks and microfinance institution are not easily accessible to farmers.

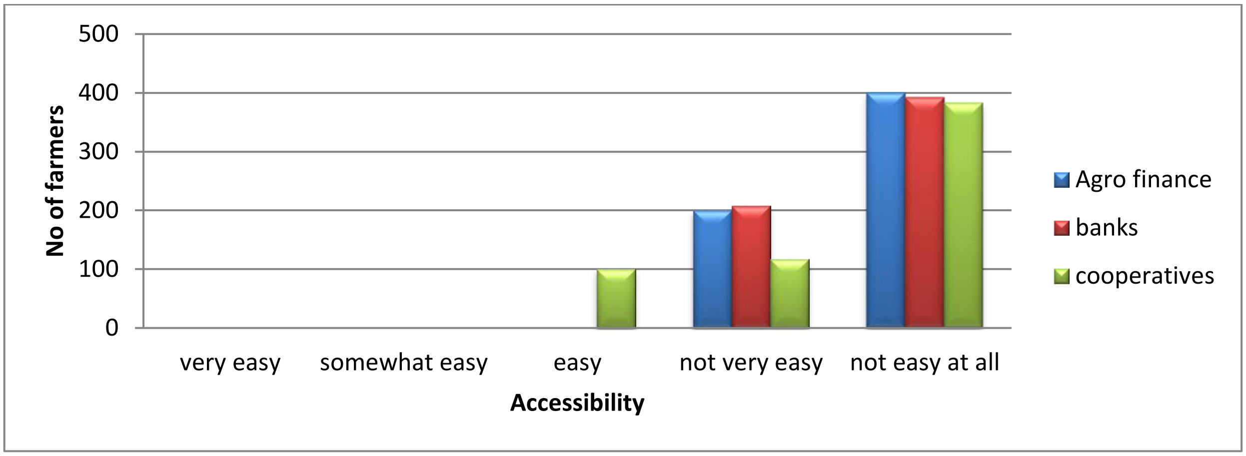


Figure 4.34: Ease of obtaining credit facilities by farmers.

4.2.2.25 Important changes best suited to maintain production under climate change

Farmers were asked to rank practice categories in order of importance to continuing production effectively under climate change. The ranking was done in relation to five categories seen with 1 being the most important and 5 the least important. Farming practices were categorized into five categories: on farm management, new technologies, conservation agriculture, diversification on and beyond farm and different dating of farming practices.

Table 4.41 shows that the important farm management practice to be prioritized will be to apply fertilizers that breaks down and releases nutrients and followed by feeding crop residues to the livestock. The results showed that with regards to conservation agriculture, ripper tillage production is preferred by most farmers, followed by the application of residue as mulch to bare soil and lastly the adoption of no-till production. With respect to diversification on and beyond the farm, farmers preferred changing from crop production to livestock and dairy production, followed by intercrop with legumes, intercropping with trees and lastly changing to non-farming activities. With regards to new technologies, farmers choose drought tolerant and fast maturing cultivars to be the most important, followed by changing tools for farming and lastly flood-tolerant crops. On farming dates, all the farmers (100%) ranked it as the most important factor to be changed.

Table 4.41: Management changes to be made for optimum production by farmers under changing climatic conditions.

	Rank	**Apply fertilizers according to fertilizer recommendations**	**Apply a fertilizer that breaks down and releases nutrients slowly**	**Changing crop produced to another**	**Feed crop residues to livestock**	**Changing plant density**
Farm Management	1	20	164	58	150	20
	2	40	10	264	20	27
	3	120	6	138	5	101
	4	8	15	52	15	22
	5	12	5	88	10	30
Conservation Agriculture		adopt no-till production	Adopt ripper tillage	Apply crop residue as a mulch to bare soil		
	1	8	180	167		
	2	6	8	13		
	3	101	2	17		
	4	73	9	2		
	5	12	1	1		
Diversification on and beyond the farm		The shift from farming to non-farming activities	Intercrop with legumes	Intercrop with trees	Changing from crop production to livestock and dairy production	
	1	7	15	50	175	
	2	6	160	20	1	
	3	53	13	100	20	
	4	101	5	19	2	
	5	4	7	11	3	
New Technologies		adopt flood tolerant cultivars	Adopt drought tolerant fast-maturing cultivars	change in farming tools		
	1	1	160	50		
	2	22	20	120		
	3	167	115	20		
	4	3	3	8		
	5	7	22	2		
Different Dating for Farming Practices		Planting Date				
	1	200				

4.2.2.26 Changes in income and revenue 2014-2017 farming season in the Free State Province

Farmers were asked about the cost incurred, as well as the revenue received from the production of sunflower, groundnut, and soybean for the 2014 to 2017 farming season as shown by Tables 4.42 to 4.44.

Table 4.42: Cost of production and revenue from groundnut production in the Free State in the 2014-2017 Farming Season.

Groundnut Production				
	The average cost of production(R/ha)	Average yield t/ha	Total revenue (R)	Yield per province t/ha
2014/2015	8500	3.3	273900	0.969
2015/206	4200	1.1	200000	0.449
2016/2017	4800	2	230900	1.5

Table 4.43: Cost of production and revenue from groundnut production in the Free State in the 2014-2017 Farming Season.

Soybean Production				
	The average cost of production(R/ha)	Average yield t/ha	Revenue (R)	Yield per province t/ha
2014/2015	6500	2.9	345000	3
2015/206	5800	2.8	280900	2.4
2016/2017	4800	3.6	212000	3.5

Table 4.44: Cost of production and revenue from groundnut production in the Free State in the 2014-2017 Farming Season.

Sunflower Production				
	The average cost of production(R/ha)	Average yield t/ha	Revenue (R)	Yield per province t/ha
2014/2015	6500	2.9	245000	3
2015/2016	6000	2.8	280000	2.4
2016/2017	8500	3.6	212000	3.5

4.2.2.27 Summary of Survey Results

The focus of carrying out this survey was to gain an understanding of the underlying agronomic and socioeconomic factors that could contribute to farmers' vulnerability to a changing climate. Farmers in specific localities within the study areas tend to be more vulnerable than others in other localities within the same study area. The causal dimensions of social vulnerability in the Limpopo and Free State Provinces across the various AEZ were identified and data collected in relation to farming practices, farmers profile, choice of adaptive responses, household information, and sources of income, aid and support received. Descriptive statistics were used to highlight the responses and indicate the differences in responses across th study area. The next section presents results on the field experiments carried out as shown in the methodology (3.2.4).

4.3 Field Experiment and Crop simulation

The results of the field experiments carried out are shown in below in Table 4.45 and in Appendices 4.3 to 4.7. Yield varied across the seasons, per fertilizer treatment and between locations. Results from the field experiments were used to feed the crop simulation model-AquaCrop.

Table 4.45: Results from field experiments showing yield per crop type (kg/ha).

Location Date	Crop	Fertilizer application	Mean Yield (kg/ha)
Syferkuil 2016/2017	Sunflower	0 Nkg/ha	1245.8
		75 Nkg/ha	1393.5
		150 Nkg/ha	2036.5
Syferkuil 2016/2017	Soybean	0Pkg/ha	1103.1
		30 Pkg/ha	1046.9
		60 Pkg/ha	1004.4
Syferkuil 2016/2017	Groundnut	0Pkg/ha	1461.7
		30 Pkg/ha	1248.2
		60 Pkg/ha	1329
Syferkuil 2017/2018	Sunflower	0 Nkg/ha	2119.8
		75 Nkg/ha	2329.9
		150 Nkg/ha	1790.5
Syferkuil 2017/2018	Soybean	0Pkg/ha	1003.7
		30 Pkg/ha	1179.9
		60 Pkg/ha	1601.1
Syferkuil 2017/2018	Groundnut	0Pkg/ha	1172.5
		30 Pkg/ha	1208.3
		60 Pkg/ha	1021.7
Ofcolaco 2016/2017	Sunflower	0 Nkg/ha	1560.7
		75 Nkg/ha	1192.1
		150 Nkg/ha	1397.6
Ofcolaco 2016/2017	Soybean	0Pkg/ha	1123.1
		30 Pkg/ha	1166.6
		60 Pkg/ha	1124.4
Ofcolaco 2016/2017	Groundnut	0Pkg/ha	2034.7
		30 Pkg/ha	2195.9
		60 Pkg/ha	2195.75
Ofcolaco 2017/2018	Sunflower	0 Nkg/ha	1319.8
		75 Nkg/ha	1529.9
		150 Nkg/ha	1990.5
Ofcolaco 2017/2018	Soybean	0Pkg/ha	993.7
		30 Pkg/ha	1000.9
		60 Pkg/ha	1000.6
Ofcolaco 2017/2018	Groundnut	0Pkg/ha	1560.5
		30 Pkg/ha	1678.6
		60 Pkg/ha	1625.7
Punda Maria 2017/2018	Sunflower	0 Nkg/ha	1355.8
		75 Nkg/ha	2149.1
		150 Nkg/ha	2374.4
Punda Maria 2017/2018	Soybean	0Pkg/ha	1086.6
		30 Pkg/ha	1459.2
		60 Pkg/ha	1185
Punda Maria 2017/2018	Groundnut	0Pkg/ha	2372.5
		30 Pkg/ha	1508.6
		60 Pkg/ha	1521.7

4.3.1 Calibration of AquaCrop model

In AquaCrop, the field experiment data of the first growing season (2016/2017) conducted at Syferkuil research farm and Ofcolaco were used for the model calibration. Crop traits from field experimental data, shown in Table 4.46, were used in the calibration process of the AquaCrop soybean sunflower and groundnut (calibrated using a generic crop) modules. The calibration models showed a close prediction of emergence, flowering, maturity, and yields. The model simulations were initiated with specified sowing dates, planting density, and observed initial soil-water and soil fertility conditions with default genotypic coefficients of the crop varieties. Thereafter, the parameters for phenology, biomass and grain yields at harvesting (Table 4.43) were adjusted to closely match the observed experimental data.

Table 4.46: Calibration results for AquaCrop - Sunflower, Soybean and Groundnut models for three fertilizer treatments using experimental data.

Crop Traits	**Units**	**Observed sunflower (0Nkg/ha fertilizer)**	**Simulated sunflower (0nkg/ha)**	**Observed sunflower (75Nkg/ha fertilizer)**	**Simulated sunflower (75nkg/ha)**	**Observed sunflower (150Nkg/ha fertilizer)**	**Simulated sunflower (150nkg/ha)**
Emergence	DAP	7	7	9	9	8	8
Flowering	DAP	47	47	58	58	51	51
Maturity	DAP	147	149	150	150	145	144
Yield	kg/ha	1560.7	1716	1192.1	1240	1397.6	1440.3
Crop traits	**2017**	**Observed soybean (0pkg/ha fertilizer)**	**Simulated soybean (0pkg/ha)**	**Observed soybean (30pkg/ha fertilizer)**	**Simulated soybean (30nkg/ha)**	**Observed soybean (60pkg/ha fertilizer)**	**Simulated soybean (60pkg/ha)**
Emergence	DAP	8	8	7	7	5	5
Flowering	DAP	60	60	60	59	57	57
Maturity	DAP	147	150	145	149	143	147
Yield	kg/ha	1223.1	1403	1166.6	1192	1154.4	1187
Crop traits	**Units**	**Observed groundnut (0pkg/ha fertilizer)**	**Simulated groundnut (0pkg/ha)**	**Observed groundnut (30pkg/ha fertilizer)**	**Simulated groundnut (30nkg/ha)**	**Observed groundnut (60pkg/ha fertilizer)**	**Simulated sunflower (60pkg/ha)**
Emergence	DAP	8	8	8	8	8	8
Flowering	DAP	57	57	63	62	58	58
Maturity	DAP	147	143	147	143	147	143
Yield	kg/ha	2034.7	2148	2195.9	2392	2195.75	2376

The calibration dataset contained nine observations across the different surface fertilizer practices described above with a close fit found for sunflower soybean and groundnut grain yield between observed and predicted data (Figure 35a, b, c – 36a, b, c). A similar strong correlation was shown between the predicted and observed yield. For soybean, the RMSE was 106.6kg/ha, 97.25 kg/ha for soybean and 167.1kg/ha for groundnut at Ofcolaco. Similarly Figure 37a, b and c results for season 1 (2016/2017) season in Syferkuil shows high correlations with RMSE of 253.8kg/ha for soybean, 169.4kg/ha for sunflower and 66.4kg/ha for groundnuts.

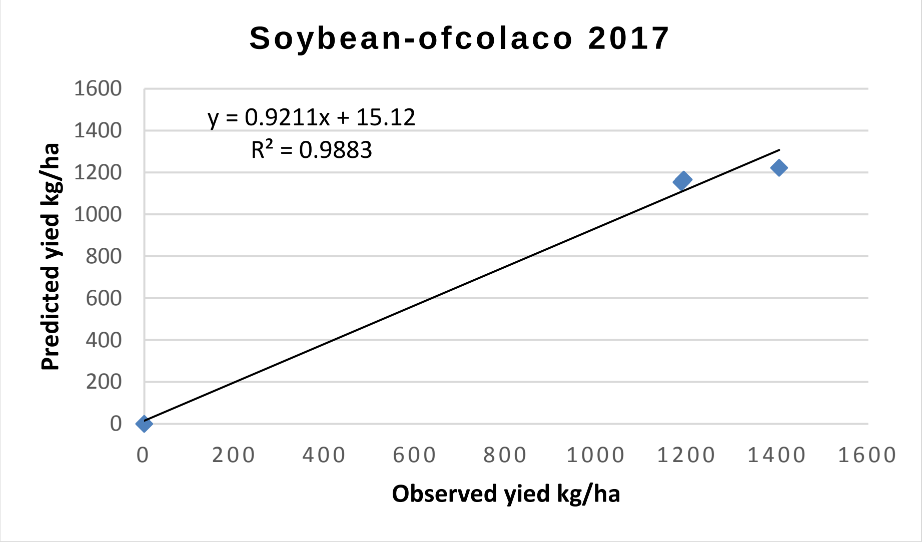


Figure 4.35a: Predicted vs. observed grain yield of soybean under different fertilizer treatment at Ofcolaco during the 2016/2017 growing season

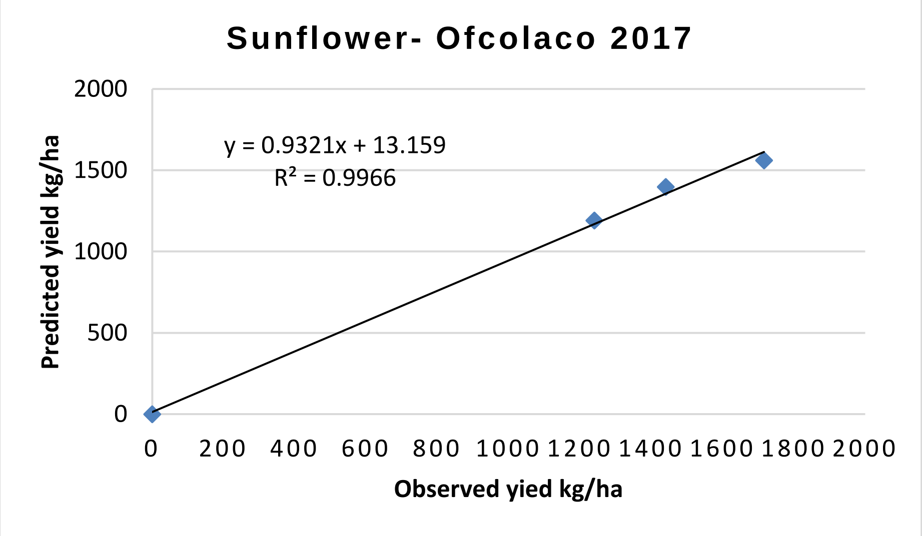


Figure4.35b: Predicted vs. observed grain yield of sunflower under different fertilizer treatment at Ofcolaco during the 2016/2017 growing season.

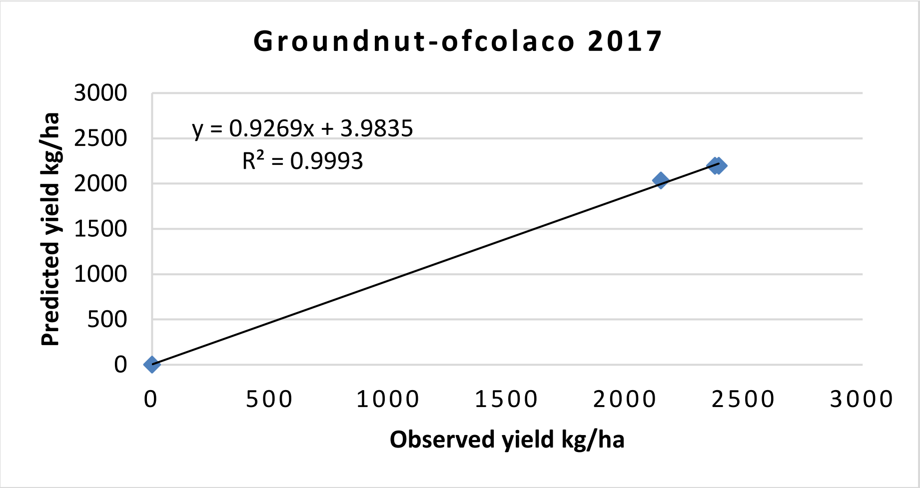


Figure4.35c: Predicted vs. observed grain yield of sunflower under different fertilizer treatment at Ofcolaco during the 2016/2017 growing season.

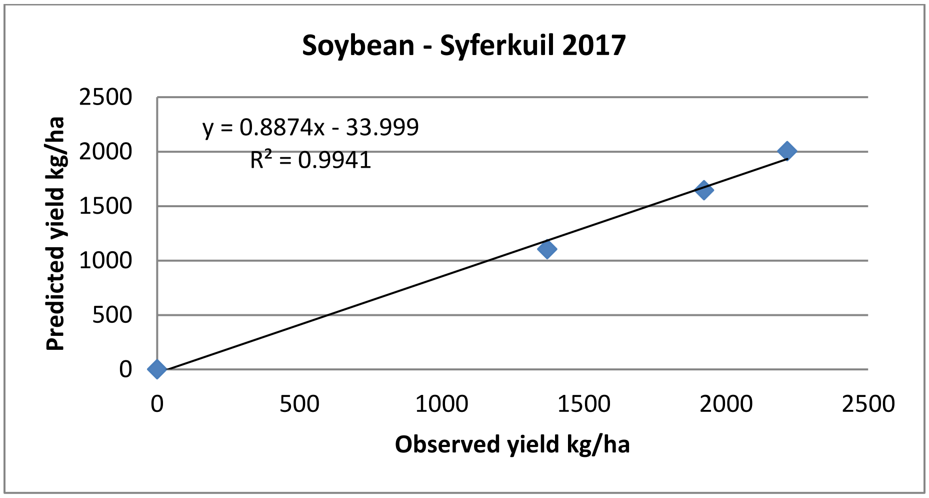


Figure4.36a: Predicted vs. observed grain yield of soybean under different fertilizer treatment at Syferkuil during the 2016/2017 growing season

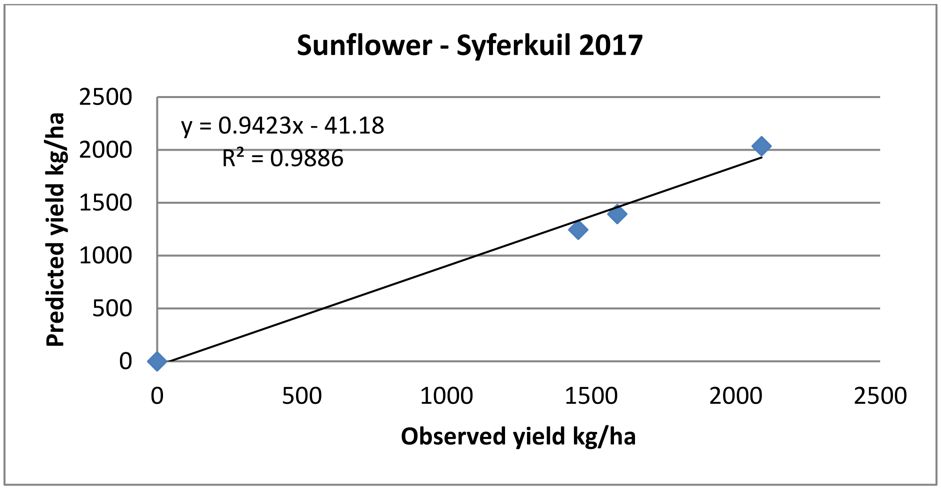


Figure4.36b: Predicted vs. observed grain yield of sunflower under different fertilizer treatment at Syferkuil during the 2016/2017 growing season

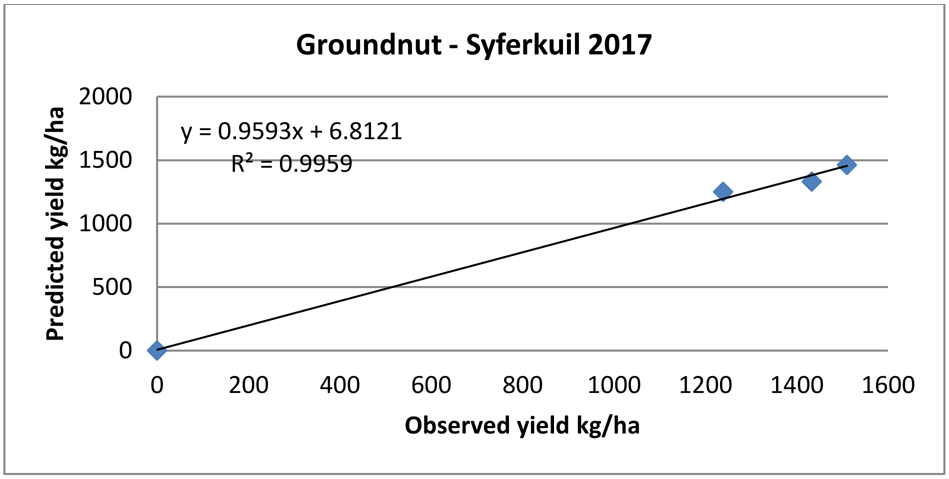


Figure 4.36c: Predicted vs. observed grain yield of groundnut under different fertilizer treatment at Syferkuil during the 2016/2017 growing season

4.3.2 Model validation

The AquaCrop model was validated to determine the confidence level in the calibrated model to simulate the experimental field conditions and treatments. The sunflower, soybean, and groundnut grain yield validation analyses showed a strong relationship between predicted and observed in Ofcolaco, Syferkuil, and Punda Maria as seen in Figures 4.37a, b, and c for Ofcolaco; Figures 4.38a, b and C for Syferkuil and Figures 4.39a, b and c for Punda Maria. The validation analyses of the model to simulate the three fertilizer treatments, in Ofcolaco, Syferkuil and Punda Maria, indicated a strong agreement between the predicted and observed soybean, sunflower and groundnut grain yield with R^2 range between 83 and 99% of yield at harvesting. The RMSE for the simulated versus the predicted yield is shown in Tables 4.47 for Ofcolaco, 4.48 for Syferkuil and 4.49 for Punda Maria for sunflower, soybean, and groundnut. RMSE ranged from 14.1kg/ha to 339kg/ha.

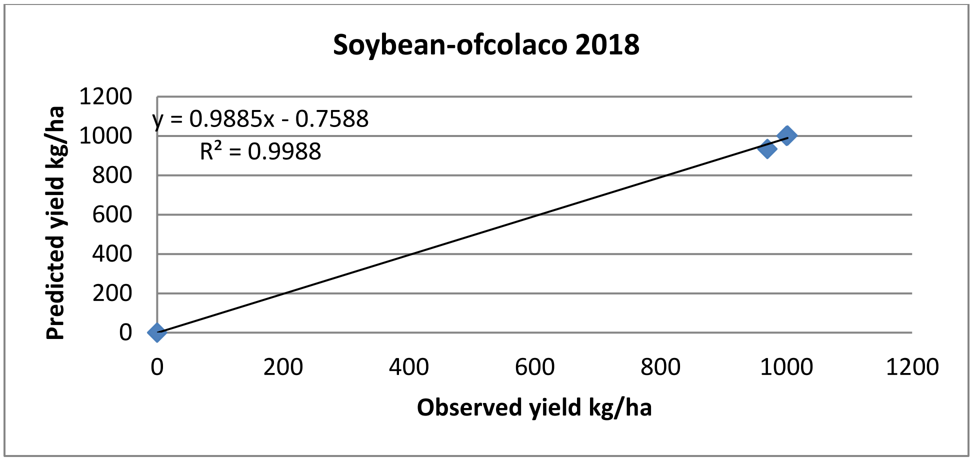


Figure 4.37a: Predicted vs. observed grain yield of soybean under different fertilizer treatment at Ofcolaco during the 2017/2018 growing season.

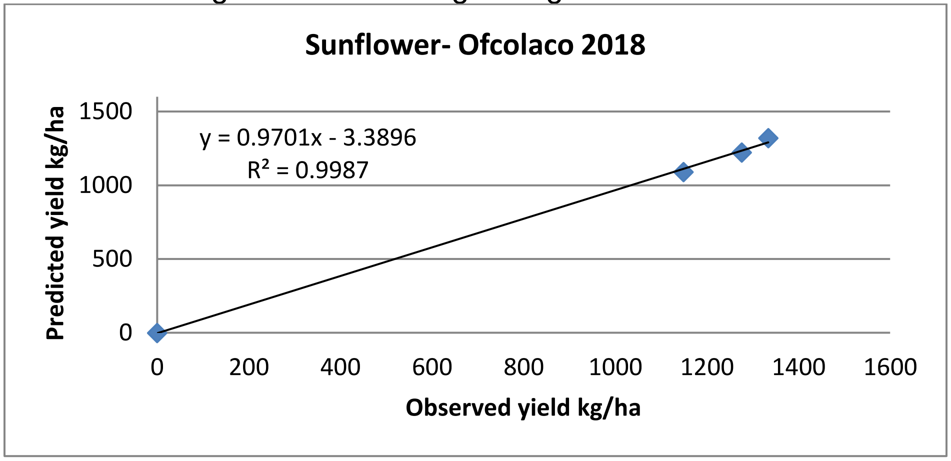


Figure 4.37b: Predicted vs. observed grain yield of sunflower under different fertilizer treatment at Ofcolaco during the 2017/2018 growing season.

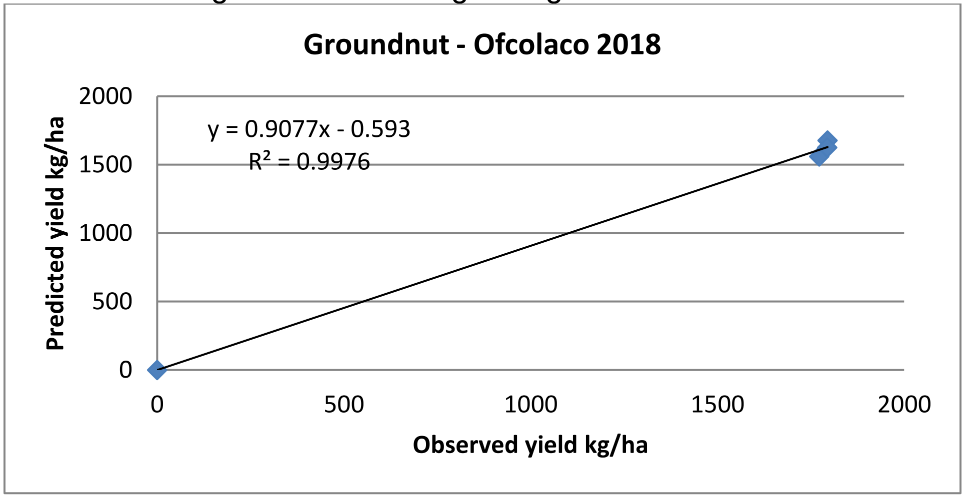


Figure4.37c: Predicted vs. observed grain yield of groundnut under different fertilizer treatment at Ofcolaco during the 2017/2018 growing season.

Table 4.47: Predicted vs. observed crop growth stages measured as days after planting under different fertilizer treatment at Ofcolaco during the 2017/2018 growing season

Crop Traits	**Units**	**observed sunflower (0Nkg/ha fertilizer)**	**simulated sunflower (0NKg/ha)**	**observed sunflower (75Nkg/ha fertilizer)**	**simulated sunflower (75NKg/ha)**	**observed sunflower (150Nkg/ha fertilizer)**	**simulated sunflower (150NKg/ha)**	**RMSE kg/ha**
emergence	DAP	7	7	9	10	8	8	
flowering	DAP	60	70	65	60	63	63	
maturity	DAP	123	123	128	125	130	128	
yield	kg/ha	1319.8	1334	1222.9	1276	1090.5	1153	97.0
Crop traits	**2017**	**Observed soybean (0pkg/ha fertilizer)**	**Simulated soybean (0pkg/ha)**	**Observed soybean (30pkg/ha fertilizer)**	**Simulated soybean (30nkg/ha)**	**Observed soybean (60pkg/ha fertilizer)**	**Simulated soybean (60pkg/ha)**	**Rmse**
emergence	DAP	8	8	7	7	5	5	
flowering	DAP	60	60	60	59	57	57	
maturity	DAP	147	150	145	149	143	147	
yield	kg/ha	1223.1	1403	1166.6	1192	1154.4	1187	46.35
Crop traits	**Units**	**Observed soybean (0pkg/ha fertilizer)**	**Simulated soybean (0pkg/ha)**	**Observed soybean (30pkg/ha fertilizer)**	**Simulated soybean (30nkg/ha)**	**Observed soybean (60pkg/ha fertilizer)**	**Simulated soybean(60pkg/ha)**	
emergence	DAP	7	8	7	7	6	5	
flowering	DAP	60	60	57	59	56	57	
maturity	DAP	146	150	145	149	144	147	
yield	kg/ha	923.7	970	1000.9	1002	1000.6	1000.3	20.9
Crop traits	**Units**	**Observed groundnut (0pkg/ha fertilizer)**	**Simulated groundnut (0pkg/ha)**	**Observed groundnut (30pkg/ha fertilizer)**	**Simulated groundnut (30nkg/ha)**	**Observed groundnut (60pkg/ha fertilizer)**	**Simulated groundnut (60pkg/ha)**	
emergence	DAP	8	8	8	8	8	8	
flowering	DAP	58	58	62	58	58	58	
maturity	DAP	147	143	147	143	147	143	
yield	kg/ha	1560.5	1773	1678.6	1795	1625.7	1794	170.3

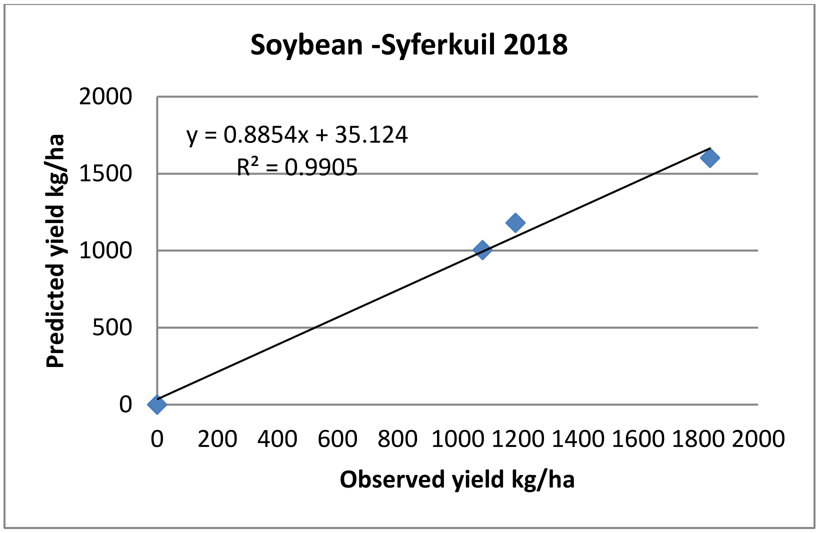


Figure 4.38a: Predicted vs. observed grain yield of soybean under different fertilizer treatment at Syferkuil during the 2017/2018 growing season.

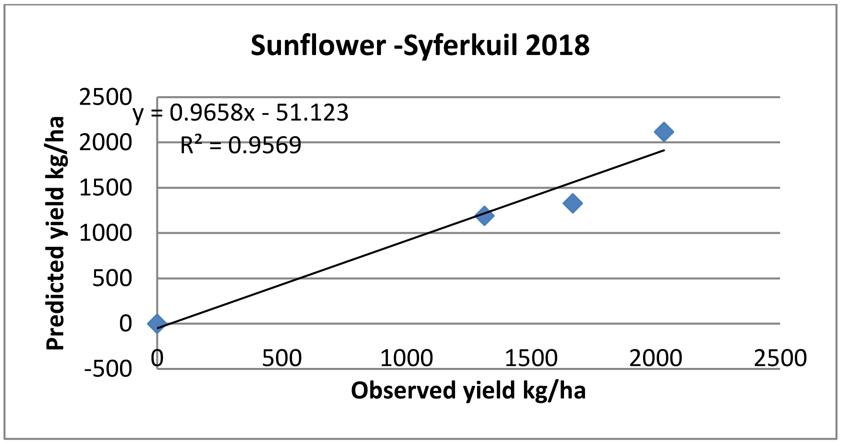


Figure 4.38b: Predicted vs. observed grain yield of sunflower under different fertilizer treatment at Ofcolaco during the 2017/2018 growing season.

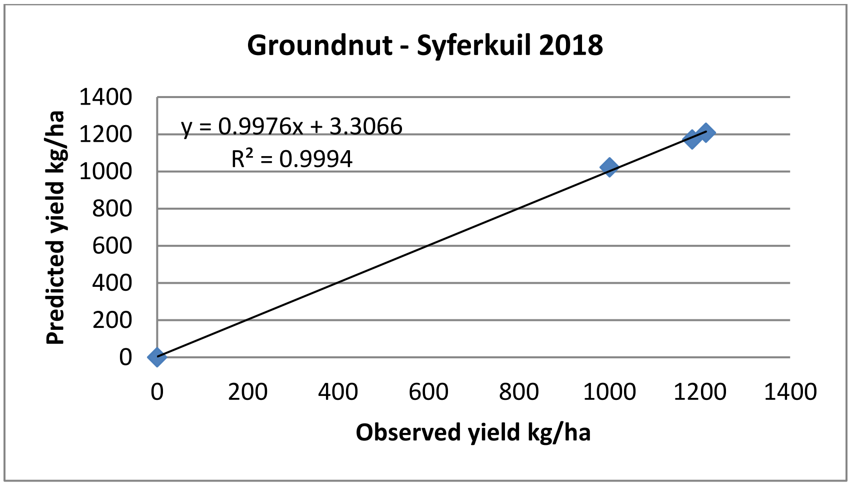


Figure 4.38c: Predicted vs. observed grain yield of groundnut under different fertilizer treatment at Syferkuil during the 2017/2018 growing season.

Table 4.48: Predicted vs. observed crop growth stages measured as days after planting under different fertilizer treatment at Ofcolaco during the 2017/2018 growing season.

Crop Traits	**Units**	**observed sunflower (0Nkg/ha fertilizer)**	**simulated sunflower (0NKg/ha)**	**observed sunflower (75Nkg/ha fertilizer)**	**simulated sunflower (75NKg/ha)**	**observed sunflower (150Nkg/ha fertilizer)**	**simulated sunflower (150NKg/ha)**	**RMSE kg/ha**
Emergence	DAP	11	11	8	8	7	7	
Flowering	DAP	55	55	51	51	63	63	
Maturity	DAP	130	115	146	138	144	125	
Yield	kg/ha	2119.8	2037	1329.9	1668	1190.5	1314	213.6
Crop Traits	Units	observed Soybean (0Pkg/ha fertilizer)	simulated Soybean (0PKg/ha)	observed Soybean (30Pkg/ha fertilizer)	simulated Soybean (30NKg/ha)	observed Soybean (60Pkg/ha fertilizer)	simulated Soybean(60PKg/ha)	RMSE
Emergence	DAP	6	6	7	7	5	5	
Flowering	DAP	67	67	73	73	62	62	
Maturity	DAP	122	113	148	114	144	141	
Yield	kg/ha	1000.3	1083	1179.9	1193	1601.1	1840	145.5
Crop Traits	Units	observed Groundnut (0Pkg/ha fertilizer)	simulated Groundnut (0PKg/ha)	observed Groundnut (30Pkg/ha fertilizer)	simulated Groundnut (30NKg/ha)	observed Groundnut (60Pkg/ha fertilizer)	simulated Groundnut (60PKg/ha)	
Emergence	DAP	8	8	8	8	8	8	
Flowering	DAP	71	70	63	63	60	60	
Maturity	DAP	110	101	130	132	110	108	
Yield	kg/ha	1172.5	1183	1208.3	1214	1021.7	1000.4	14.1

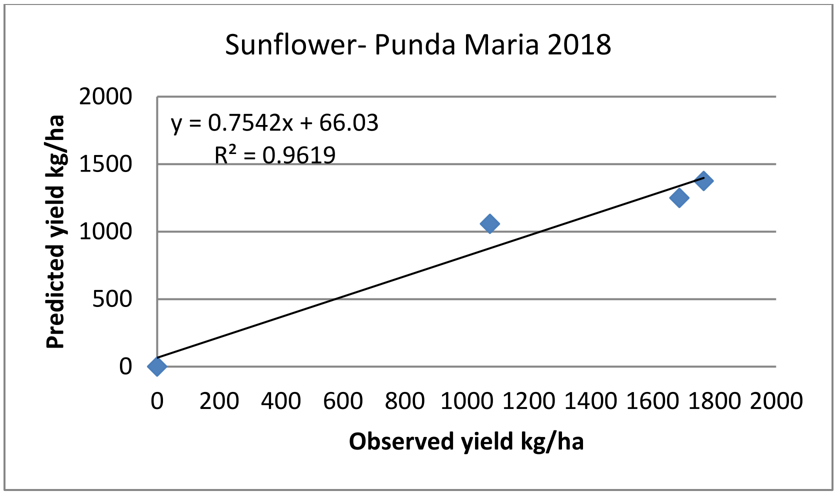


Figure 4.39a: Predicted vs. observed grain yield of sunflower under different fertilizer treatment at Punda Maria during the 2017/2018 growing season

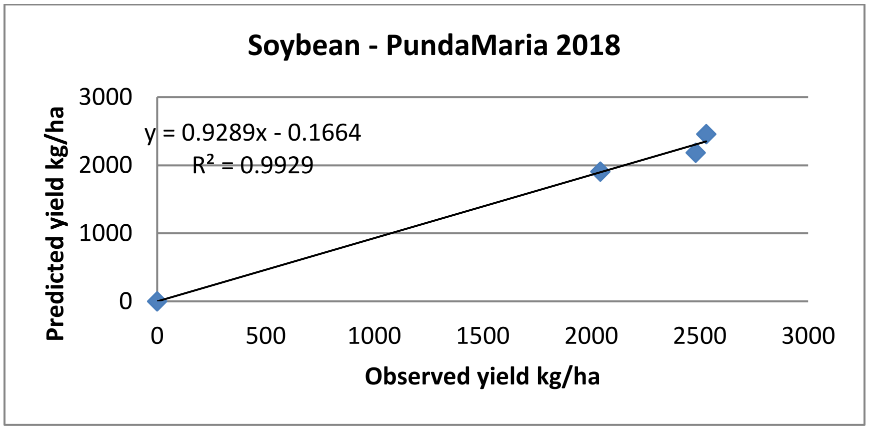


Figure 4.39b: Predicted vs. observed grain yield of soybean under different fertilizer treatment at Punda Maria during the 2017/2018 growing season

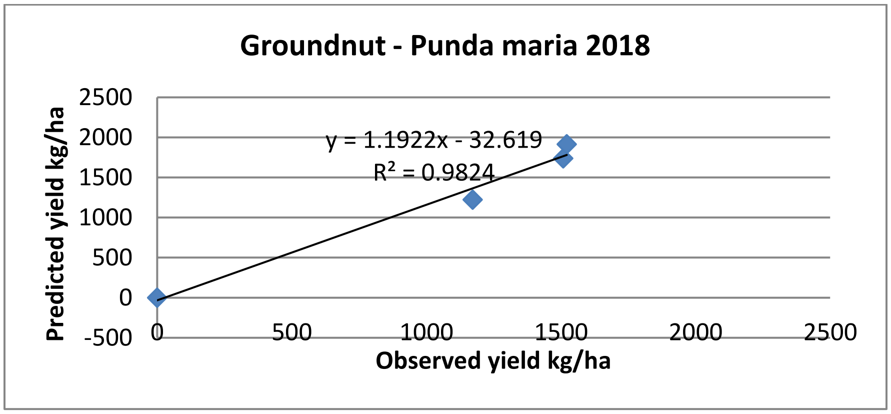


Figure 4.39c: Predicted vs. observed grain yield of groundnut under different fertilizer treatment at Punda Maria during the 2017/2018 growing season

Table 4.49.: Predicted vs. observed crop growth stages measured as days after planting under different fertilizer treatment at Punda Maria during the 2017/2018 growing season

Crop Traits	**Units**	**observed sunflower (0Nkg/ha fertilizer)**	**simulated sunflower (0NKg/ha)**	**observed sunflower (75Nkg/ha fertilizer)**	**simulated sunflower (75NKg/ha)**	**observed sunflower (150Nkg/ha fertilizer)**	**simulated sunflower (150NKg/ha)**	**RMSE kg/ha**
Emergence	DAP	7	7	6	7	9	7	
Flowering	DAP	90	91	85	91	93	91	
Maturity	DAP	130	120	128	120	128	120	
Yield	kg/ha	1055.8	1075	1249.1	1687	1374.4	1766	339.4
Crop Traits	2017	observed Soybean (0Pkg/ha fertilizer)	simulated Soybean (0PKg/ha)	observed Soybean (30Pkg/ha fertilizer)	simulated Soybean (30NKg/ha)	observed Soybean (60Pkg/ha fertilizer)	simulated Soybean(60PKg/ha)	
Emergence	DAP	10	8	8	8	7	8	
Flowering	DAP	85	60	80	60	75	60	
Maturity	DAP	158	160	156	160	155	160	
Yield	kg/ha	1908.6	2043	2459.2	2530	2185	2482	192.6
Crop Traits	Units	observed Groundnut (0Pkg/ha fertilizer)	simulated Groundnut(0PKg/ha)	observed Groundnut (30Pkg/ha fertilizer)	simulated Groundnut (30NKg/ha)	observed Groundnut (60Pkg/ha fertilizer)	simulated Groundnut (60PKg/ha)	
Emergence	DAP	8	8	7	8	6	8	
Flowering	DAP	60	62	58	62	56	60	
Maturity	DAP	130	110	120	110	120	102	
Yield	kg/ha	1172.5	1224	1508.6	1741	1521.7	1915	265.4

AquaCrop generally performed well in simulating the emergence, flowering, maturity and crop yields under three fertilizer levels. The reliable prediction of yield gives confidence in the model to account for the climate variability and management practices. Further, the validation analysis performed in this study and other similar analysis gives confidence in AquaCrop model to be used for upscaling or simulation in different conditions within the summer rainfall areas.

4.3.3 Statistical Analysis

4.3.3.1 Effects of fertilizer on yields in season I2016/2017 for soybean, sunflower and groundnut in Ofcolaco, Syferkuil and Punda Maria.

Figures 4.40 shows the effects of fertilizer on the various crops in the season I, 2016/2017. Figure 4.40a shows that 88% of the variability in soybean yield in Ofcolaco was explained by fertilizer while in Syferkuil it was 99% as shown in Figure 4.40b. Given that the probability corresponding to the F value, in the case of Ofcolaco, is 0.23, Syferkuil .08 (Appendices 4.7 and 4.8) and given the significance level of 5%, and that the F values are higher than the p=.05, the null hypothesis is accepted.

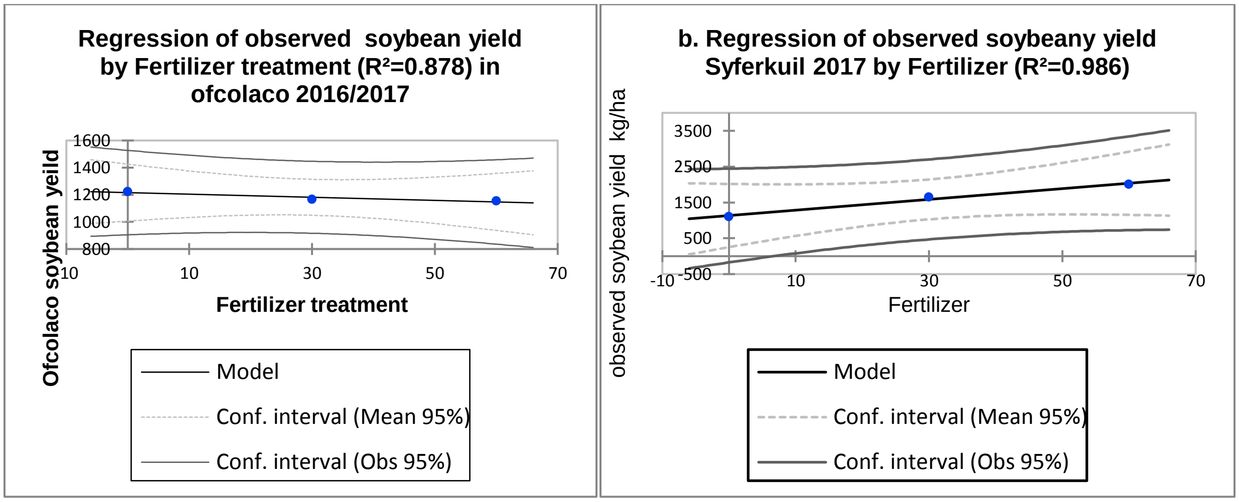


Figure 4.40a, b: Regression of soybean yield by fertilizer in Ofcolaco and Syferkuil in 2016/2017season.

Figure 4.41a shows that 19% of the variability in sunflower yield in Ofcolaco was explained by fertilizer while in Syferkuil, it was 88% as shown in Figure 4.41b. Given that the probability corresponding to the F value, in this case of Ofcolaco, is 0.71, Syferkuil .58 (Appendices 4.9 and 4.10) and given the significance level of 5%, and that the F values are higher than the p=.05, the null hypothesis is accepted.

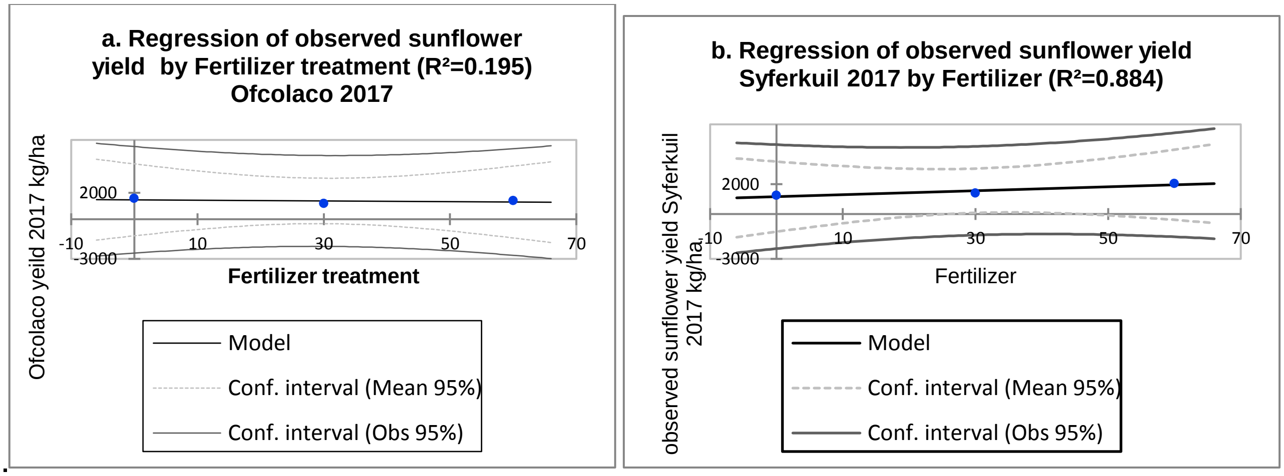


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Figure 4.41a, b: Regression of sunflower yield by fertilizer in Ofcolaco and Syferkuil in 2016/2017season.

Figure 4.43a shows that 75% of the variability in groundnut yield in Ofcolaco was explained by fertilizer while in Syferkuil, it was 98% as shown in Figure 4.43b. Given that the probability corresponding to the F value, in this case of Ofcolaco, is 0.33, Syferkuil .58 (Appendices 4.11 and 4.12) and given the significance level of 5%, and that the F values are higher than the p=.05, the null hypothesis is accepted.

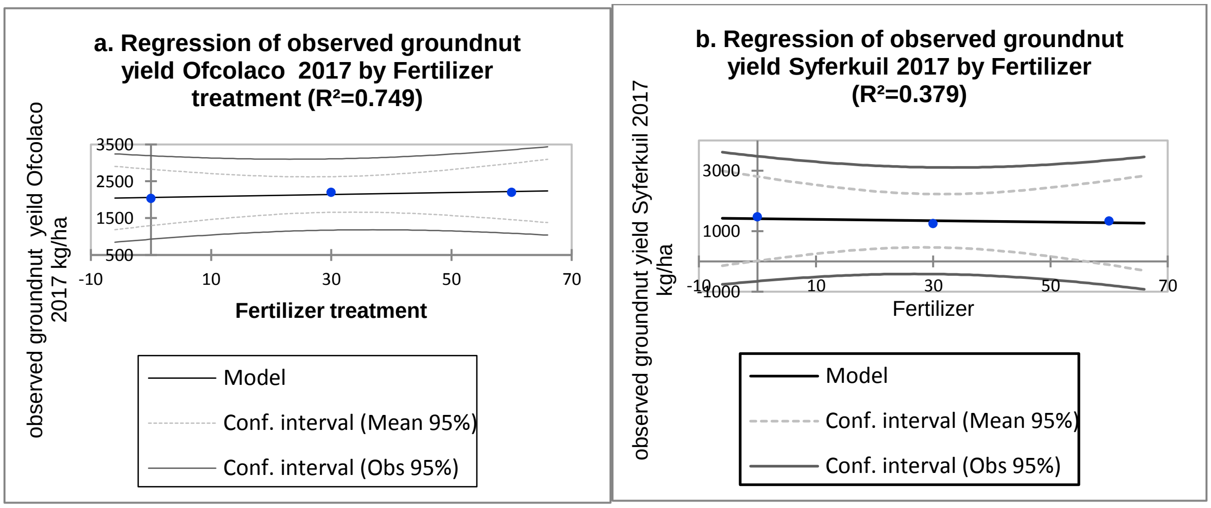


Figure 4.42a, b: Regression of groundnut yield by fertilizer in Ofcolaco in 2016/2017season.

4.3.3.2 Effects of fertilizer on yields in season 1 and for soybean, sunflower, and groundnut in Ofcolaco, Syferkuil, and Punda Maria.

In the 2017/2018 season, R^2**,** as seen in Figure 4.43a to c, shows that in Ofcolaco 75% of the soybean yield variability was explained by the Nitrogen (N) fertilizer treatment, while in Syferkuil and Punda Maria it was 95% and 25% respectively as seen in Figure 4.43b and 4.43c. Given that the probability corresponding to the F value, in this case of Ofcolaco, is 0.336, Syferkuil 0.148 and Punda Maria 0.665 (Appendices 4.13 to 4.15) and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted some covariates that would help to explain the variability are missing. The null hypothesis is accepted.

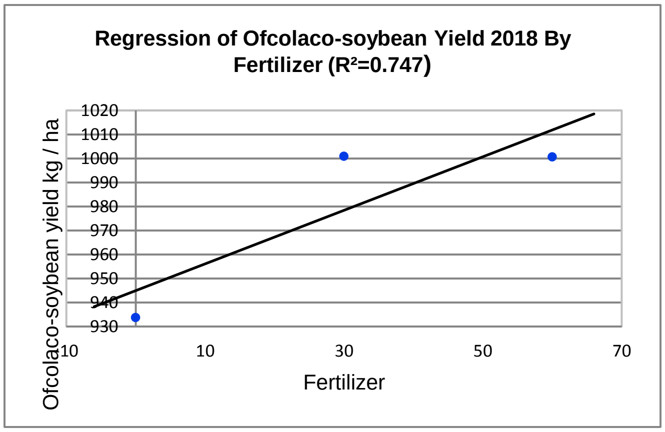


Figure 4.43a: Regression of soybean yield by fertilizer in Ofcolaco in 2017/2018 season.

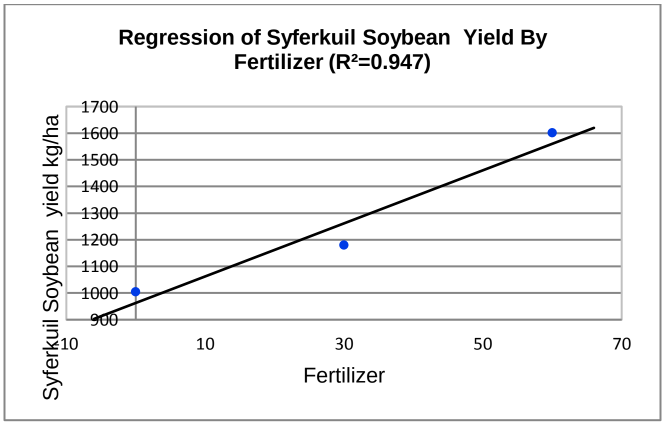


Figure 4.43b: Regression of soybean yield by Fertilizer in Syferkuil in 22017/2018 season.

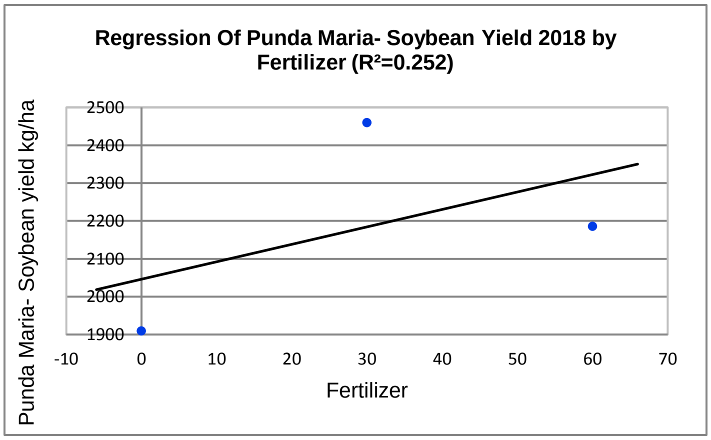


Figure 4.43c: Regression of soybean yield by fertilizer in Punda Maria in 2017/2018 season.

In the 2017/2018 season for the experimental sites, in Figure 4.44a that in Ofcolaco 14% of the sunflower yield is explained by P. In Figure 4.44b R^2 indicates that 71% of yield is explained by P, while in Punda Maria, Figure 4.44c that 98% of the yield variability was explained by the P. Given that the probability corresponding to the F value, in this case of Ofcolaco, is 0.76, Syferkuil is .25 and Punda Maria is 0.08 (Appendices 4.16 to 4.18) and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring in the model. Given that the F values are higher than the significance level alpha=0.05, the null hypothesis is therefore accepted.

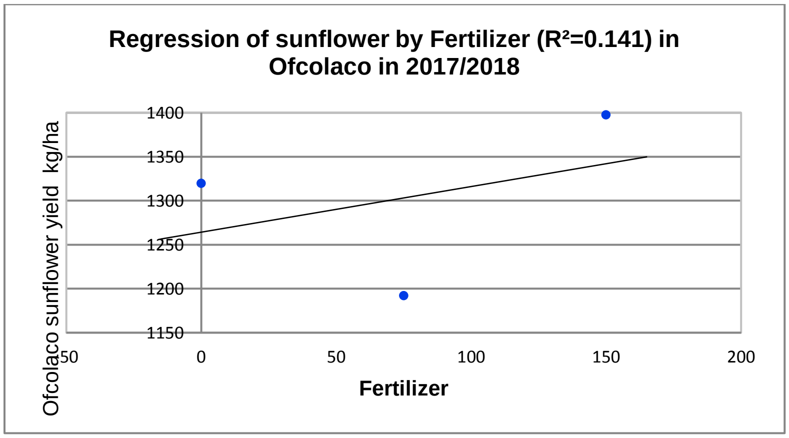


Figure 4.44a: Regression of sunflower yield by fertilizer in Ofcolaco in 2017/2018 season.

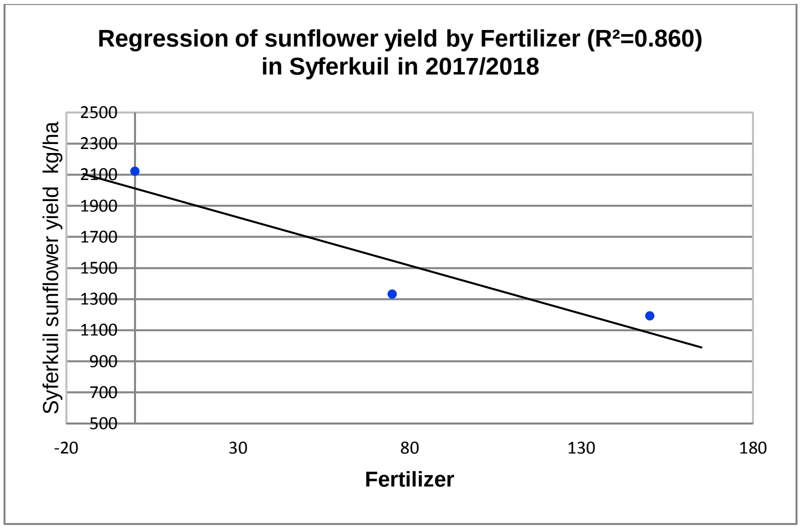


Figure 4.44b: Regression of sunflower yield by fertilizer in Syferkuil in 2017/2018 season.

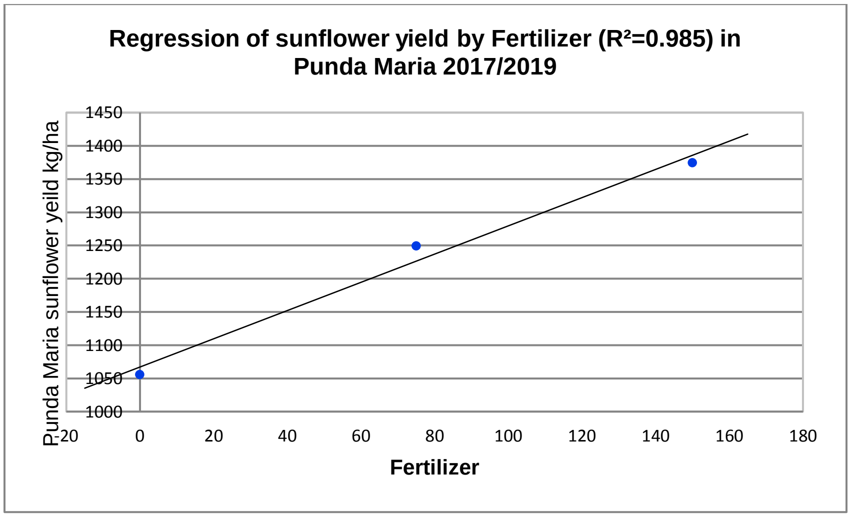


Figure 4.44c: Regression of sunflower yield by fertilizer in Punda Maria in 2017/2018 season.

In the 2017/2018 season, R^2**,** as seen in Figure 4.45a**,** shows that in Ofcolaco 30% of the groundnut yield variability was explained by the Nitrogen (N) fertilizer treatment, while in Syferkuil and Punda Maria it was 58% and 78% respectively as seen in Figure 4.45b and 4.45c. Given that the probability corresponding to the F value, in the case of Ofcolaco, is 0.63, Syferkuil 0.45 and Punda Maria 0.31 (Appendices 4.19 to 4.21) and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted that some covariates that would help to explain the variability are missing. The null hypothesis is accepted.

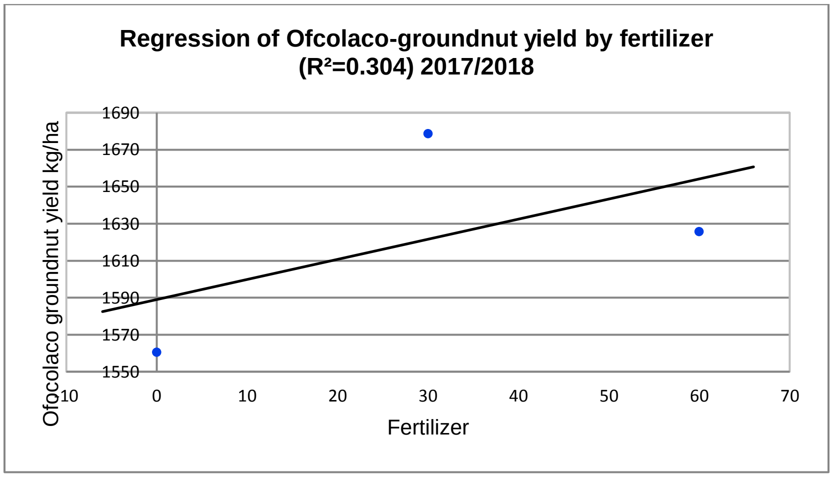


Figure 4.45a: Regression of sunflower yield by fertilizer in Ofcolaco in 2017/2018 season.

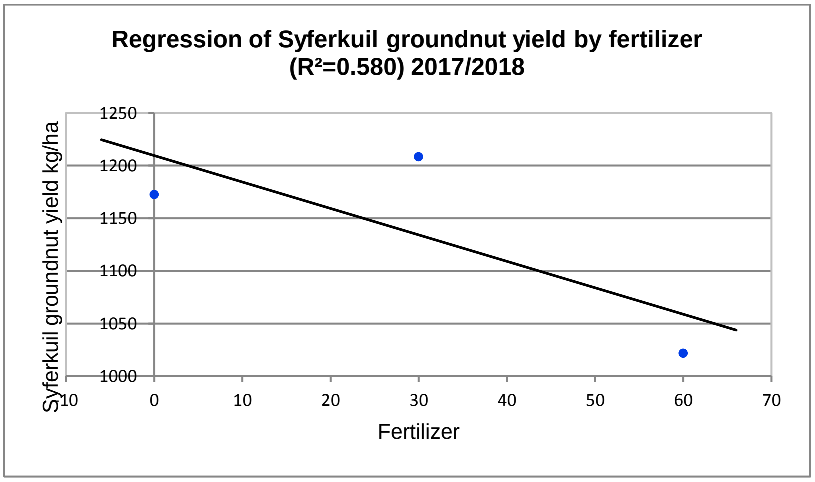


Figure 4.45b: Regression of groundnut yield by fertilizer in Syferkuil in 2017/2018 season.

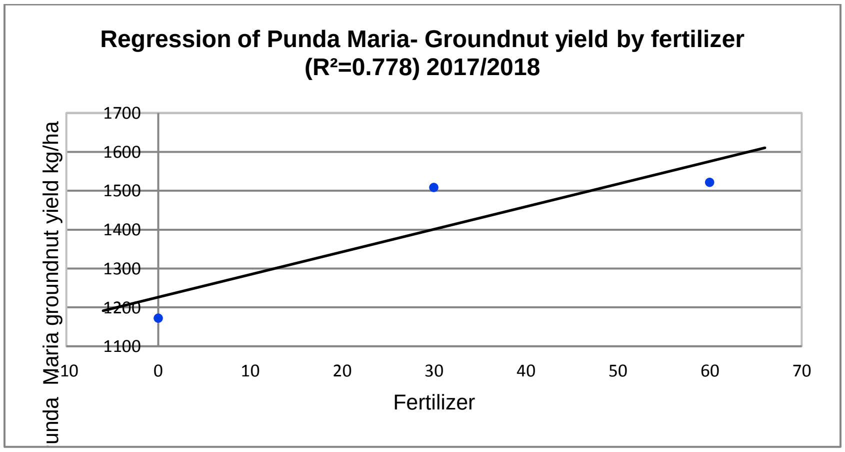


Figure 4.45c: Regression of groundnut yield by fertilizer in Punda Maria in 2017/2018 season.

4.3.3.3 Yield variation across seasons in Ofcolaco and test of significance

Yields were compared across the seasons for locations Ofcolaco, Syferkuil, Punda Maria and for crops soybean, sunflower and ground. Results of the T-test carried out showed that for yields soybean varied across the seasons. Results showed a variation in yields (Appendix 4.22 to 24) for all crops. As shown in Figure 4.46a, the computed p-value is lower than the significance level alpha=0.05, the null hypothesis was rejected. In Figure 4.46b, the computed p-value is higher than the alpha=.05, the null hypothesis is accepted. In Figure 4.46c, the computed p-value is lower than the significance level alpha=0.05, the null hypothesis was rejected.

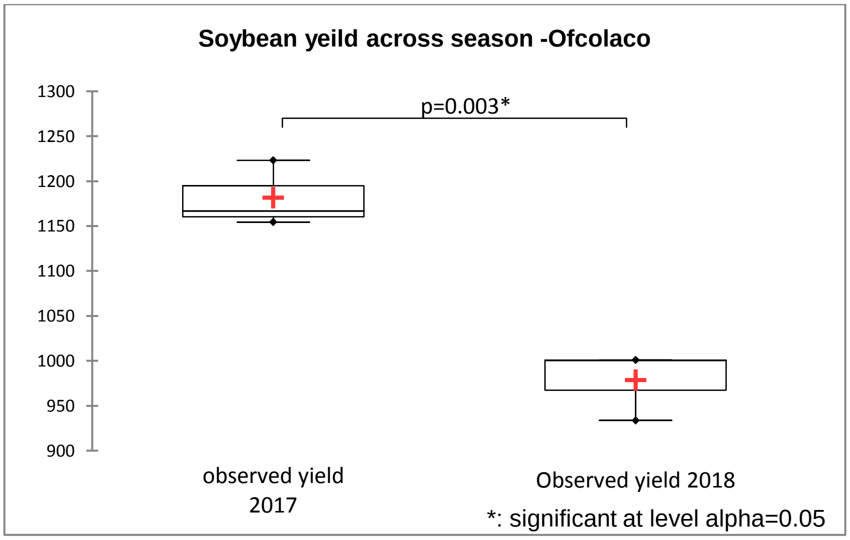


Figure 4.46a: T-test results on soybean yield in Ofcolaco for two seasons.

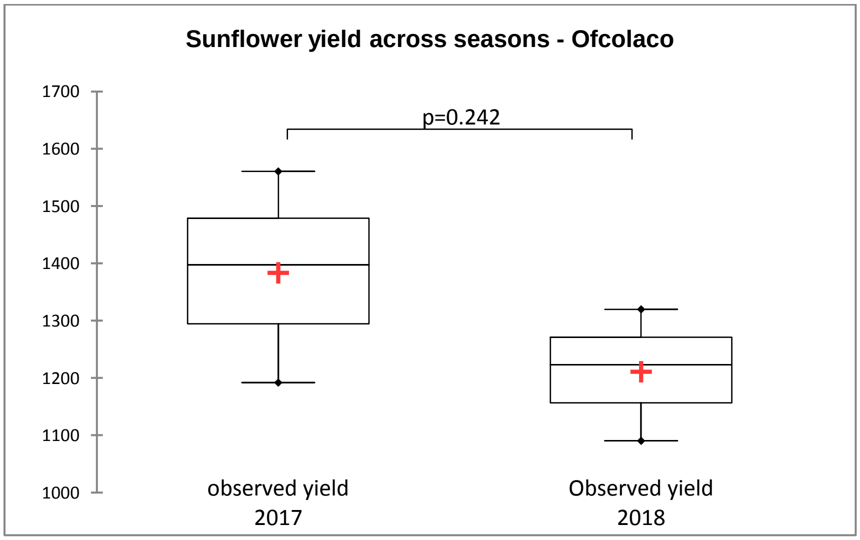


Figure 4.46b: T-test results on sunflower yield in Ofcolaco for two seasons.

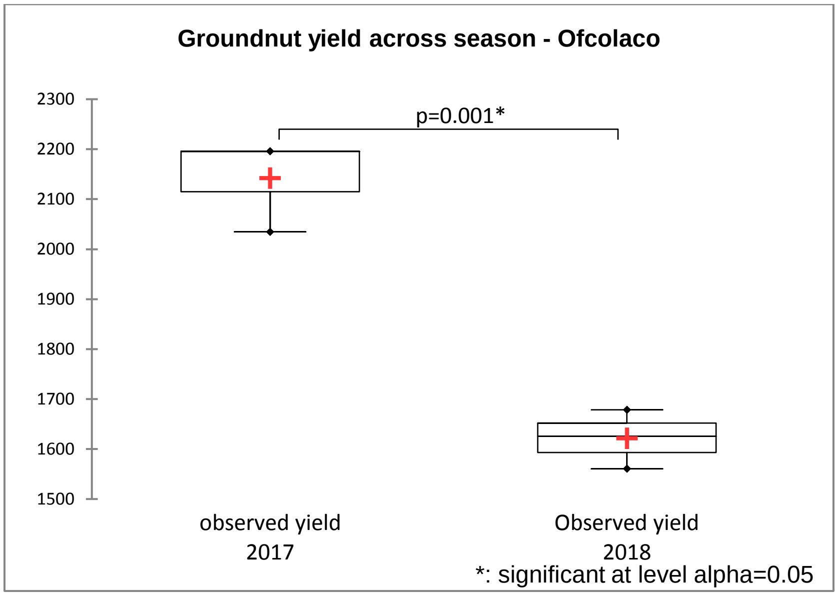


Figure 4.46c: T-test results on groundnut yield in Ofcolaco for two seasons.

4.3.3.4 Yield variation across seasons in Syferkuil and test of significance

Table 4.50 below shows results of the statistical test carried out between the yield results of seasons I and II in Syferkuil.For all the crops, the p-value is higher than the alpha=0.05, hence the null hypothesis is accepted. There isn't a significant difference in the mean yields across the season.

Figure 4.50: Summary statistics for the test of significance across seasons in Syferkuil.

	Soybean	Sunflower	Groundnut
Difference	323.233	11.867	212.133
t (Observed value)	1.022	0.031	2.510
|t| (Critical value)	2.776	2.776	2.776
DF	4	4	4
p-value (Two-tailed)	0.365	0.976	0.066
alpha	0.05	0.05	0.05

4.3.3.5 Yield variation across seasons in Ofcolaco, Syferkuil and Punda Maria with a test of significance

A Kruskal Wallis test was carried out on soybean yield across Ofcolaco, Syferkuil and Punda Maria for the 2017/2018 cropping season so as to determine the variation across the sites and the fertilizers applied. As seen in Table 4.51, there is no significant difference in yield across the regions. This is based on the premise that the calculated p-value is higher than alpha=0.05, thereby the null hypothesis is accepted. Further results presented in Table 4.45 is that of pairwise comparison and the Bonferroni results show that on a one on one comparison, there is a statistical difference between the yields in Ofcolaco and Punda Maria.

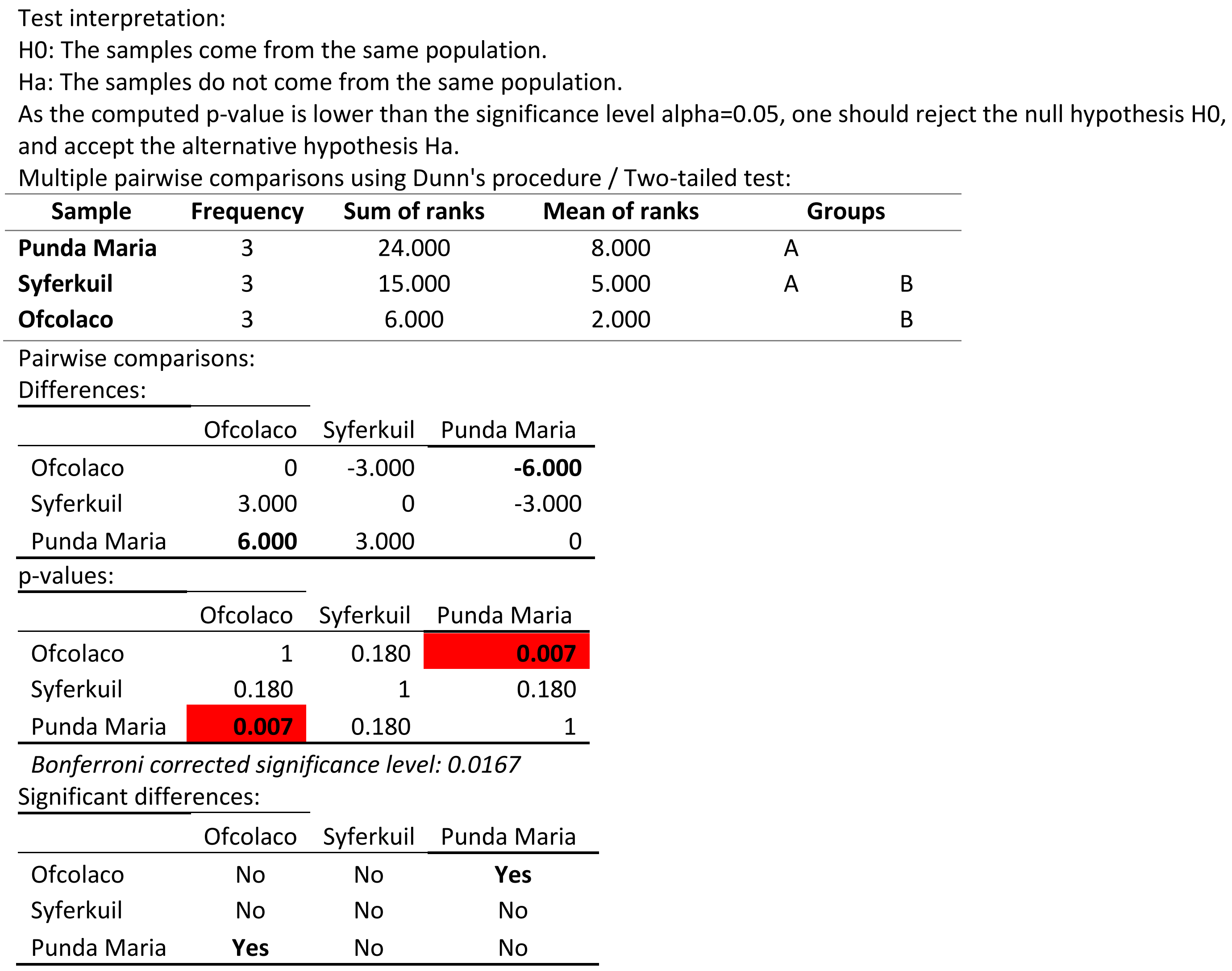
Table 4.51: Summary statistics for Kruskal-Wallis test of significance across Ofcolaco, Syferkuil and Punda Maria for soybean yield.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ofcolaco	3	0	3	933.700	1000.900	978.400	38.712
Syferkuil	3	0	3	1003.700	1601.100	1261.567	306.959
Punda Maria	3	0	3	1908.600	2459.200	2184.267	275.301

Kruskal-Wallis test / Two-tailed test:

K (Observed value)	7.200
K (Critical value)	5.991
DF	2
p-value (one-tailed)	0.027
alpha	0.05

An approximation has been used to compute the p-value.



Test interpretation:
H0: The samples come from the same population.
Ha: The samples do not come from the same population.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Multiple pairwise comparisons using Dunn's procedure / Two-tailed test:

Sample	Frequency	Sum of ranks	Mean of ranks	Groups	
Punda Maria	3	24.000	8.000	A	
Syferkuil	3	15.000	5.000	A	B
Ofcolaco	3	6.000	2.000		B

Pairwise comparisons:
Differences:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	0	-3.000	**-6.000**
Syferkuil	3.000	0	-3.000
Punda Maria	**6.000**	3.000	0

p-values:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	1	0.180	**0.007**
Syferkuil	0.180	1	0.180
Punda Maria	**0.007**	0.180	1

Bonferroni corrected significance level: 0.0167

Significant differences:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	No	No	**Yes**
Syferkuil	No	No	No
Punda Maria	**Yes**	No	No

Results from Table 4.52 on sunflower yield across Ofcolaco, Syferkuil and Punda Maria for the 2017/2018 cropping season shows there is no significant difference in yield across the regions. The calculated p-value is higher than alpha=0.05, thereby the null hypothesis is accepted. Further results from the Bonferroni test shows, there is no statistical difference between the yields in these locations.

Table 4.52: Summary statistics for Kruskal-Wallis test of significance across Ofcolaco, Syferkuil and Punda Maria for sunflower yield.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ofcolaco	3	0	3	1192.100	1397.600	1303.167	103.755
Syferkuil	3	0	3	1190.500	2119.800	1546.733	501.161
Punda Maria	3	0	3	1055.800	1374.400	1226.433	160.505

Kruskal-Wallis test / Two-tailed test:

K (Observed value)	0.622
K (Critical value)	5.991
DF	2
p-value (one-tailed)	0.733
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.

Multiple pairwise comparisons using Dunn's procedure / Two-tailed test:

Sample	Frequency	Sum of ranks	Mean of ranks	Groups
Syferkuil	3	17.000	5.667	A
Ofcolaco	3	16.000	5.333	A
Punda Maria	3	12.000	4.000	A

Pairwise comparisons:

Differences:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	0	-0.333	1.333
Syferkuil	0.333	0	1.667
Punda Maria	-1.333	-1.667	0

p-values:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	1	0.881	0.551
Syferkuil	0.881	1	0.456
Punda Maria	0.551	0.456	1

Bonferroni corrected significance level: 0.0167

Significant differences:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	No	No	No
Syferkuil	No	No	No
Punda Maria	No	No	No

Results from Table 4.53 on groundnut shows there is no significant difference in yield across the regions. The calculated p-value is higher than alpha=0.05, thereby the null hypothesis is accepted. The Bonferroni test shows that there are no statistical differences between the yield in Ofcolaco and Syferkuil.

Table 4.53: Summary statistics for Kruskal-Wallis test of significance across Ofcolaco, Syferkuil and Punda Maria for sunflower yield

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ofcolaco	3	0	3	1560.500	1678.600	1621.600	59.157
Syferkuil	3	0	3	1021.700	1208.300	1134.167	99.030
Punda Maria	3	0	3	1172.500	1521.700	1400.933	197.937

Kruskal-Wallis test / Two-tailed test:

K (Observed value)	6.252
K (Critical value)	5.991
DF	2
p-value (one-tailed)	0.044
alpha	0.05

An approximation has been used to compute the p-value.

Test interpretation:

H0: The samples come from the same population.

Ha: The samples do not come from the same population.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

Ties have been detected in the data and the appropriate corrections have been applied.

Multiple pairwise comparisons using Dunn's procedure / Two-tailed test:

Sample	Frequency	Sum of ranks	Mean of ranks	Groups	
Ofcolaco	3	24.000	8.000	A	
Syferkuil	3	13.500	4.500	A	B
Punda Maria	3	7.500	2.500		B

Pairwise comparisons:

Differences:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	0	**5.500**	3.500
Syferkuil	**-5.500**	0	-2.000
Punda Maria	-3.500	2.000	0

p-values:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	1	**0.014**	0.116
Syferkuil	**0.014**	1	0.369
Punda Maria	0.116	0.369	1

Bonferroni corrected significance level: 0.0167

Significant differences:

	Ofcolaco	Syferkuil	Punda Maria
Ofcolaco	No	**Yes**	No
Syferkuil	**Yes**	No	No
Punda Maria	No	No	No

4.4 Vulnerability analysis and adaptive response

4.4.1 Potential Crop yield variability over space and time frames for sunflower, soybean, and groundnut

4.4.1.1 Potential Crop yield variability over space and time frames for sunflower, soybean, and groundnut

In the low input baseline scenario, as shown in Figures 4.47a, yield output for soybean production is up to 1.3 t/ha. The Eastern Cape, Mpumalanga, North West, and Free State all show yields output of 1.2 t/ha. The lower yield of about 0.3 t/ha is seen in the Northern Cape, Gauteng, some patches in Limpopo. The yield of about 0.5 t/ha is mostly found in areas of Mpumalanga, Free State. In Limpopo, areas in the semi regions had a yield of less than 1t/ha. Areas showing a yield of above 1 t/ha are in the semi-arid and the humid areas as seen in Figure 4.47b.

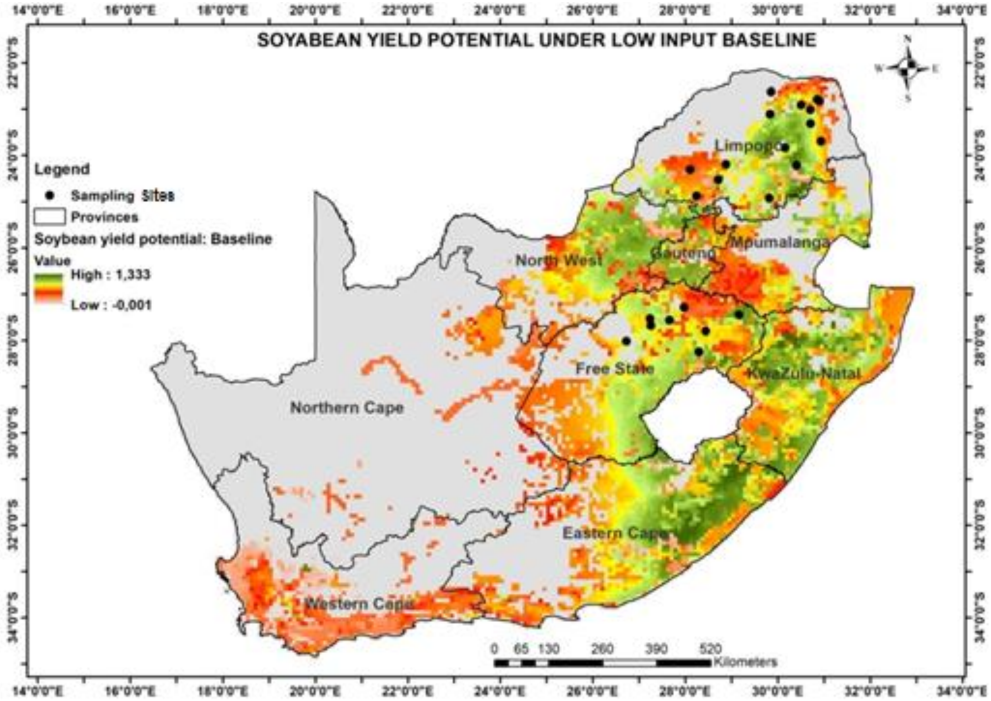


Figure 4.47a: Potential soybean yield for low input scenario South Africa. (Calculated from GAEZ, 2012).

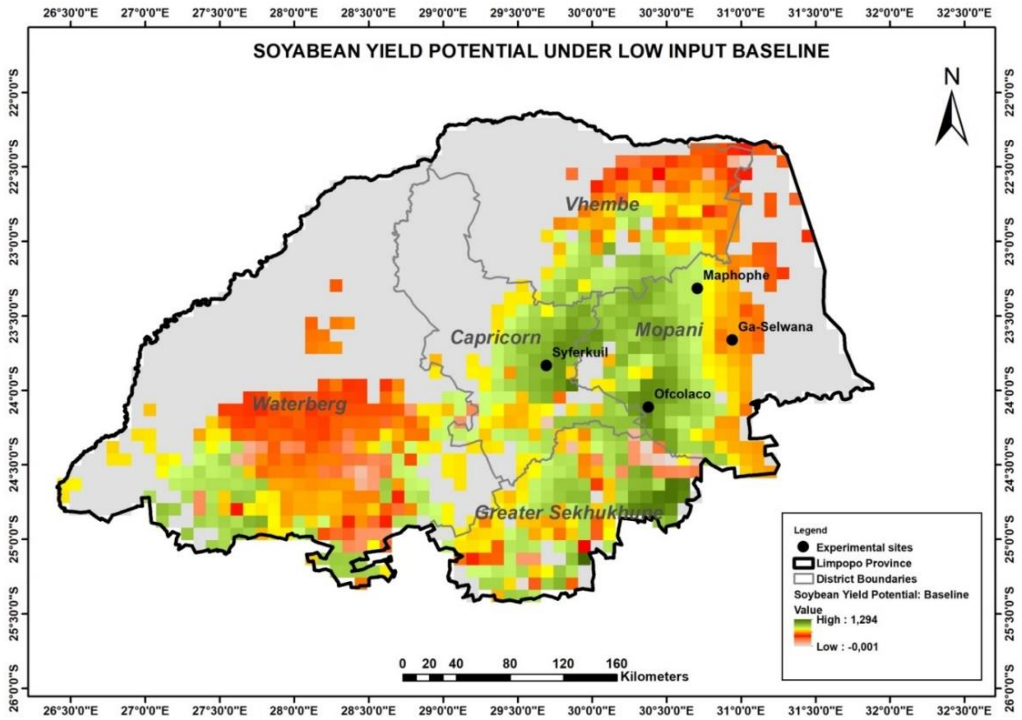


Figure 4.47b: Potential soybean yield for low input baseline scenario for Limpopo. (Calculated from GAEZ, 2012).

In the intermediate baseline scenario, as seen in Figure 4.48a, soybean production is up to 2.5t/ha. Areas showing a high yield of 2.5 t/ha include patches in, Mpumalanga, KZN, North West, and Free State. Some areas in the Free State show a yield of about 1.5t/ha with other areas such as Gauteng showing a yield of less thean1t/ha. In Figure 4.48b, In Limpopo, yields are up to 2.8 t/ha.

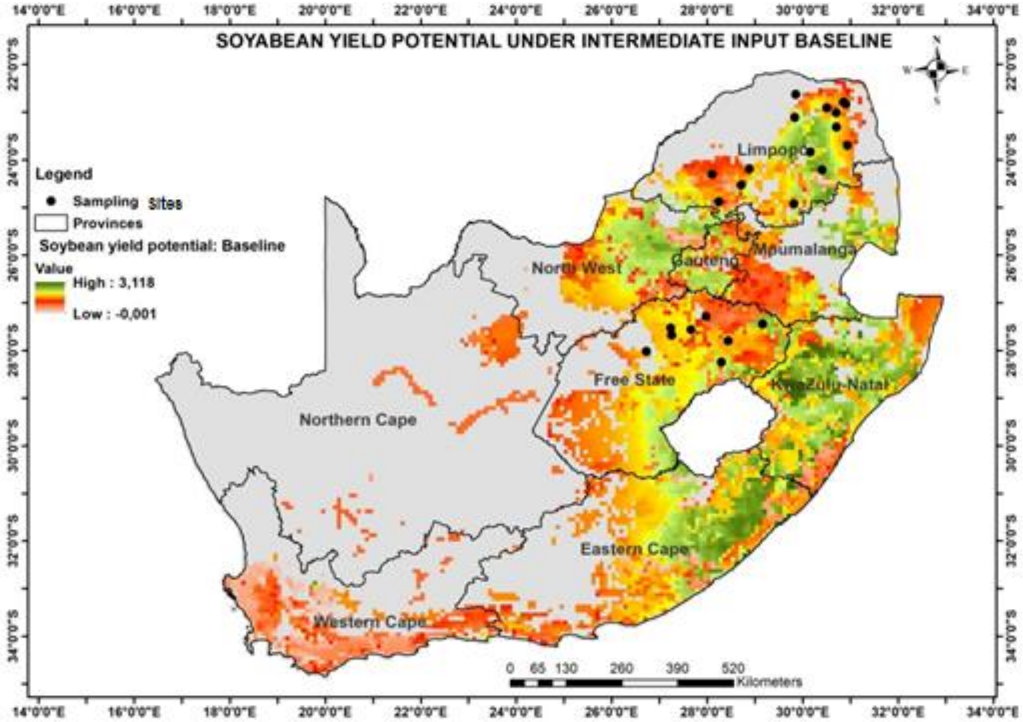


Figure 4.48a: Potential soybean yield for intermediate input baseline scenario for Limpopo. (Calculated from GAEZ, 2012).

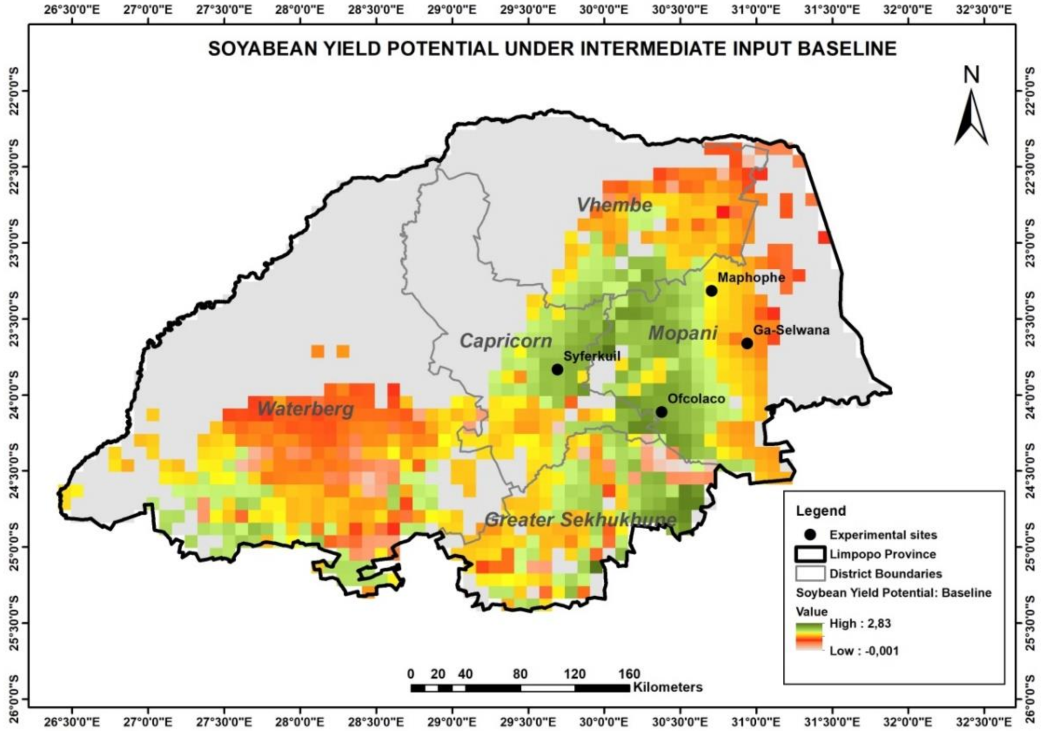


Figure 4.48b: Potential soybean yield for the intermediate baseline scenario for Limpopo. (Calculated from GAEZ, 2012).

4.4.1.2 Future potential yield output for soybean under different climate change models for the time period 2020 under the low input scenario

Under the low input scenario for CCCMA, yield ranges up to 1.5t/ha. Higher yields are found in the Free State, North West, Limpopo, Mpumalanga, and KZN as shown in Figure 4.49a. Low yield of about half a ton can be seen in areas of Gauteng and Limpopo. A closer look at Limpopo (Figure 4.49b) shows yields ranging up to 1.44 t/ha.

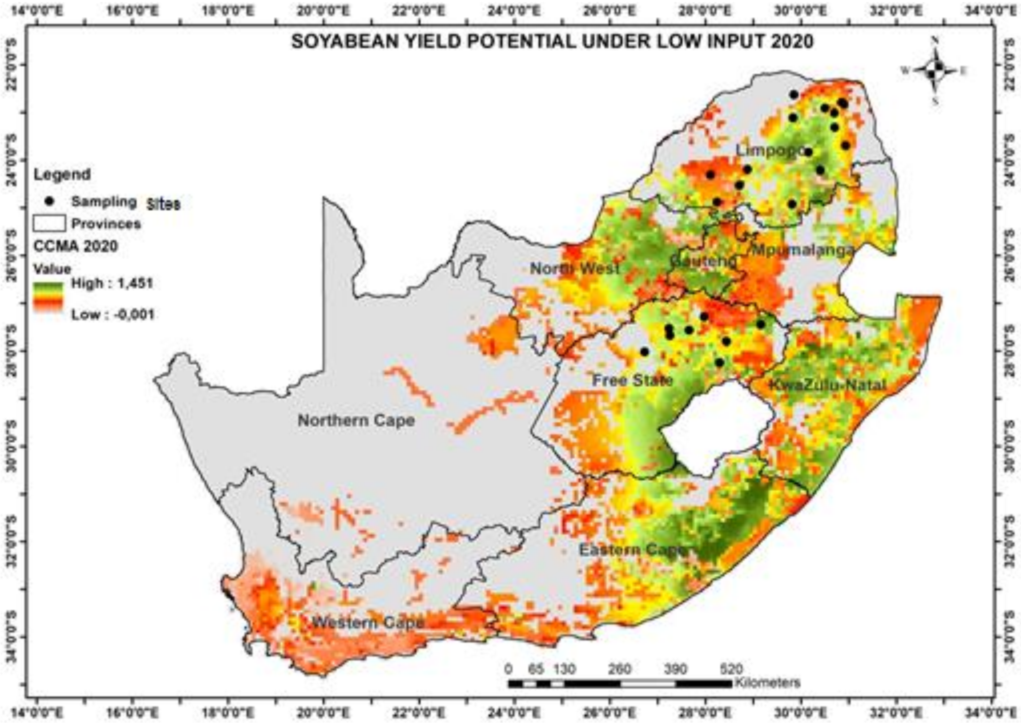


Figure 4.49a: Potential soybean yield for low input scenario for South Africa for CCCMA model for the period 2020. (Calculated from GAEZ, 2012).

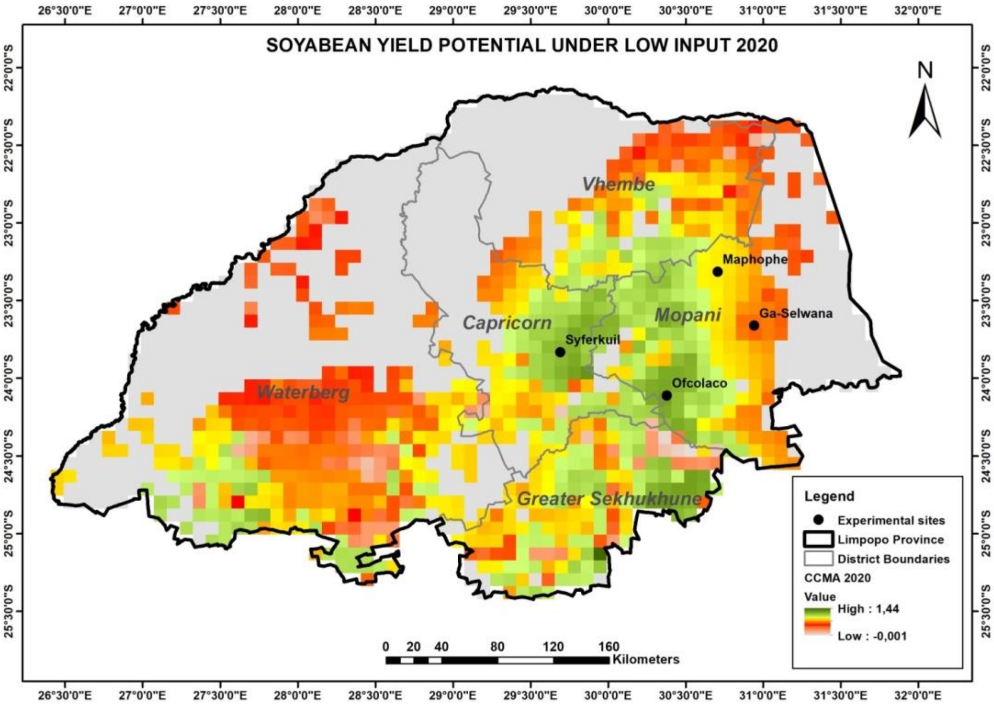


Figure 4.49b: Potential soybean yield for low input scenario for Limpopo for CCCMA model for the period 2020. (Calculated from GAEZ, 2012).

Potential yield output under the CSIRO model is up to 1.44 t/ha, and for Limpopo is up to 1.35t/ha as seen in figures 4.50a and 4.50b.

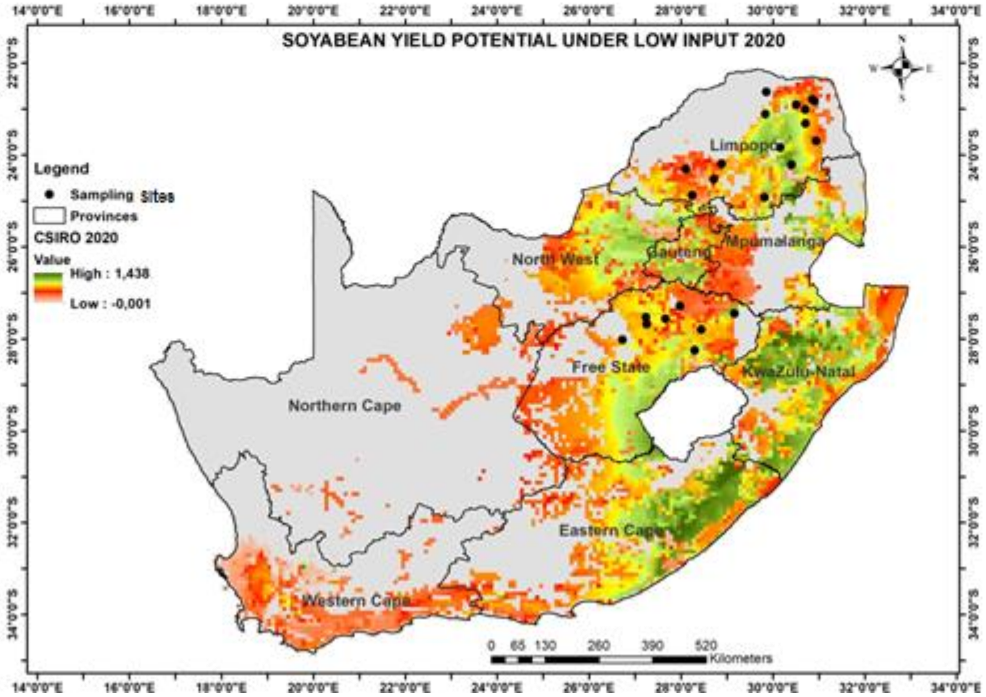


Figure 4.50a: Potential soybean yield for low input scenario for CSIRO model for the period 2020. (Calculated from GAEZ, 2012).

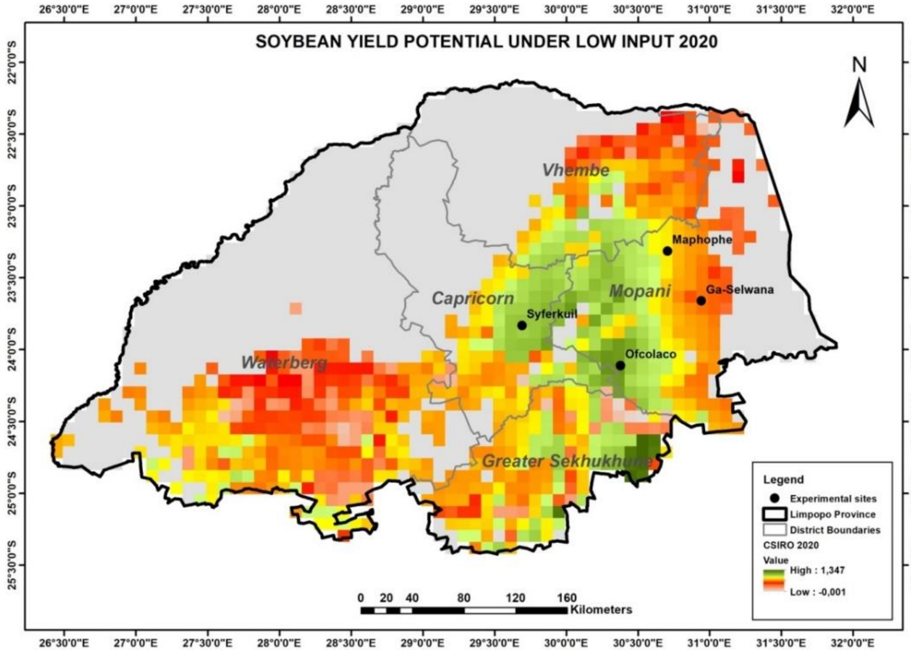


Figure 4.50b: Potential soybean yield for low input scenario for Limpopo for the CSIRO model for the period 2020. (Calculated from GAEZ, 2012).

Potential yields under the ECHAM model shows yields of up to 1.5 t/ha in areas of Limpopo, Eastern Cape, Gauteng, KwaZulu Natal and Free State Provinces as seen in Figure 4.51a.In Figure 4.51b, areas in Limpopo with yields of up to 1.5 t/ha are found mostly in the humid and semi-arid areas.

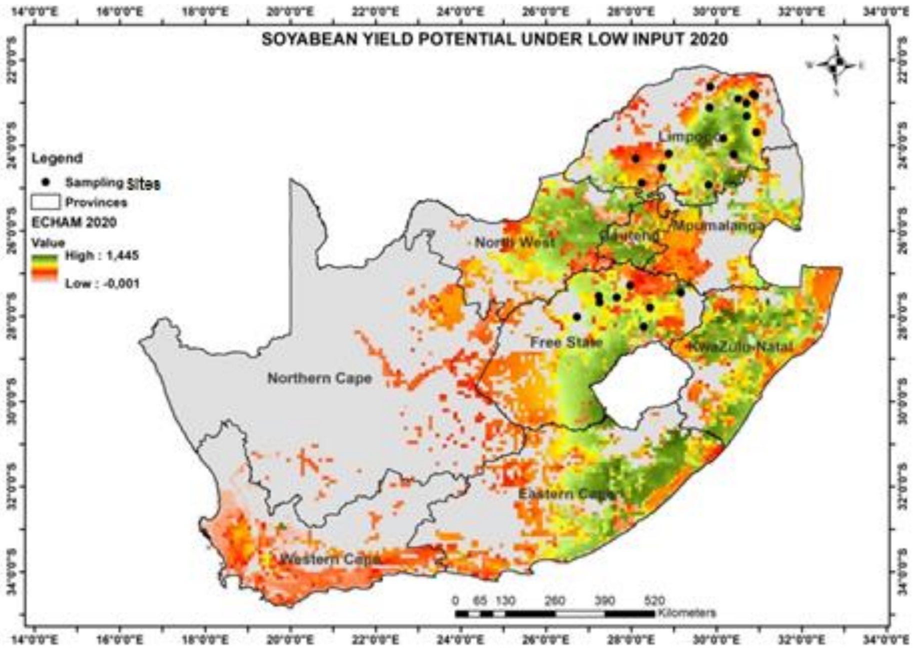


Figure 4.51a: Potential soybean yield for low input scenario for the ECHAM model for the period 2020. (Calculated from GAEZ, 2012).

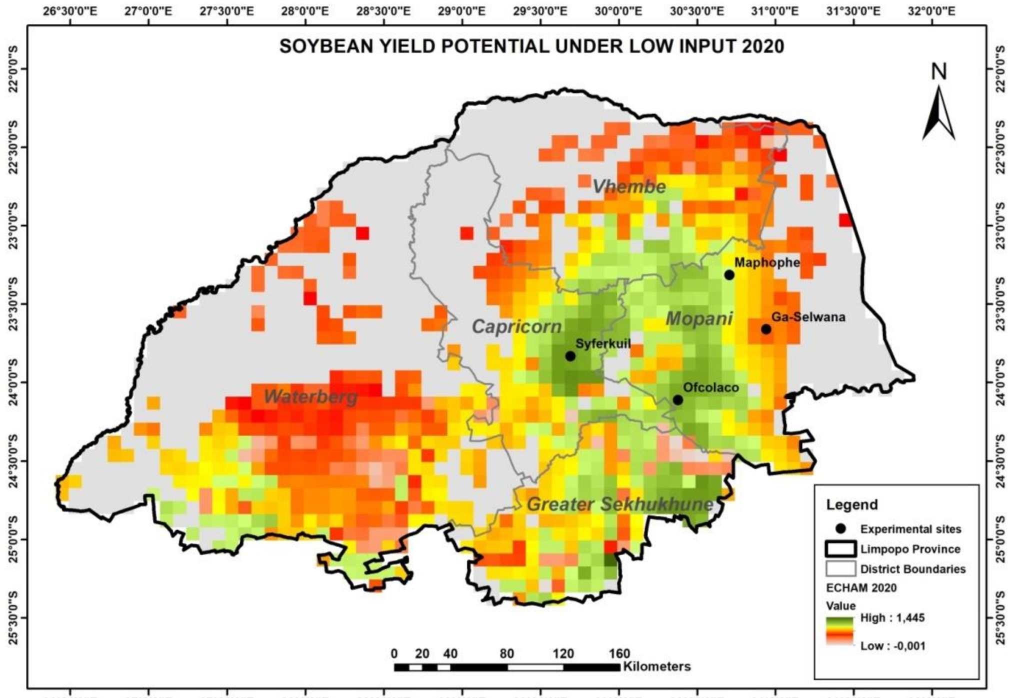


Figure 4.51b: Potential soybean yield for low input scenario for Limpopo for the ECHAM model. (Calculated from GAEZ, 2012).

Potential yield under the HADLEY model as seen in Figure 4.52a, show yields up to 1.44t/ha in areas of the Eastern Cape and KwaZulu Natal. Areas in the Northern Cape shows the highest yield at about 0.5t/ha. In Limpopo, as shown in Figure 4.52b, yields go up to 1.3 t/ha.

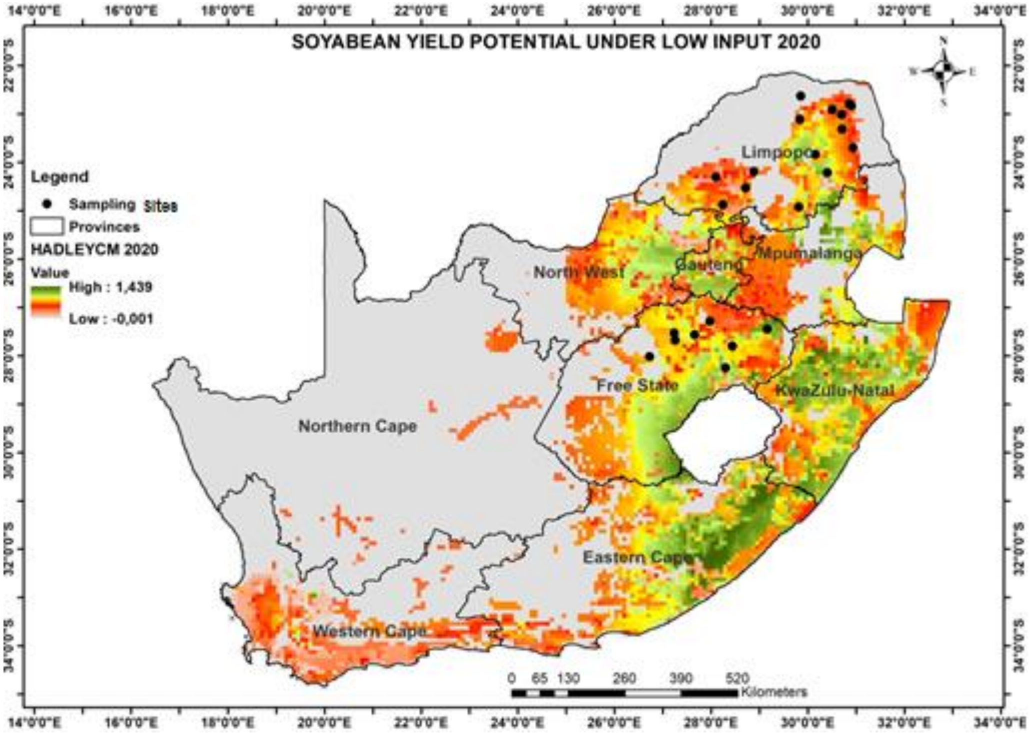


Figure 4.52a: Potential soybean yield for low input scenario HADLEY model. (Calculated from GAEZ, 2012).

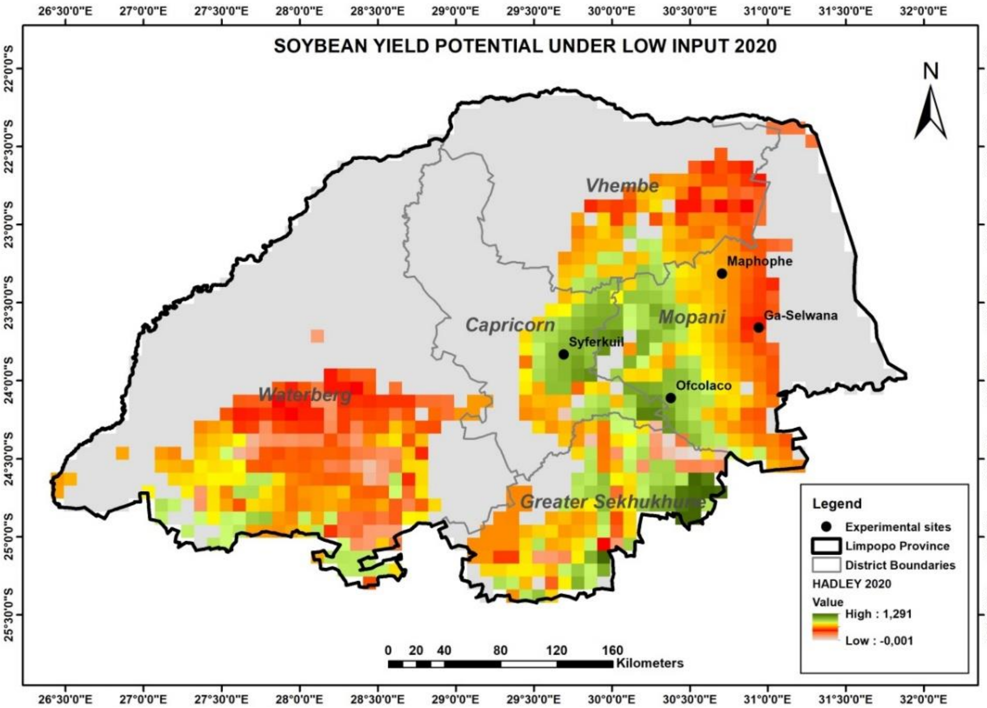


Figure 4.52b: Potential soybean yield for low input scenario for Limpopo for HADLEY model. (Calculated from GAEZ, 2012).

4.4.1.3 Future potential yield output for soybean under different climate change models for the time period 2020 under the intermediate input scenario.

As with the low input scenario, Figure 4.53a and b to Figures, 4.55 a and b show that under the CCCMA, CSIRO, ECHAM, and HADLEY5 models, the maximum potential yield is estimated at 3.3 t/ha and in Limpopo up to 3.1t/ha.

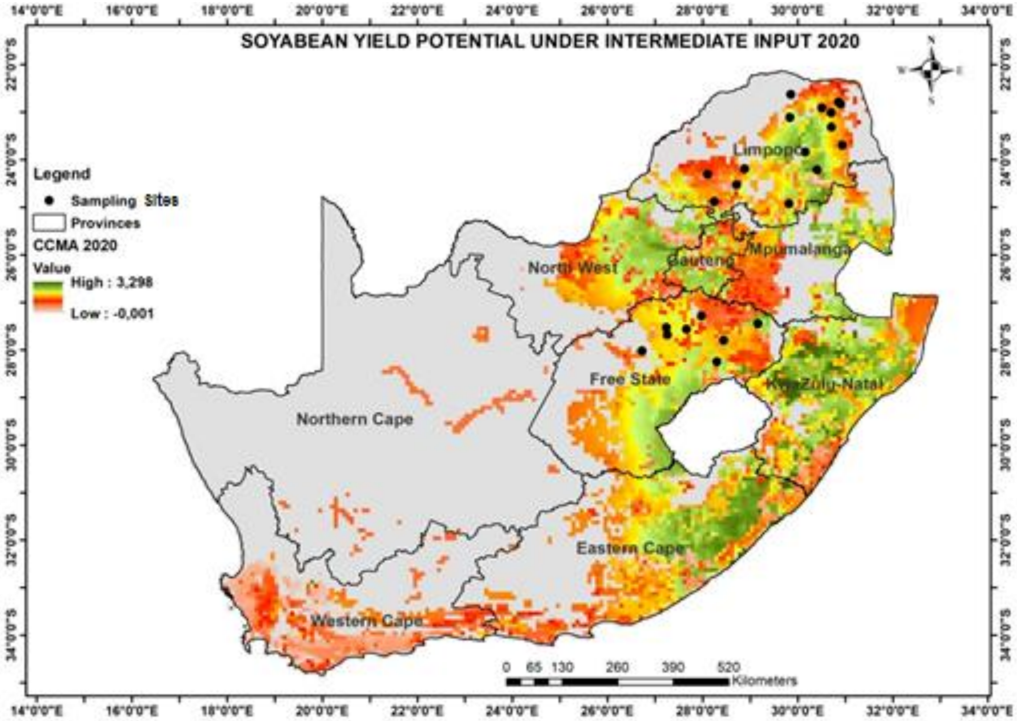


Figure 4.53a: Potential soybean yield for intermediate input scenario for CCCMA model for the period 2020. (Calculated from GAEZ, 2012)

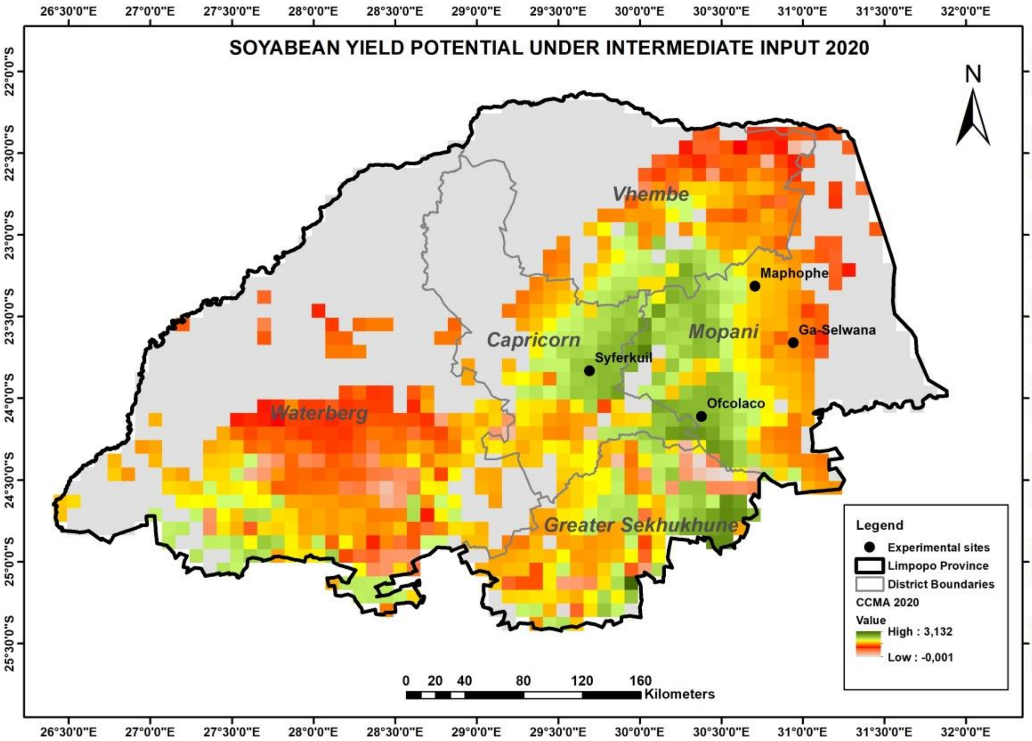


Figure 4.53b: Potential soybean yield for intermediate input scenario for CCCMA model for Limpopo for the period 2020. (Calculated from GAEZ, 2012).

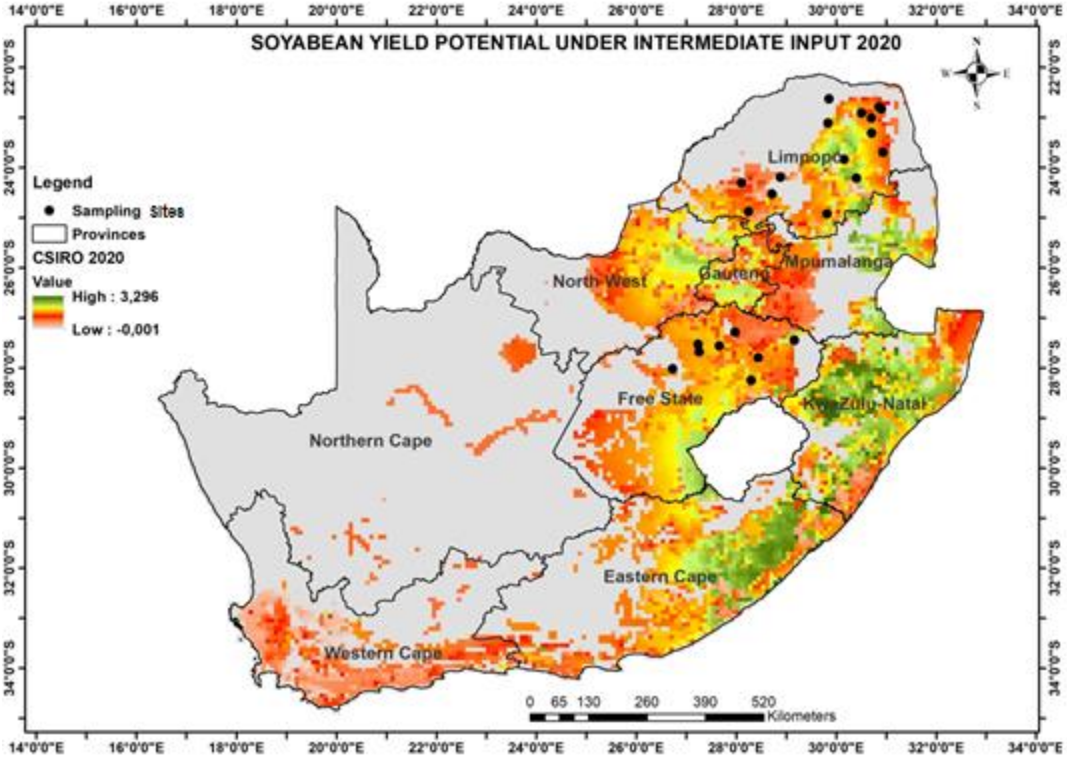


Figure 4.54a: Potential soybean yield for intermediate input scenario for CSIRO model for the period 2020. (Calculated from GAEZ, 2012).

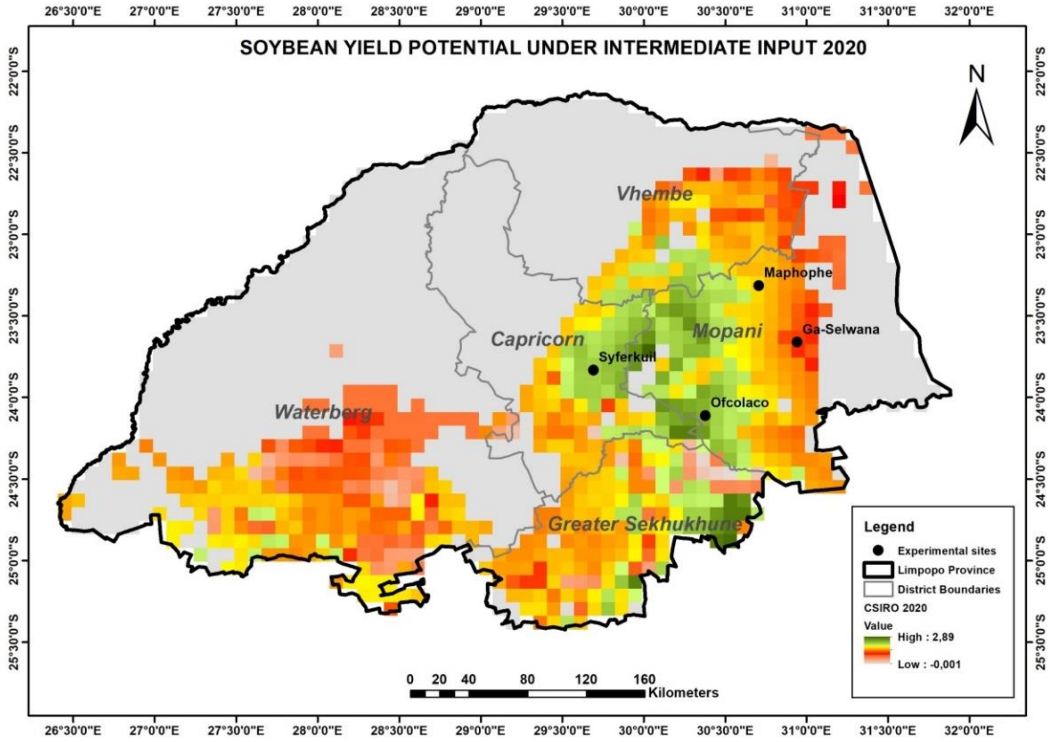


Figure 4.54b: Potential soybean yield for intermediate input scenario for CSIRO model for Limpopo for the period 2020. (Calculated from GAEZ, 2012.

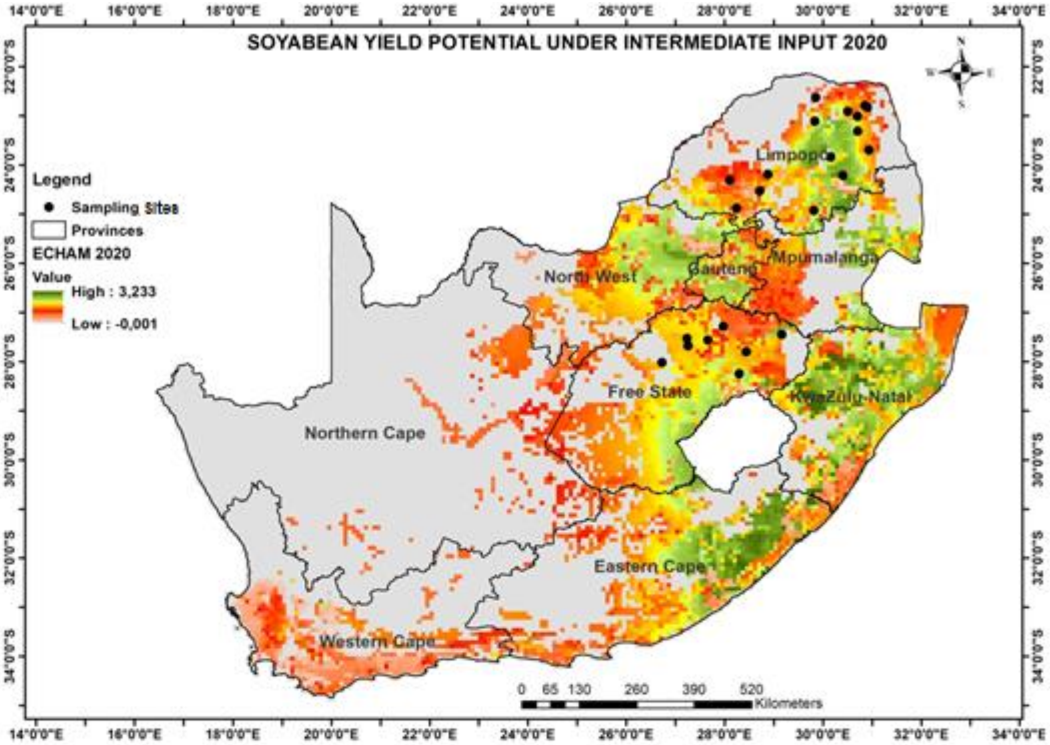


Figure 4.55a: Potential soybean yield for intermediate input scenario for the ECHAM model for the period 2020. (Calculated from GAEZ, 2012).

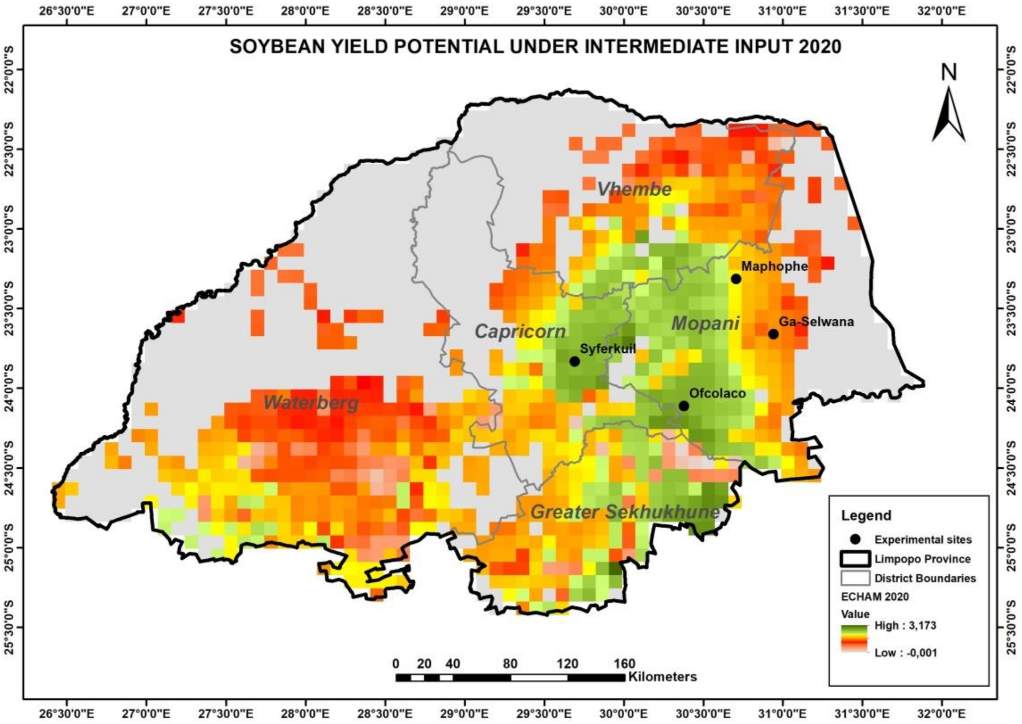


Figure 4.55b: Potential soybean yield for intermediate input scenario for the ECHAM model for Limpopo for the period 2020. (Calculated from GAEZ, 2012).

4.4.1.4 Future potential yield output for soybean under different climate change models for the time period 2050 under the low and intermediate input scenarios

Under the low input scenario as seen in Figures 4.56a, 4.57a,4.58a, and 4.59a all climate models show yield output of up to 1.6 t/ha. Figures 4.56b, 4.57b, 4.58b, and 4.59b shows that potential yield for Limpopo is up to 1.54 t/ha.

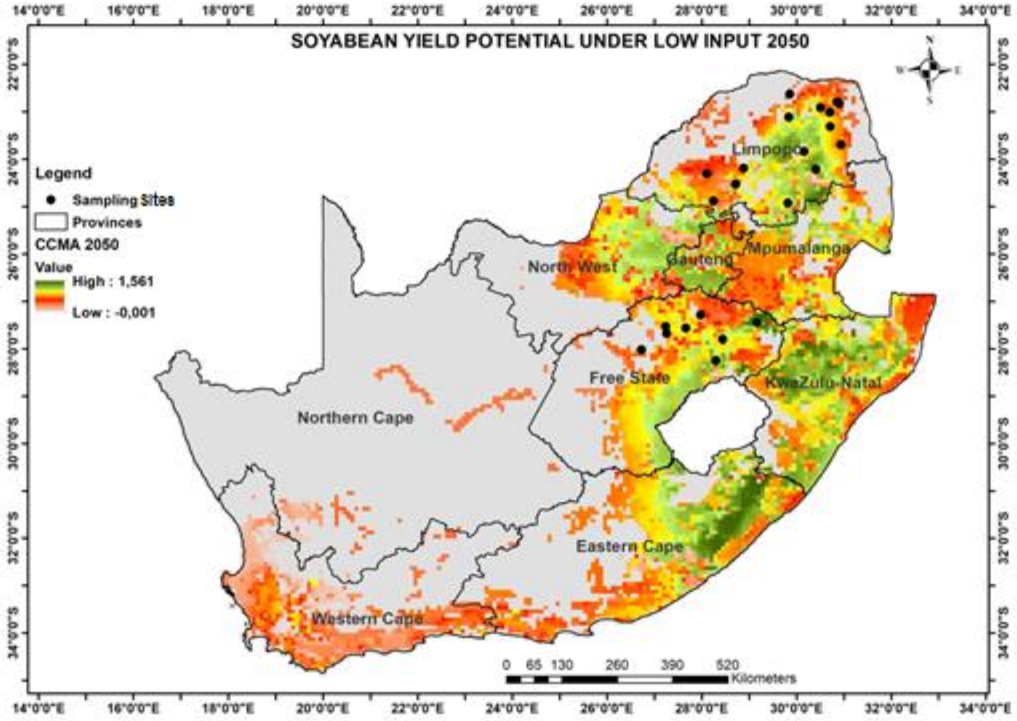


Figure 4.56a: Potential soybean yield for low input scenario for CCCMA model for the period 2050. (Calculated from GAEZ, 2012).

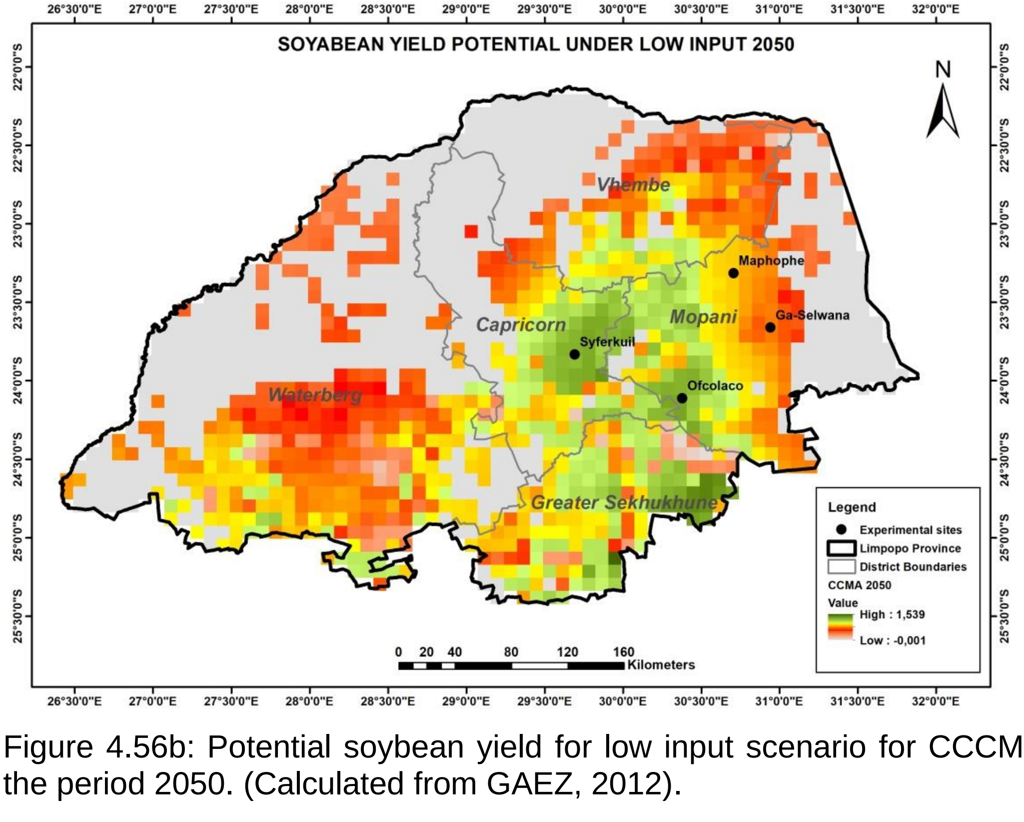


Figure 4.56b: Potential soybean yield for low input scenario for CCCMA model for Limpopo for the period 2050. (Calculated from GAEZ, 2012).

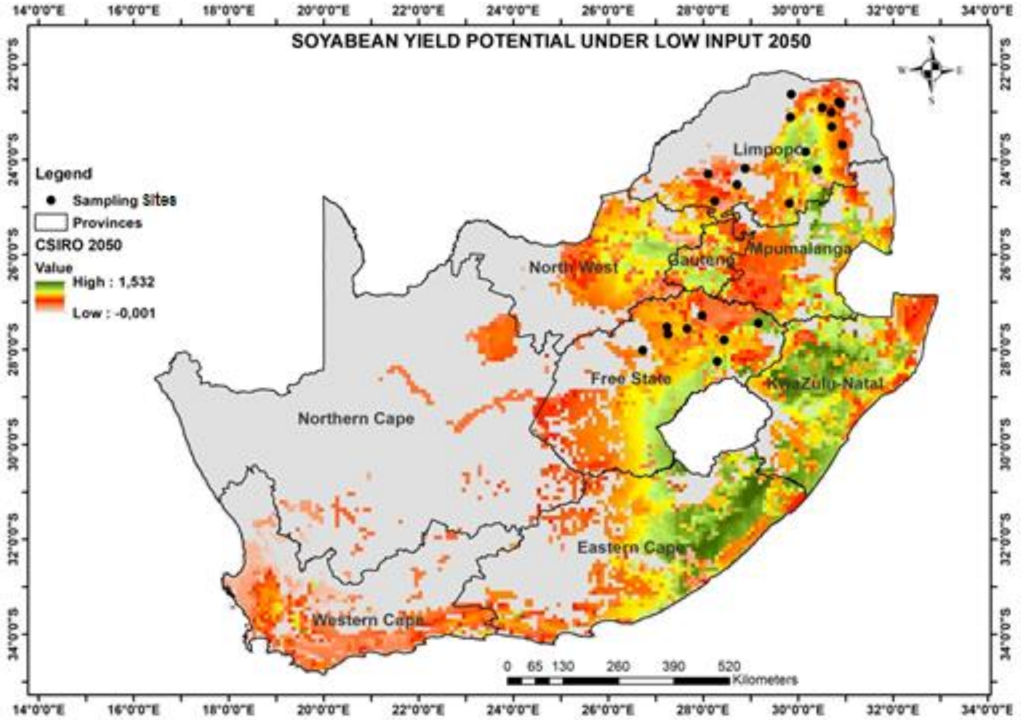


Figure 4.57a: Potential soybean yield for low input scenario for CSIRO model for the period 2050. (Calculated from GAEZ, 2012).

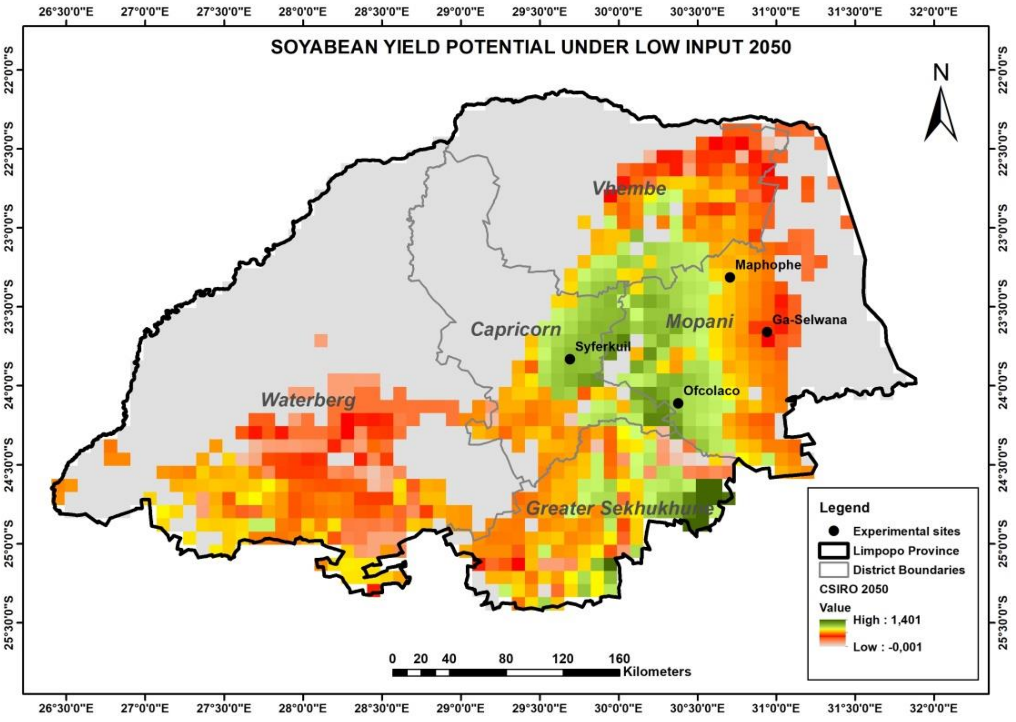


Figure 4.57b: Potential soybean yield for low input scenario for CSIRO model for Limpopo for the period 2050. (Calculated from GAEZ, 2012).

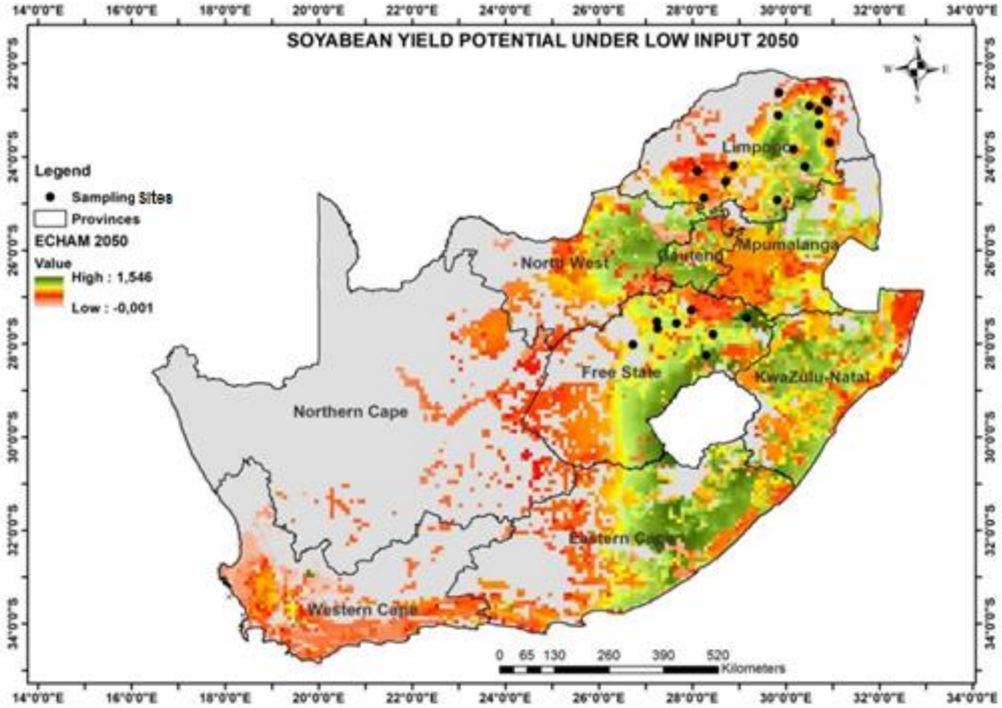


Figure 4.58a: Potential soybean yield for low input scenario for the ECHAM model for the period 2050. (Calculated from GAEZ, 2012).

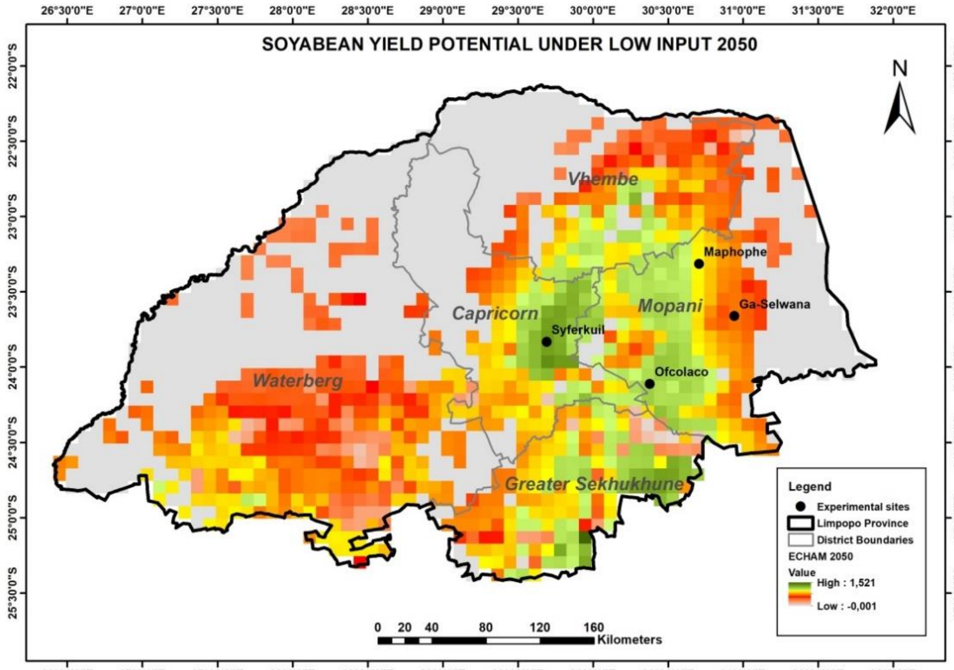


Figure 4.58b: Potential soybean yield for low input scenario for CCCMA model for Limpopo for the period 2050. (Calculated from GAEZ, 2012).

In the intermediate scenario Figures, 4.59 to 4.4.61, yield increase up to 2.5t/ha in certain areas of the summer rainfall areas.

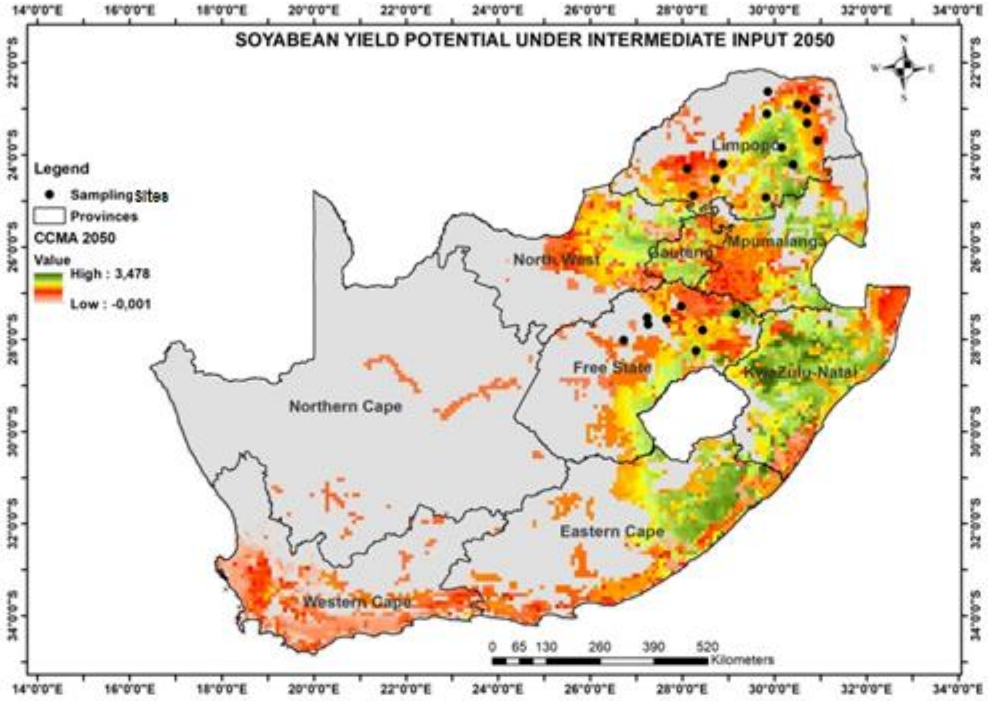


Figure 4.59a: Potential soybean yield for the intermediate scenario for CCCMA model for the period 2050. (Calculated from GAEZ, 2012).

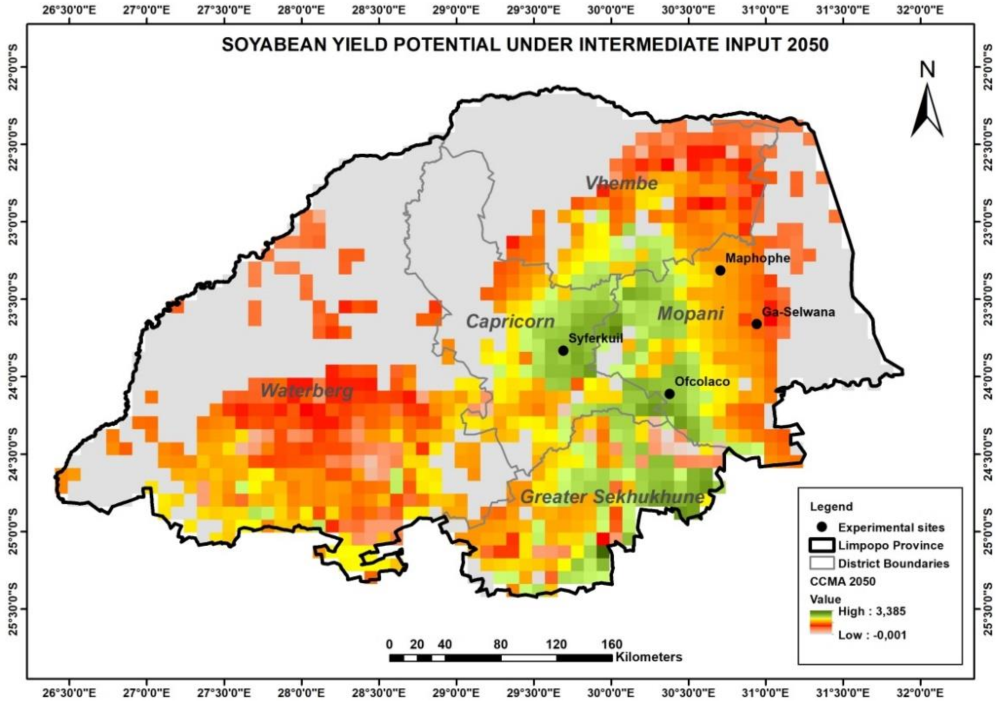


Figure 4.59b: Potential soybean yield for the intermediate scenario for CCCMA model for the Limpopo for period 2050. (Calculated from GAEZ, 2012).

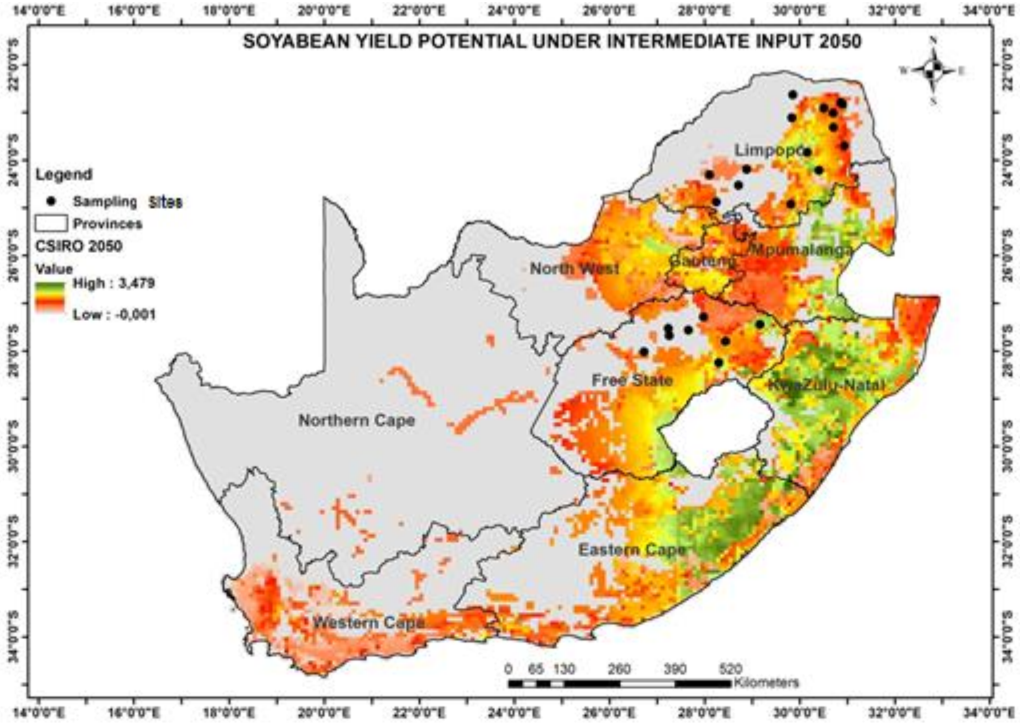


Figure 4.60a: Potential soybean yield for the intermediate scenario for CSIRO model for the period 2050. (Calculated from GAEZ, 2012).

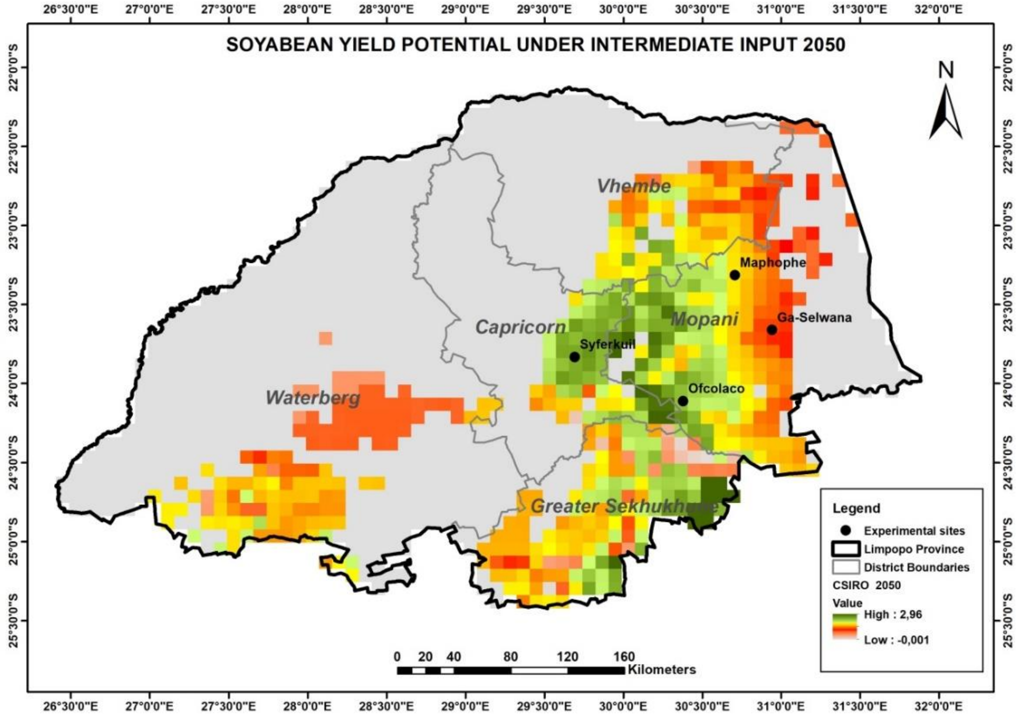


Figure 4.60b: Potential soybean yield for the intermediate scenario for CSIRO model for the period 2050. (Calculated from GAEZ, 2012).

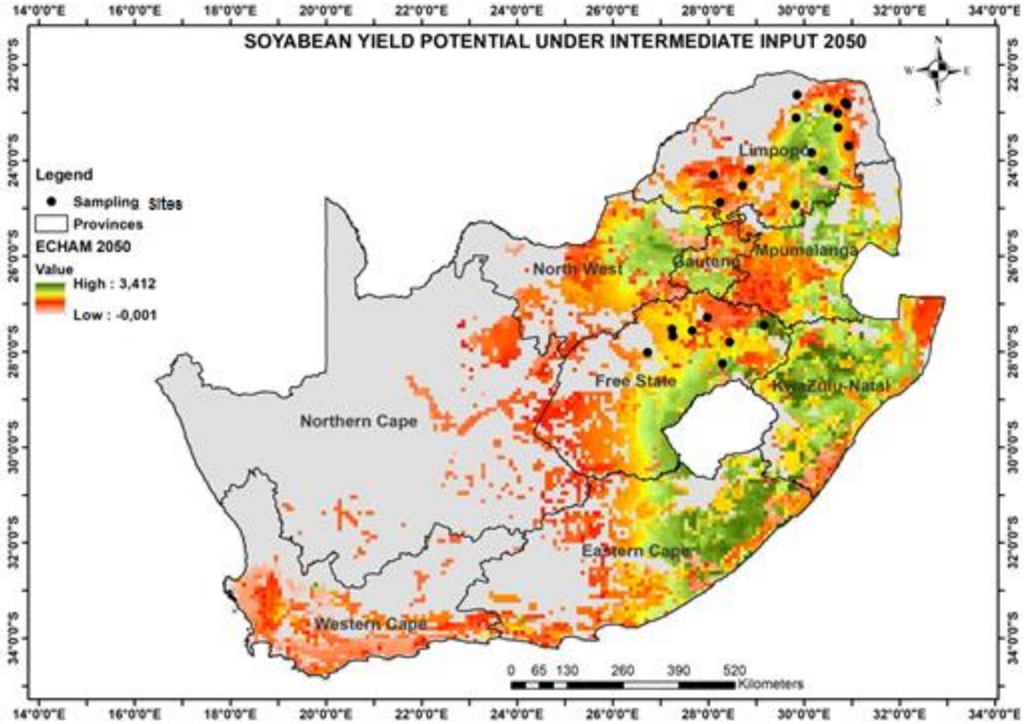


Figure 4.61a: Potential soybean yield for the intermediate scenario for the ECHAM model for the period 2050. (Calculated from GAEZ, 2012).

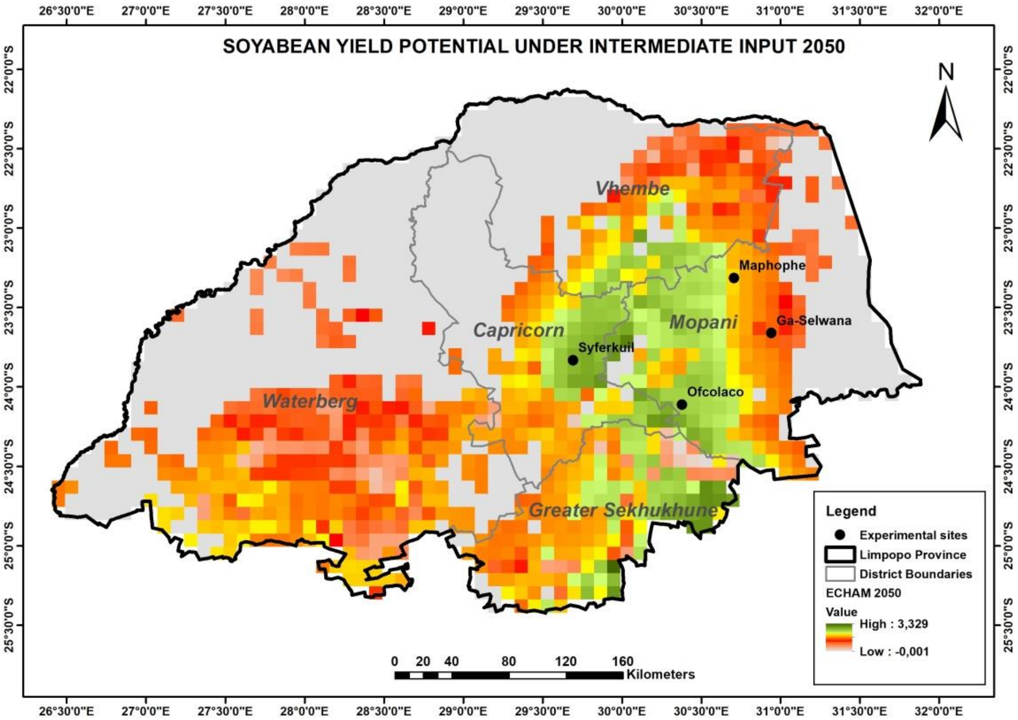


Figure 4.61b: Potential soybean yield for the intermediate scenario for the ECHAM model for Limpopo for the period 2050. (Calculated from GAEZ, 2012).

4.4.1.5 Future potential yield output for soybean under different climate change models for the time period 2080 under the low and intermediate input scenario

Under the low input scenario, all climate models show yield output of up to 1.6t/ha as shown in Figure 4.62 to 4.64. In the intermediate scenario, yield increase up to 3.6t/ha in certain areas of the summer rainfall areas for the 2080-time frame as seen in Figures 4.66 to 4.68.

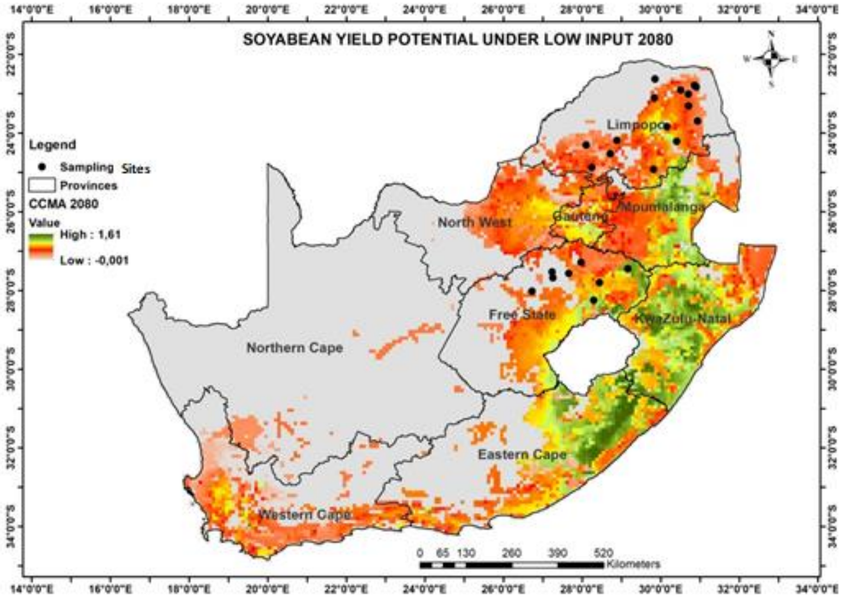


Figure 4.62a: Potential soybean yield for low input scenario for CCCMA model for the period 2080. (Calculated from GAEZ, 2012).

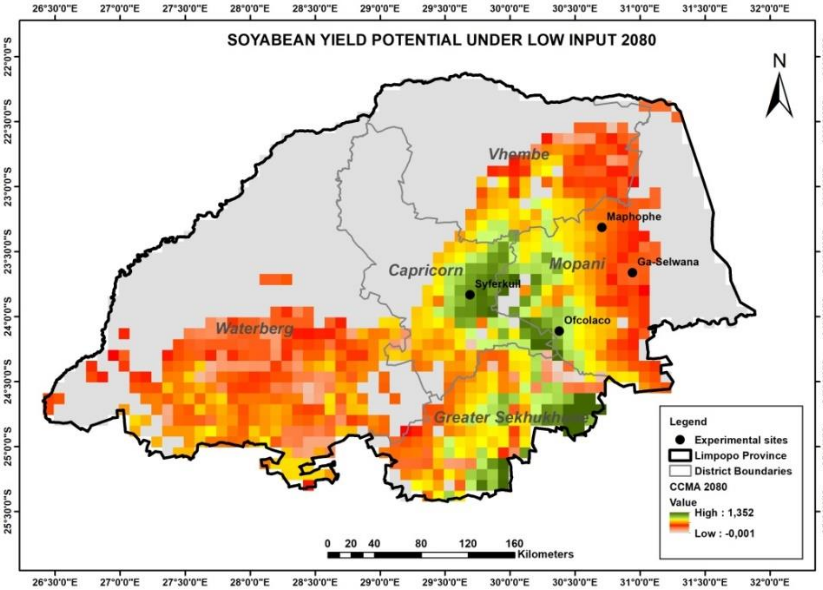


Figure 4.62b: Potential soybean yield for low input scenario for CCCMA model for the period 2080. (Calculated from GAEZ, 2012).

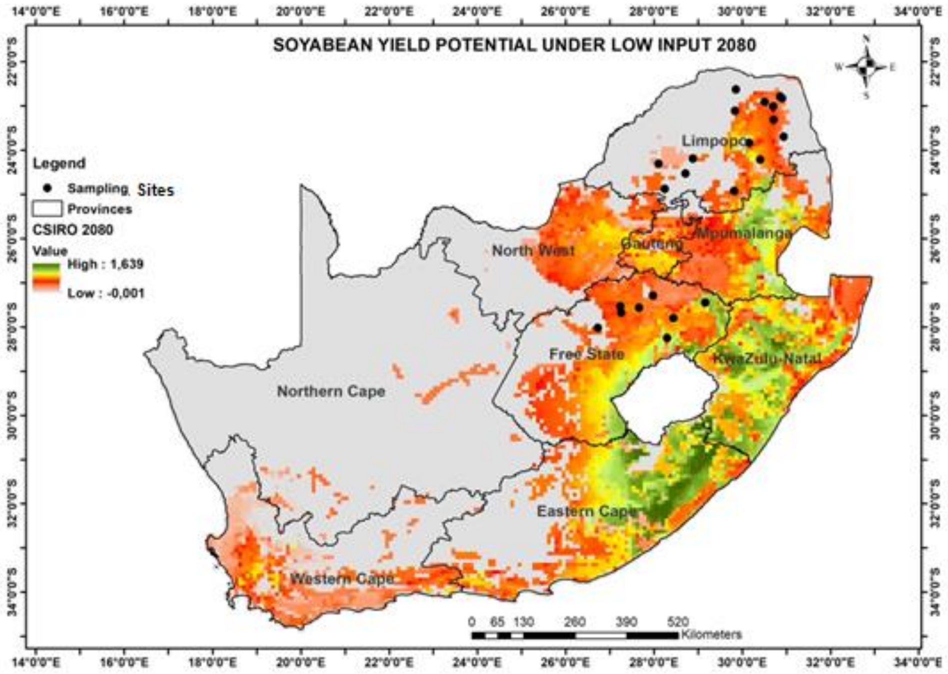


Figure 4.63a: Potential soybean yield for low input scenario for CSIRO model for the period 2080. (Calculated from GAEZ, 2012).

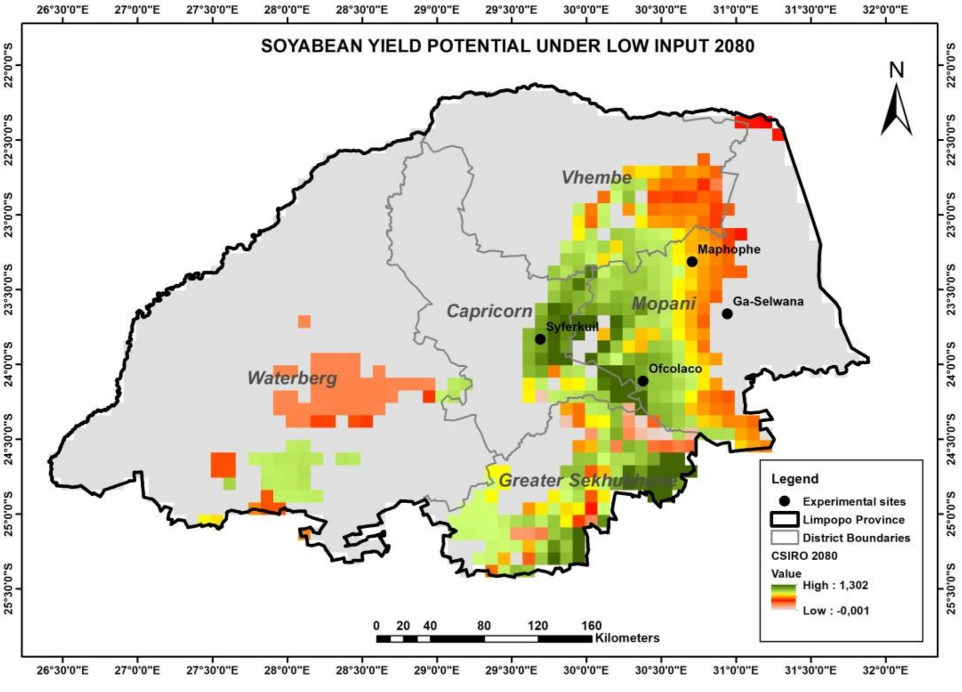


Figure 4.63b: Potential soybean yield for low input scenario for CSIRO model for the period 2080. (Calculated from GAEZ, 2012).

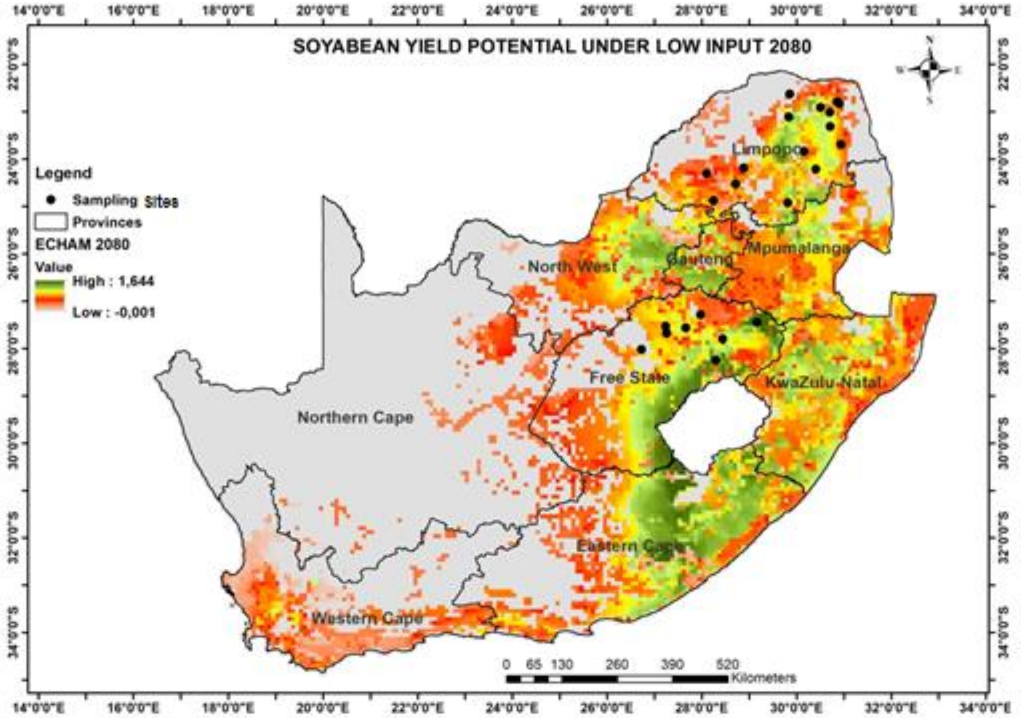


Figure 4.64a: Potential soybean yield for low input scenario for ECHAM model for the period 2080. (Calculated from GAEZ, 2012).

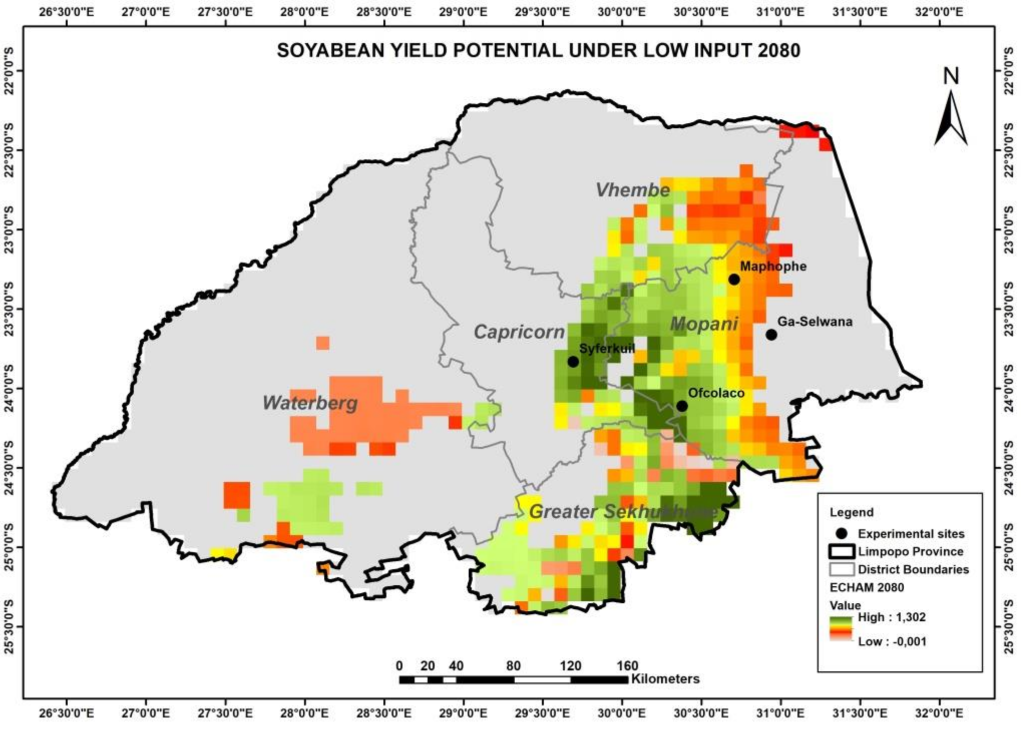


Figure 4.64b: Potential soybean yield for low input scenario for the ECHAM model for Limpopo for the period 2080. (Calculated from GAEZ, 2012).

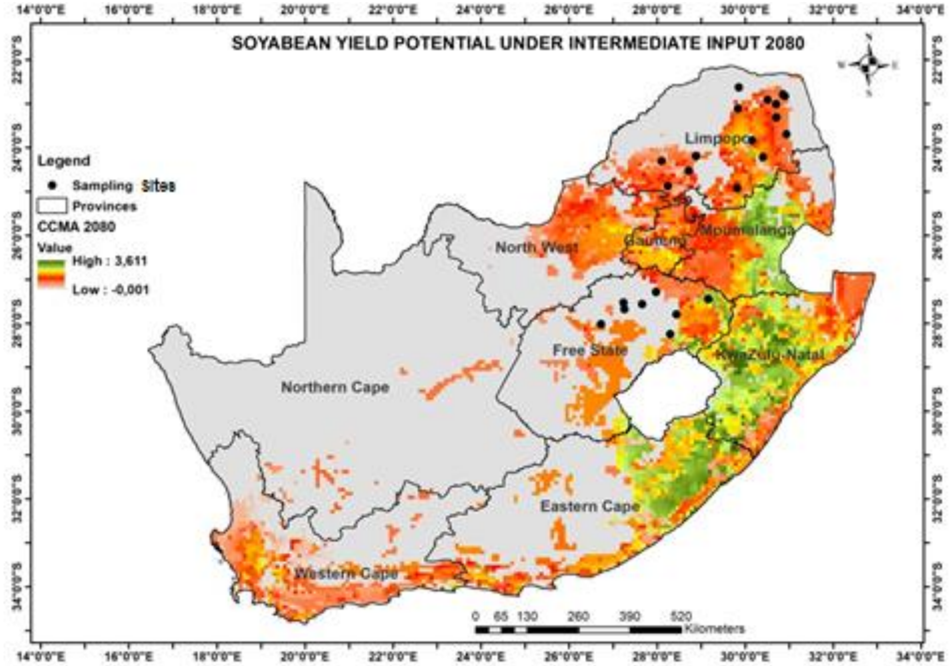


Figure 4.65a: Potential soybean yield under intermediate input scenario for CCCMA model for the period 2080. (Calculated from GAEZ, 2012).

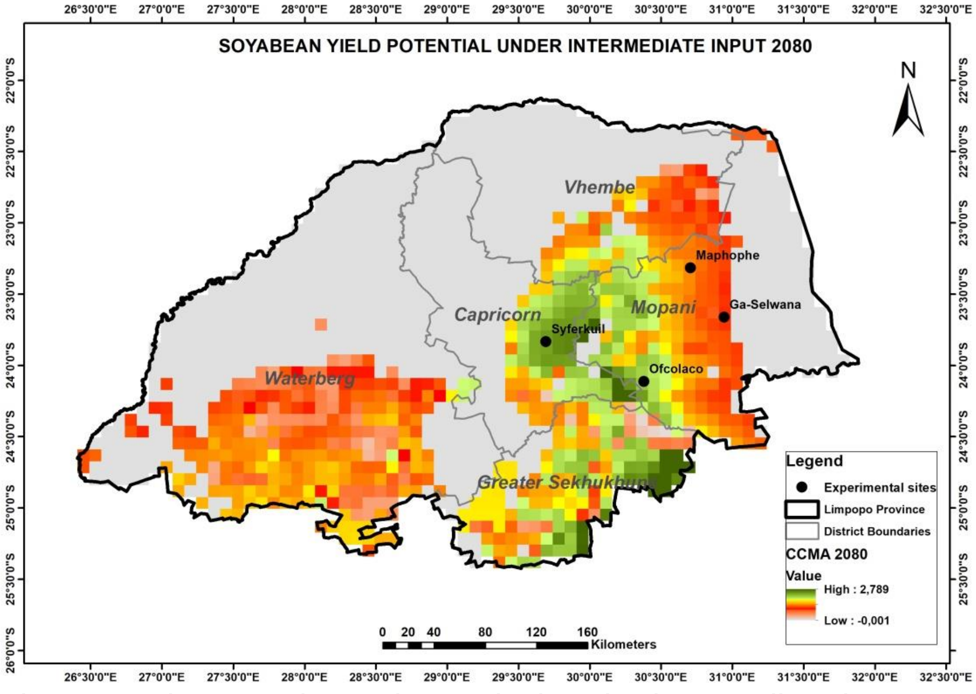


Figure 4.65b: Potential soybean yield under intermediate input scenario for CCCMA model for Limpopo for the period 2080. (Calculated from GAEZ, 2012).

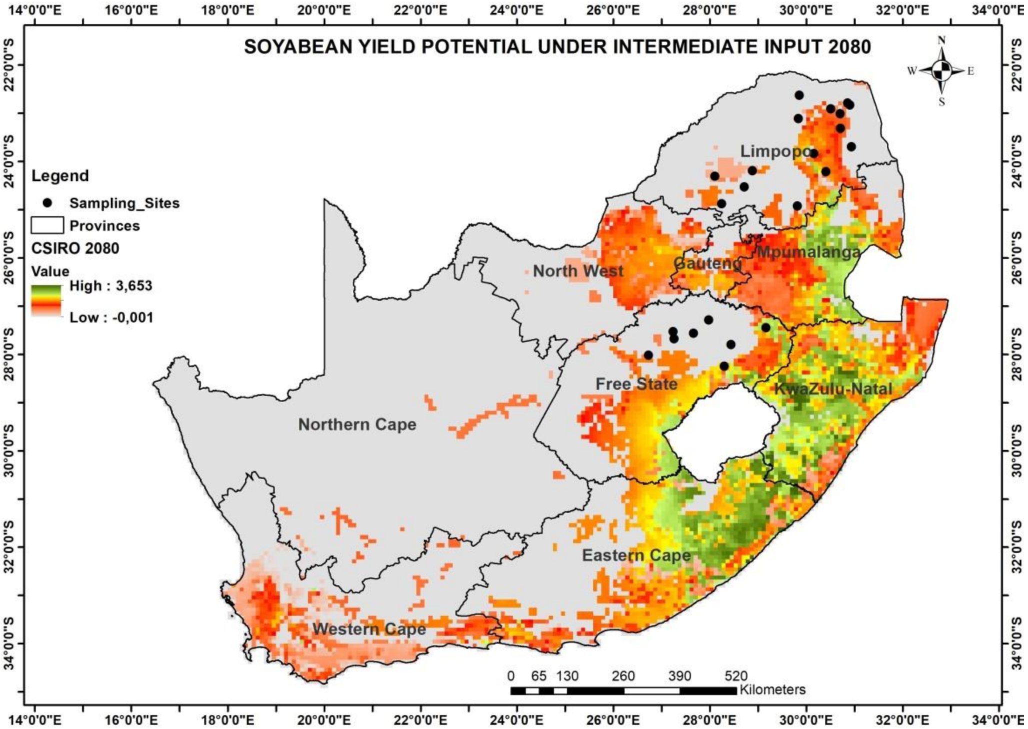


Figure 4.66a: Potential soybean yield for intermediate input scenario for CSIRO model for the period 2080. (Calculated from GAEZ, 2012).

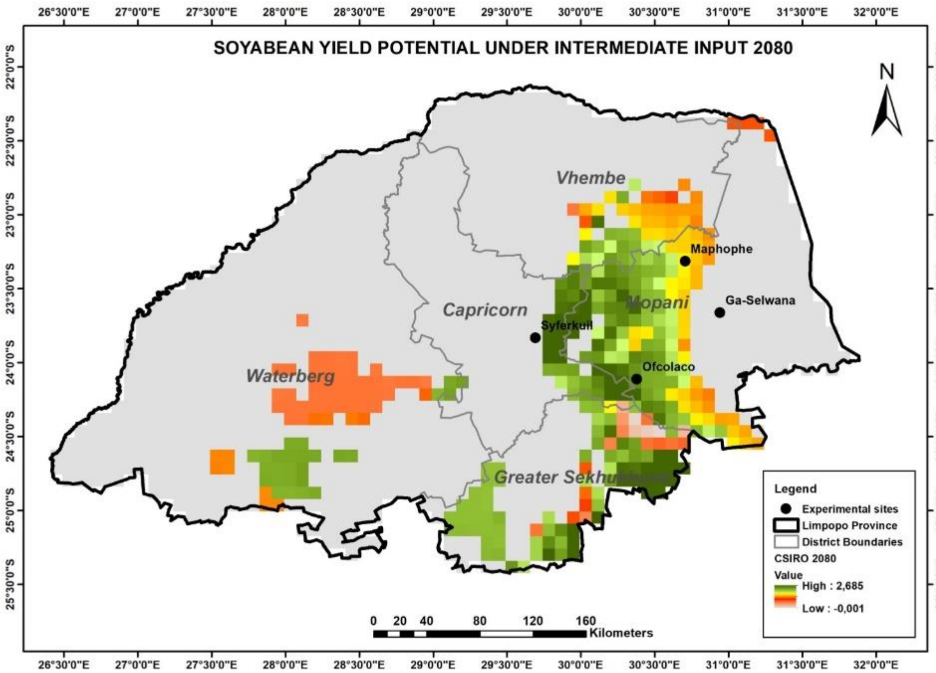


Figure 4.66b: Potential soybean yield for intermediate input scenario for CSIRO model for Limpopo for the period 2080. (Calculated from GAEZ, 2012).

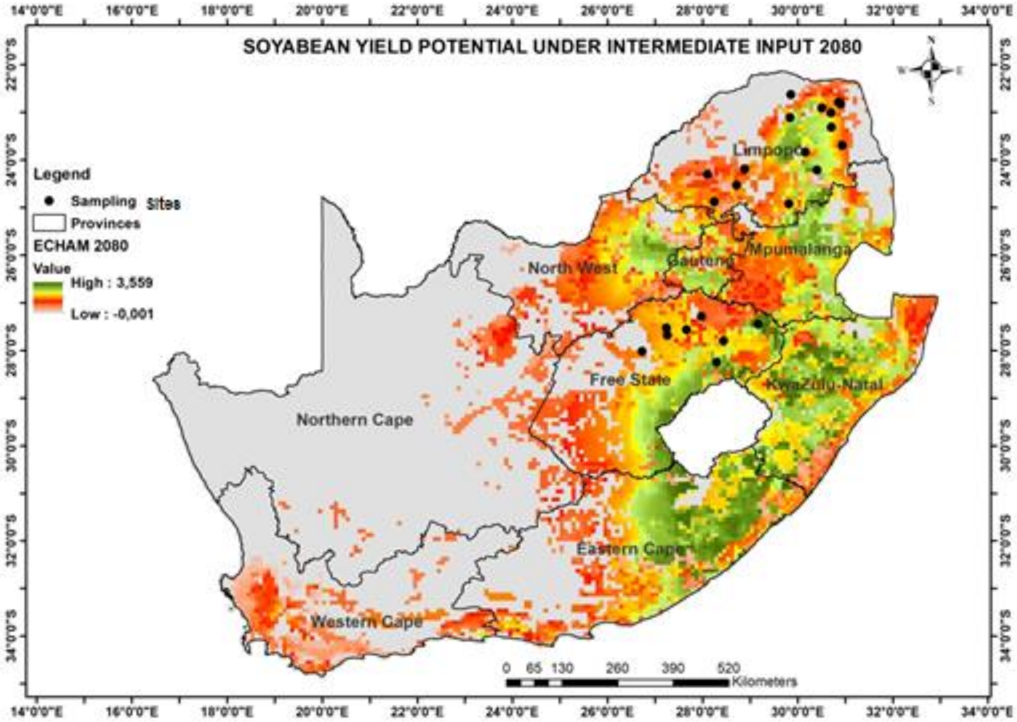


Figure 4.67a: Potential soybean yield for intermediate input scenario for the ECHAM model for the period 2080. (Calculated from GAEZ, 2012).

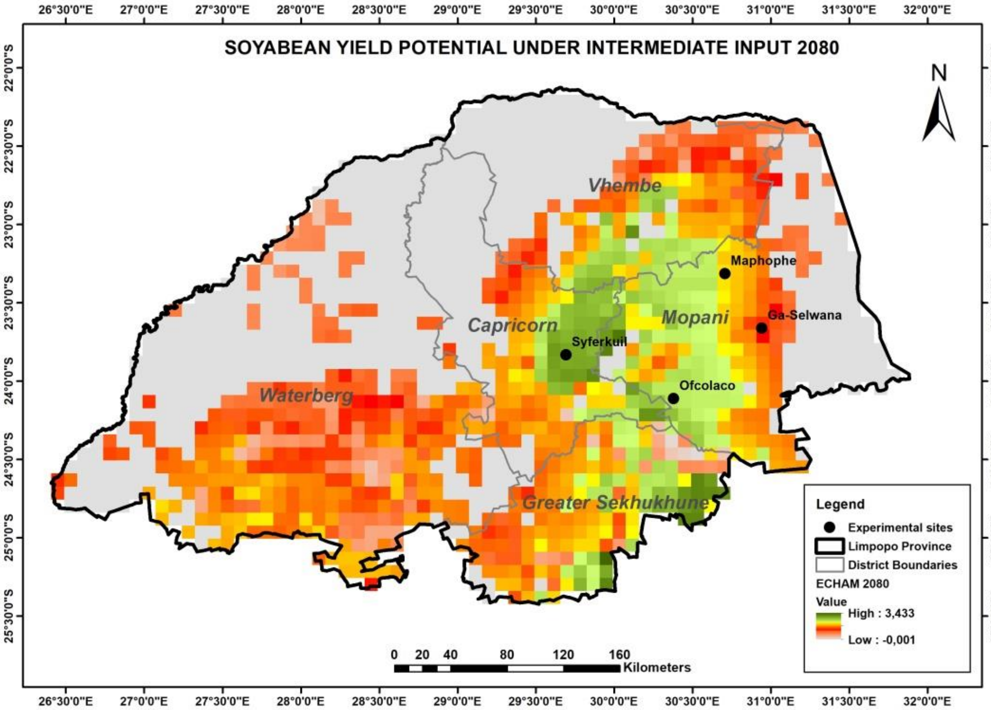


Figure 4.67b: Potential soybean yield for intermediate input scenario for the ECHAM model for Limpopo for the period 2080. (Calculated from GAEZ, 2012).

4.4.2 Potential Crop yield variability over space and time frames for sunflower

In the low input baseline scenario, as shown in Figures 4.68, yield output for sunflower production is up to 2.04 t/ha. These high yield outputs are shown to be in areas of Mpumalanga, KZN, Free State. In Limpopo areas in the semi arid areas had a yield of up to 1.5 t/ha. Areas showing a yield of above 1 t/ha are in the semi-arid and the humid areas as seen in Figure 4.68b.

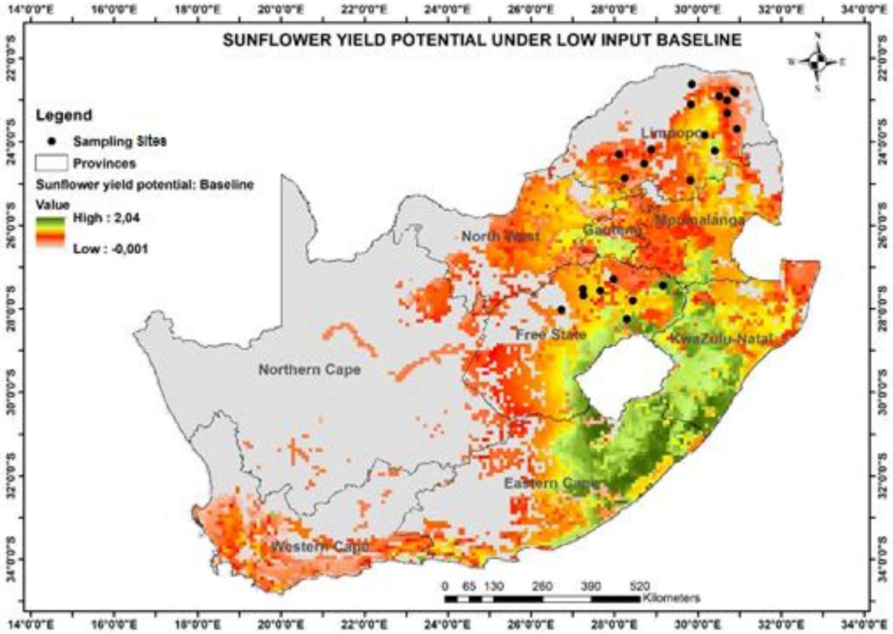


Figure 4.68a: Potential sunflower yield for low input scenario for CCCMA model for the period 2020. (Calculated from GAEZ, 2012).

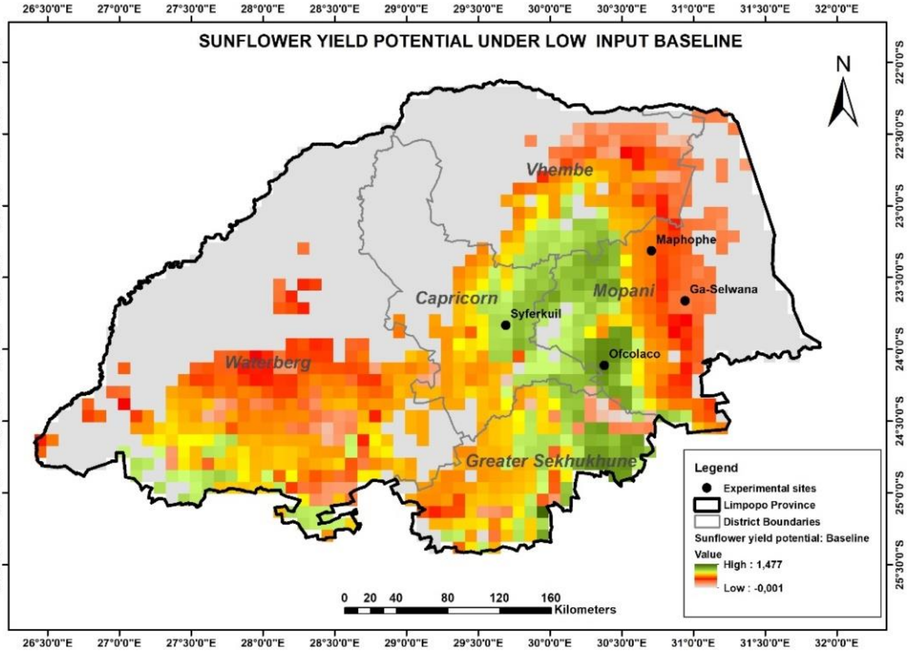


Figure 4.68b: Potential sunflower yield for low input scenario for CCCMA model for the period 2020. (Calculated from GAEZ, 2012)

In the intermediate baseline scenario, as seen in Figure 4.69a, sunflower production is up to 3.2 t/ha. Areas showing a high yield of 3.2 t/ha include patches in the Free State, Mpumalanga. Some areas in the Free state show yield of as low as about 0.2 t/ha with other areas such as Limpopo, North West, Gauteng showing yields of less thean1t/ha.

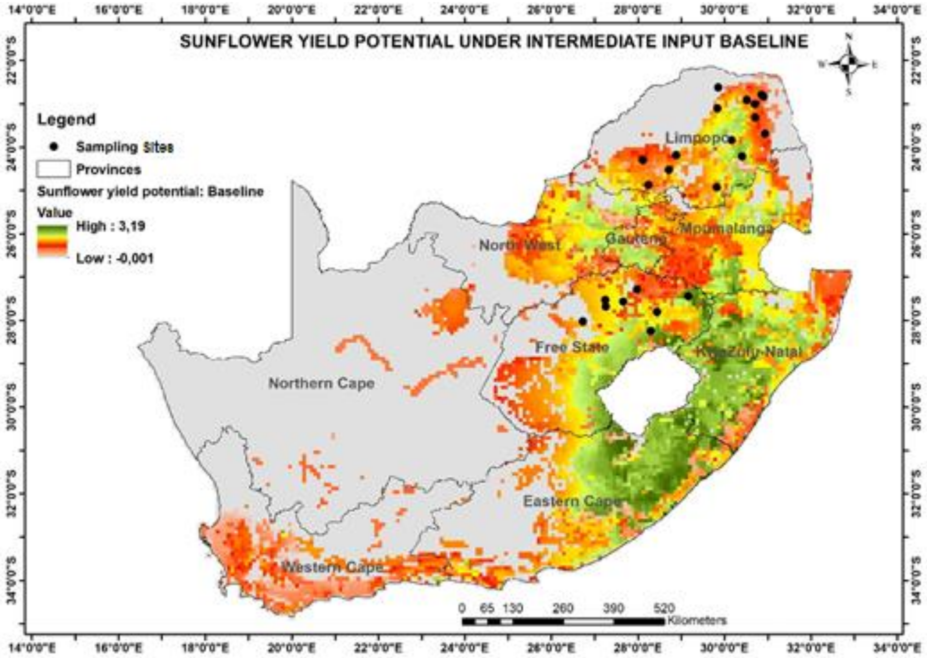


Figure 4.69a: Potential sunflower yield for low input scenario for the baseline the period 2020. (Calculated from GAEZ, 2012).

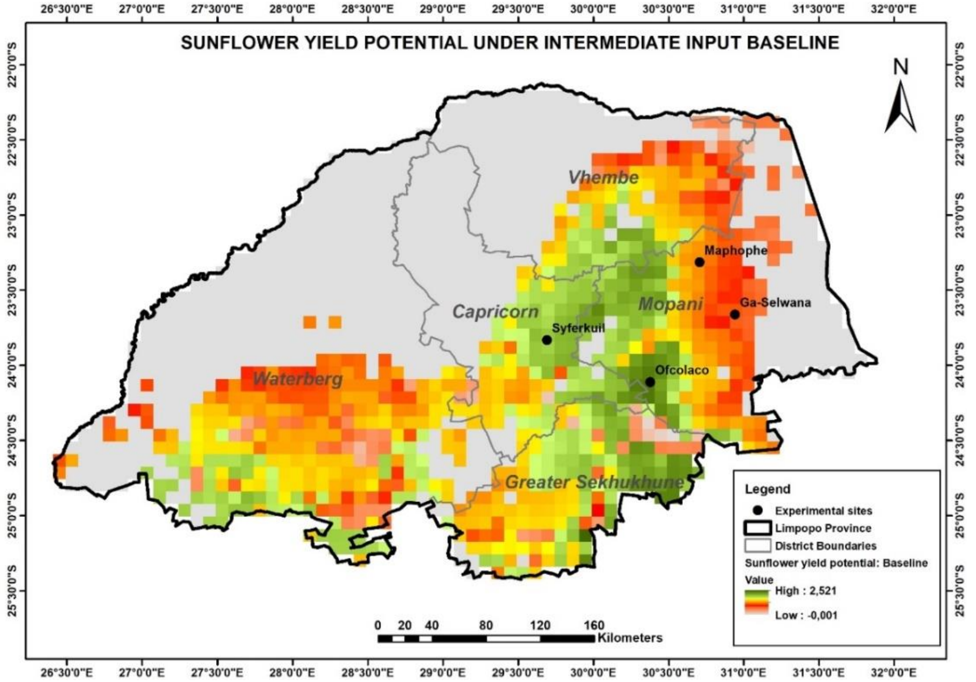


Figure 4.69b: Potential sunflower yield for the intermediate baseline period (Calculated from GAEZ, 2012).

4.4.2.1 Future potential yield output for sunflower under different climate change models for the time period 2020 under the low input scenario

Under the low input scenario for CCCMA, yield ranges up to 2.2 t/ha. Higher yields are found in the Free State, Mpumalanga and KZN as shown in Figure 4.70a. Low yield of about half a ton can be seen in areas of North West, Gauteng, Limpopo, and parts of Free State and Northern Cape. Figure 4.70b shows that yield in Limpopo for the 2020 periods are up to 1.6 t/ha.

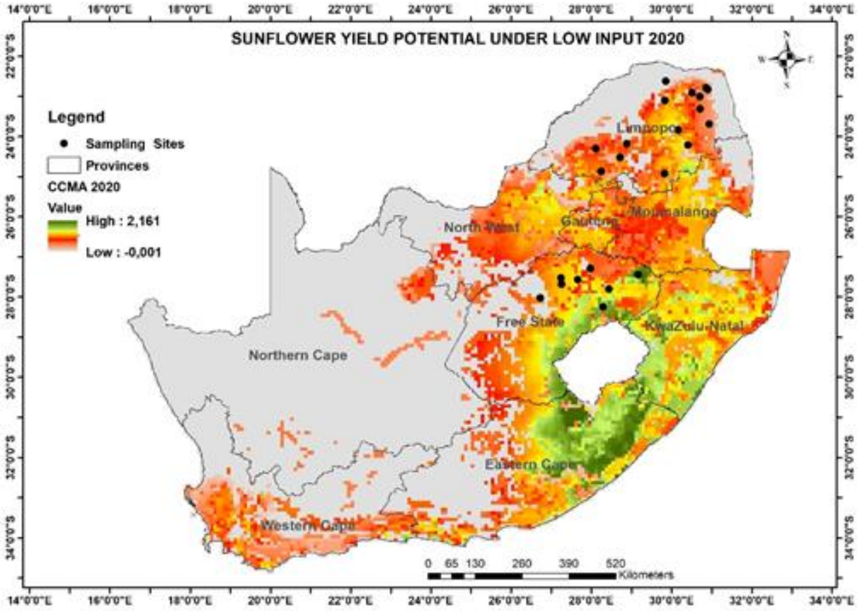


Figure 4.70a: Potential sunflower yield for low input fir model CCCMA for the 2020 period (Calculated from GAEZ, 2012).

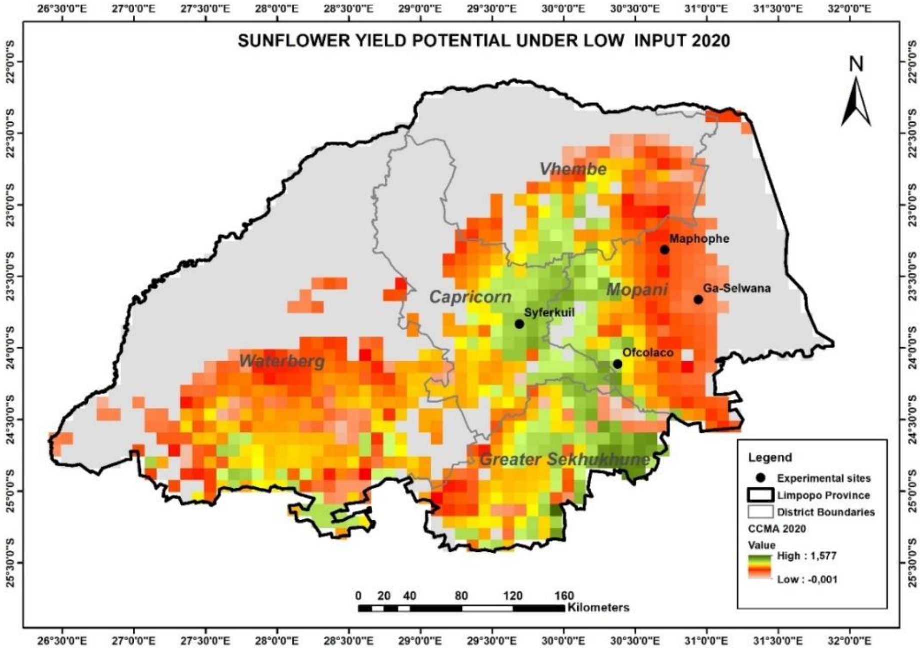


Figure 4.70b: Potential sunflower yield for low input for model CCCMA for Limpopo for the 2020 period (Calculated from GAEZ, 2012).

Yield output is shown for CSIRO, ECHAM3 models with the optimum yield at 2.1t//ha. As with the CCCMA model, the areas showing a yield of up to 2.1t/ha are found in Mpumalanga, KZN, Free State as seen in Figure 4.71a and 4.72b. In Limpopo, under the CSIRO model yields ranges up to 1.4t/ha in areas of the humid and semi-arid areas as seen in Figures 4.71b. Under the ECHAM model, yields in Limpopo are up to 1.6t/ha are mostly found in the humid and semi-arid areas as seen in 4.72b.

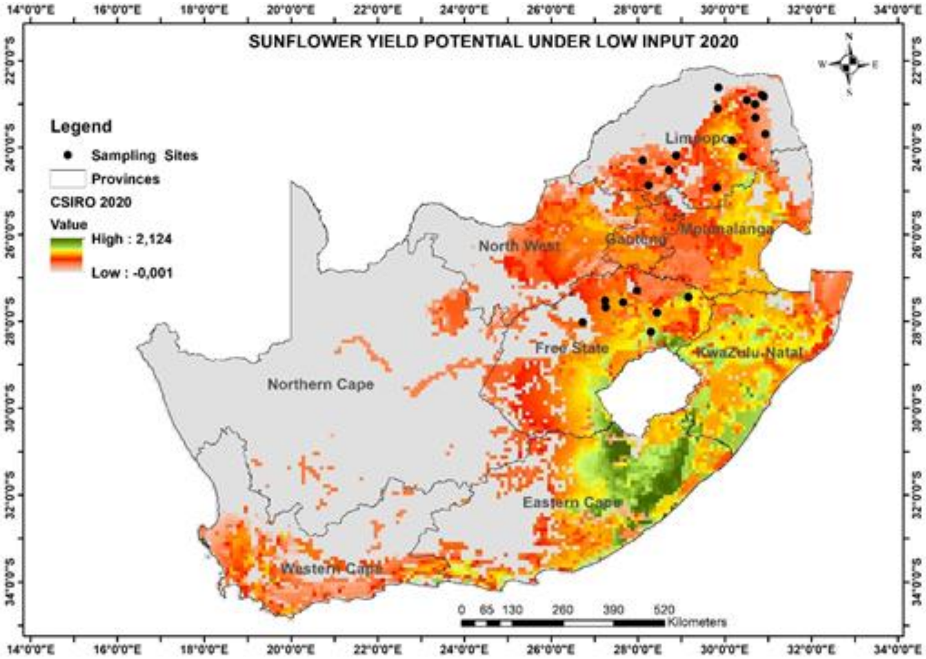


Figure 4.71a: Potential sunflower yield for low input for model CSIRO for the 2020 period (Calculated from GAEZ, 2012).

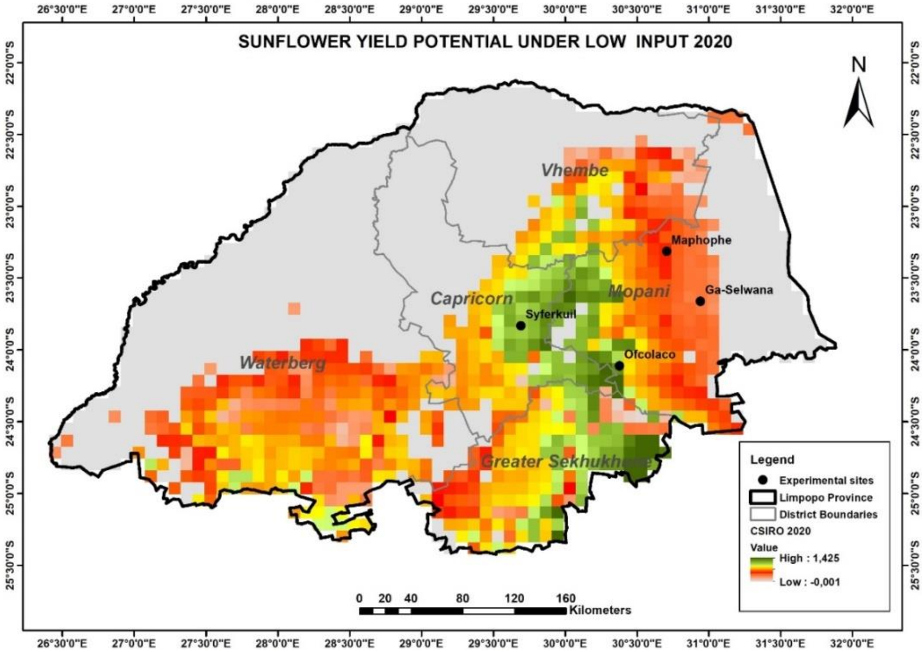


Figure 4.71b: Potential sunflower yield for low input for model CSIRO for Limpopo for the 2020 period (Calculated from GAEZ, 2012).

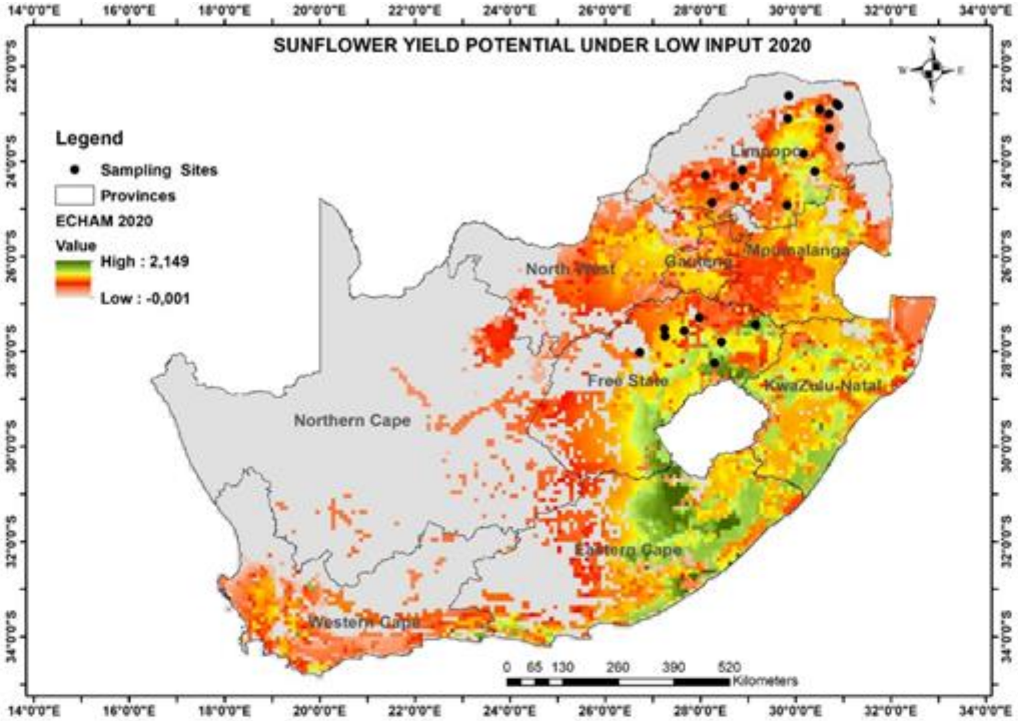


Figure 4.72a: Potential sunflower yield for low input for model ECHAM for the 2020 period (Calculated from GAEZ, 2012).

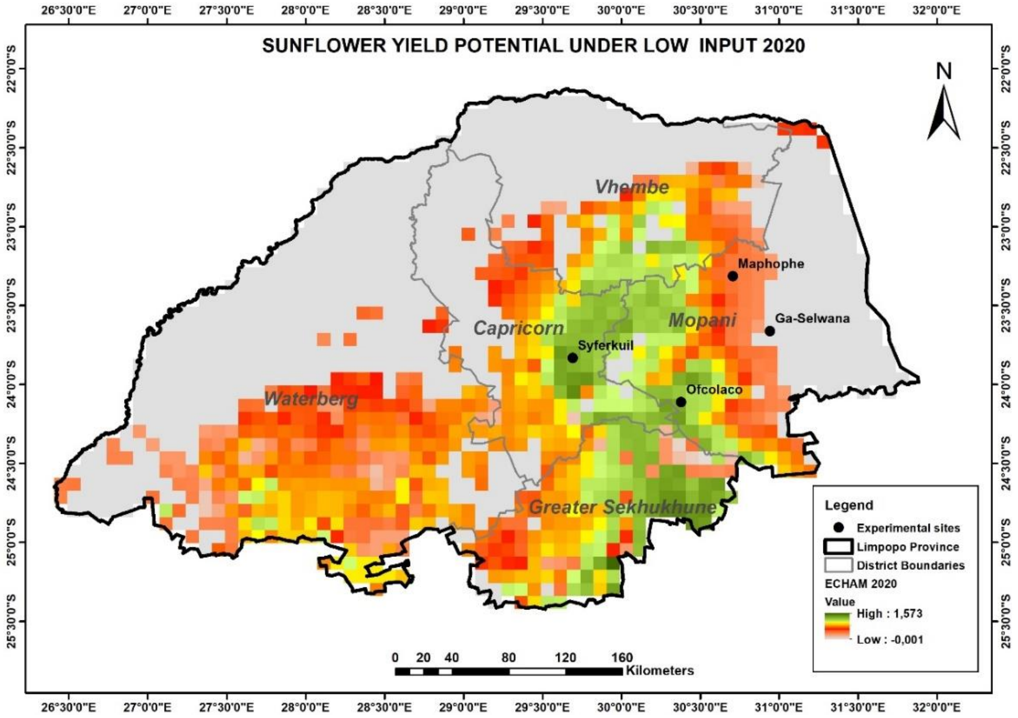


Figure 4.72b: Potential sunflower yield for low input for model ECHAM for the 2020 period (Calculated from GAEZ, 2012).

4.4.2.2 Future potential yield output for sunflower under different climate change models for the time period 2020 under the intermediate input scenario

Figure 4.73a shows that under the CCCMA yields range up to 3.3 t/ha with areas such as Eastern Cape, Kwazulu Natal, Free State and patches in North West having yields of 3.3. In Figure in 4.73b, shows yields in Limpopo up to 3 t/ha. Figures 4.74a and b shows that, for the model CSIRO yields for some areas in the country goes up to 3 t/ha while in Limpopo the highest yields recorded are up to 2.5t/ha. The ECHAM model shows maximum yield is estimated at 3.3t/ha for the country as seen in Figure 4.76a and up to 2.8t/ha in Limpopo as shown by 4.74b.

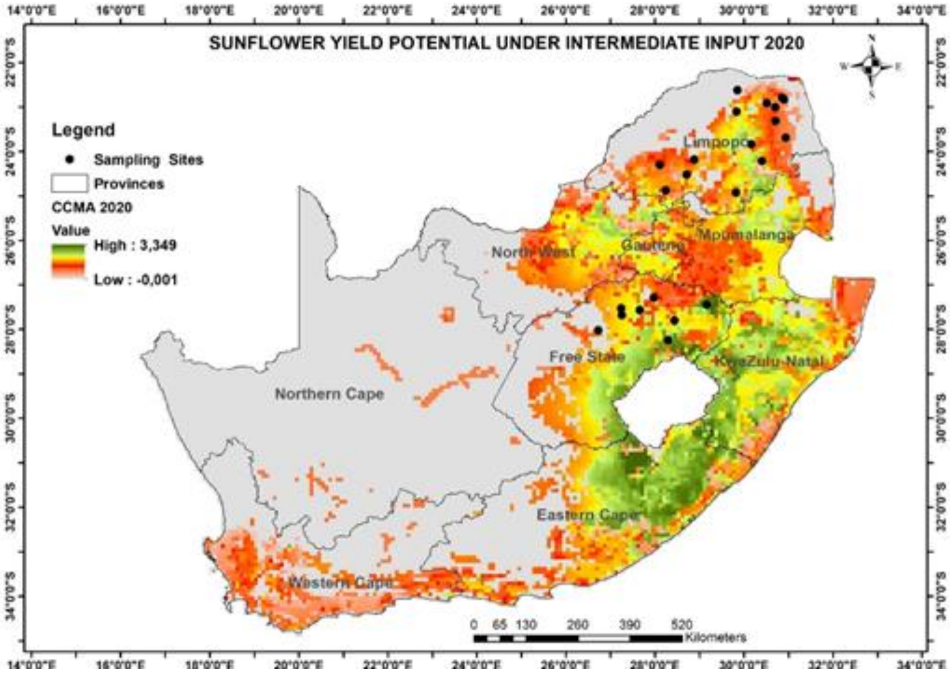


Figure 4.73a: Potential sunflower yield for intermediate input for model CCCMA for the 2020 period (Calculated from GAEZ, 2012).

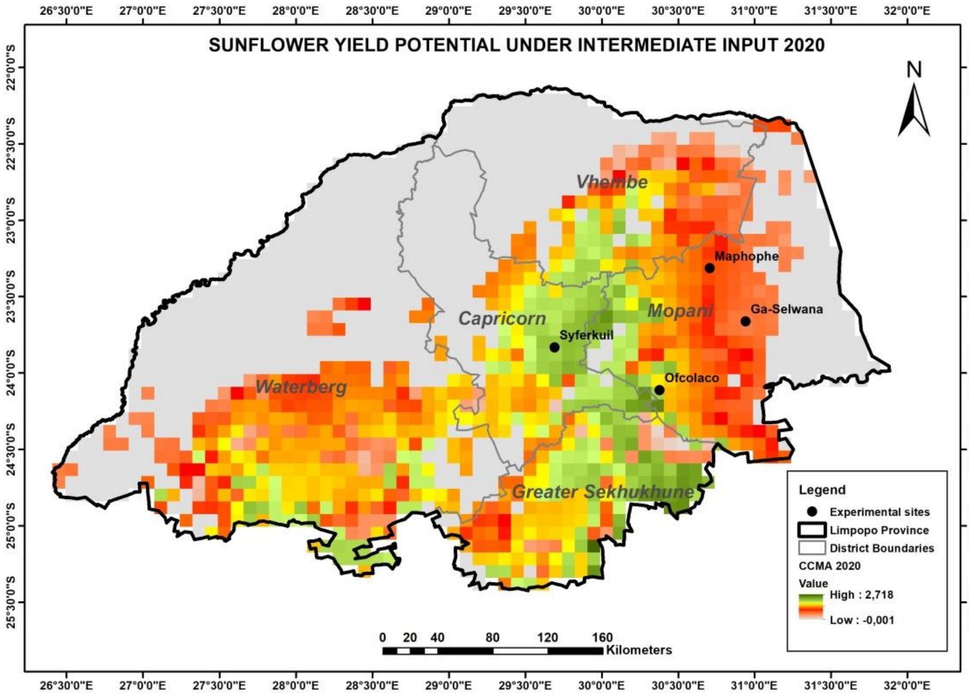


Figure 4.73b: Potential sunflower yield for intermediate input for model CCCMA for Limpopo for the 2020 period (Calculated from GAEZ, 2012).

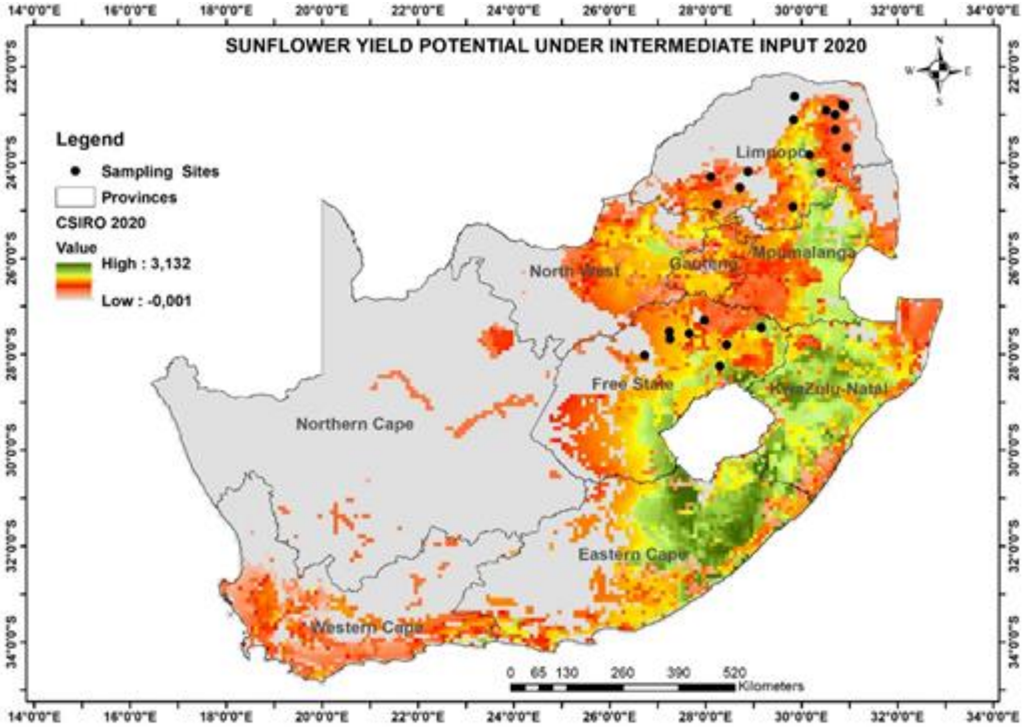


Figure 4.74a: Potential sunflower yield for intermediate input for model CSIRO for the 2020 period (Calculated from GAEZ, 2012).

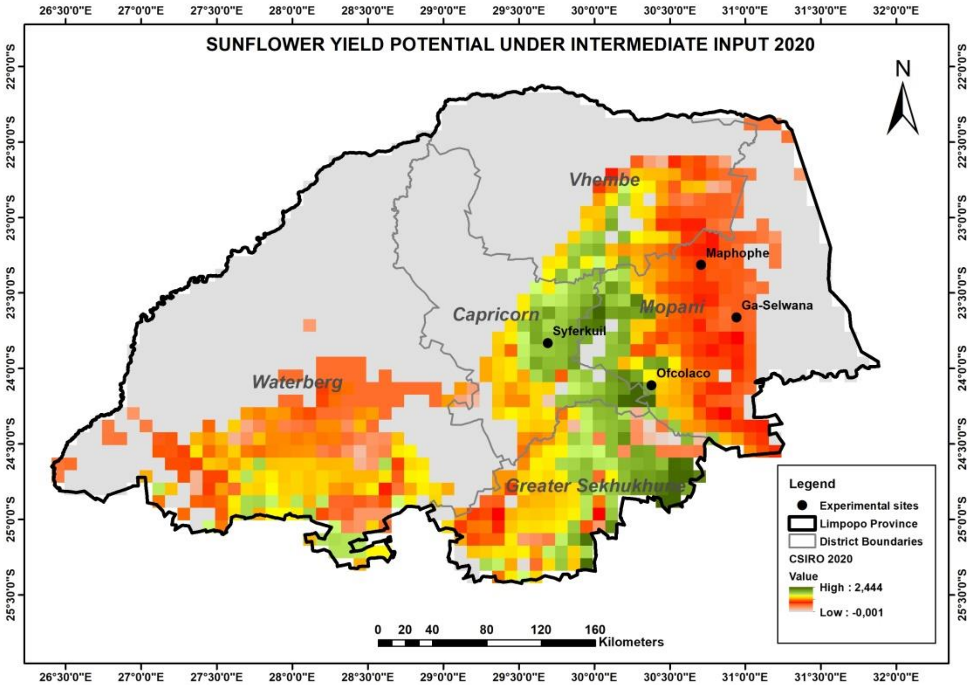


Figure 4.74b: Potential sunflower yield for intermediate input for model CSIRO for Limpopo for the 2020 period (Calculated from GAEZ, 2012).

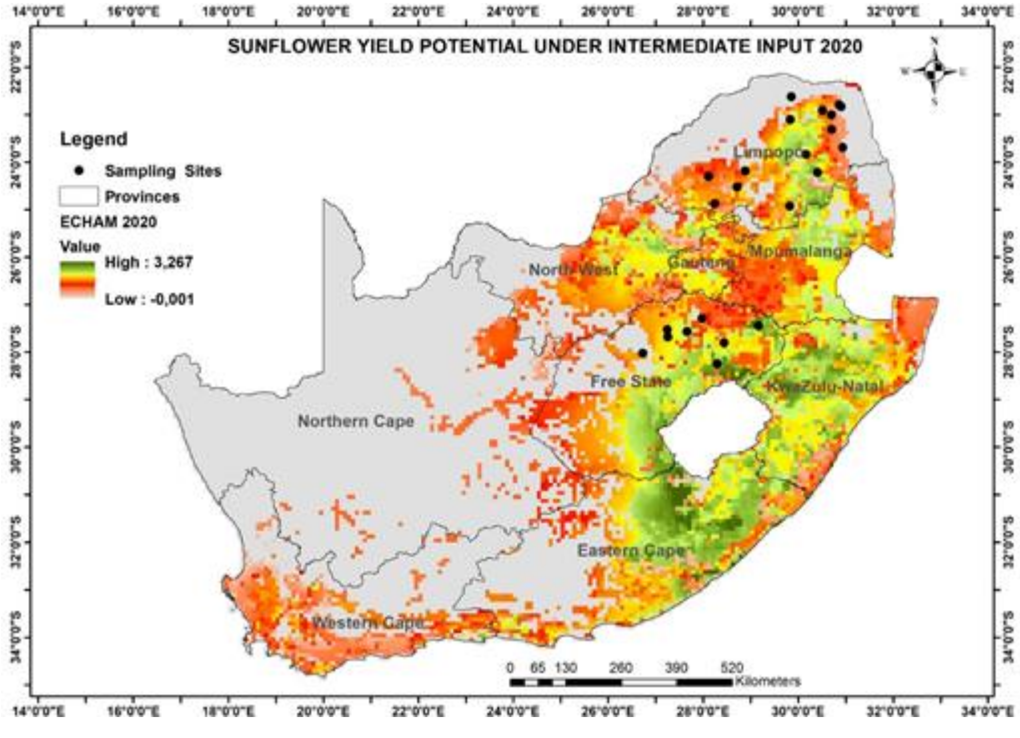


Figure 4.75a: Potential sunflower yield for intermediate input for model ECHAM for the 2020 period (Calculated from GAEZ, 2012).

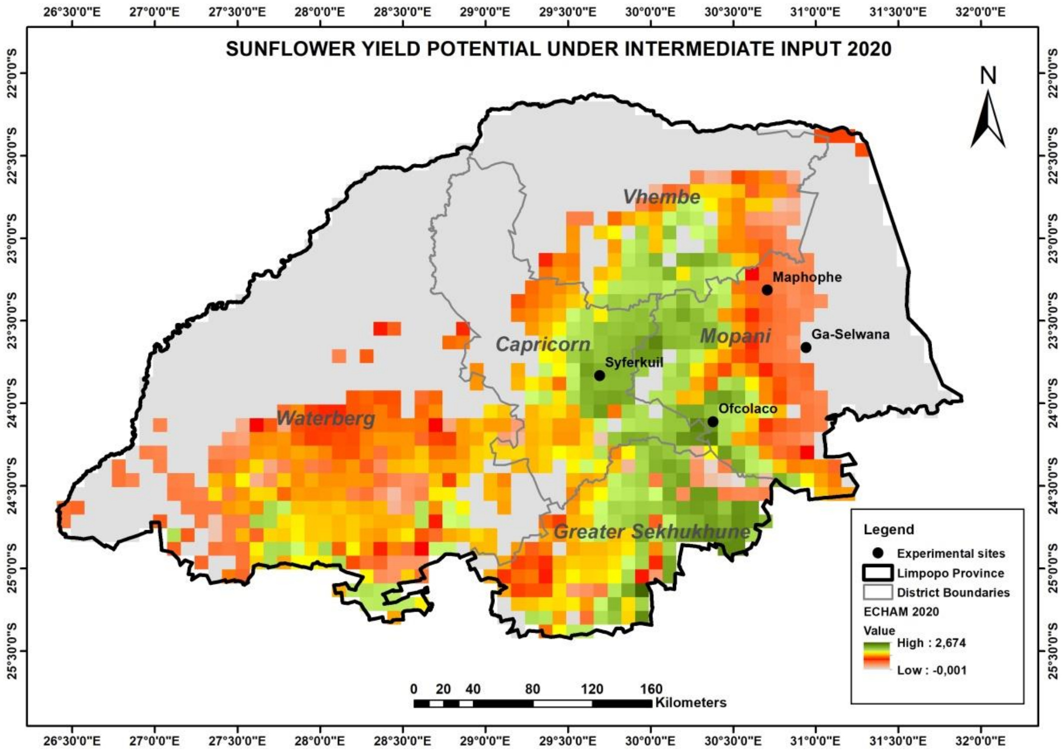


Figure 4.75b: Potential sunflower yield for intermediate input for model ECHAM for Limpopo for the 2020 period (Calculated from GAEZ, 2012).

4.4.2.3 Future potential yield output for sunflower under different climate change models for the time period 2050 under the low and intermediate input scenario

Under the low input scenario as seen in Figures 4.76a the climate model CCCMA show yield output of up to 1.8 t/ha. Areas of Eastern Cape, KwaZulu Natal, patches in Free State and Limpopo, show yields of 1.8t/ha. In Limpopo as seen in Figure 4.76b, yields are up to 1.5 t/ha. In the intermediate scenario Figures, 4.90 to 4.94, yield increase up to 2.48 t/ha in certain areas of the summer rainfall areas.

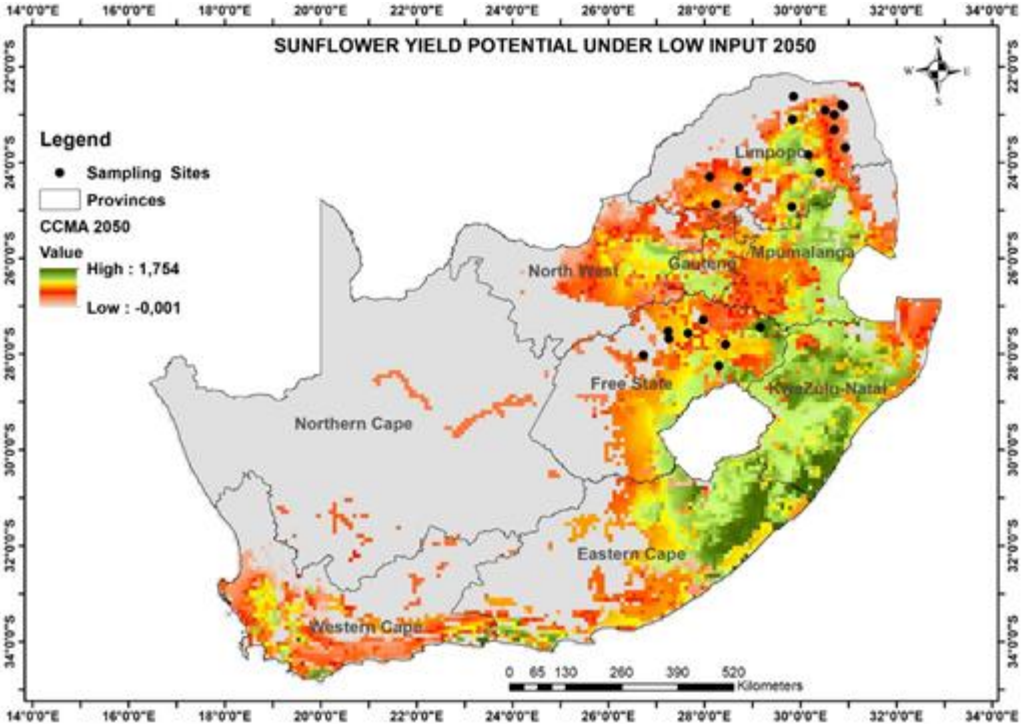


Figure 4.76a: Potential sunflower yield for low input for model CCCMA for the 2050 period. (Calculated from GAEZ, 2012).

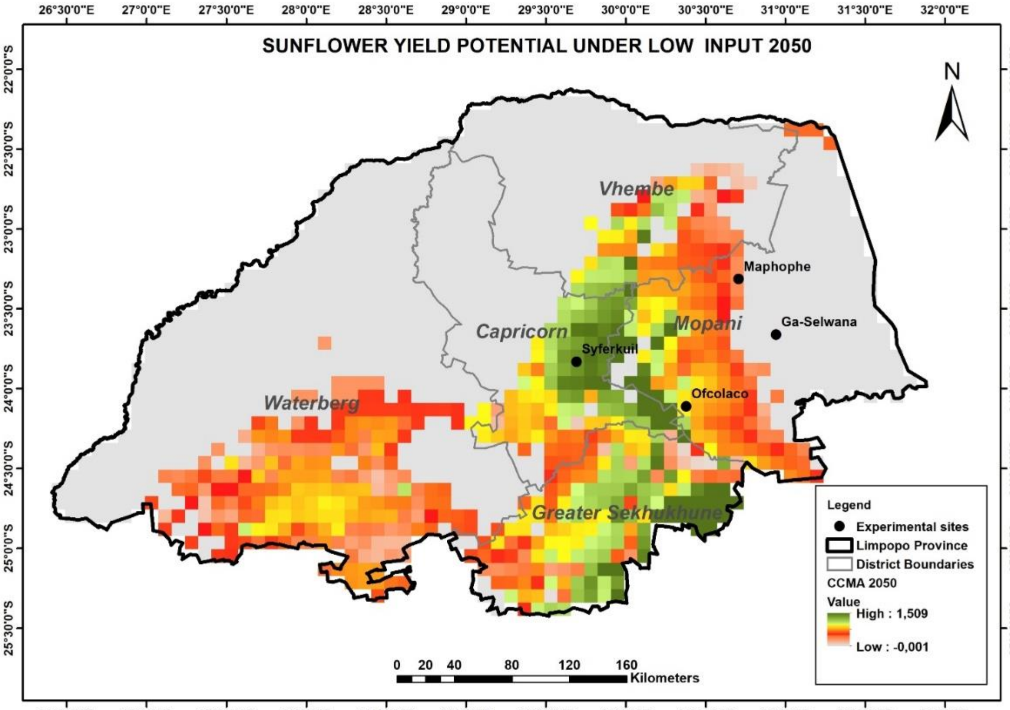


Figure 4.76b: Potential sunflower yield for low input for model CCCMA for Limpopo for the 2050 period (Calculated from GAEZ, 2012).

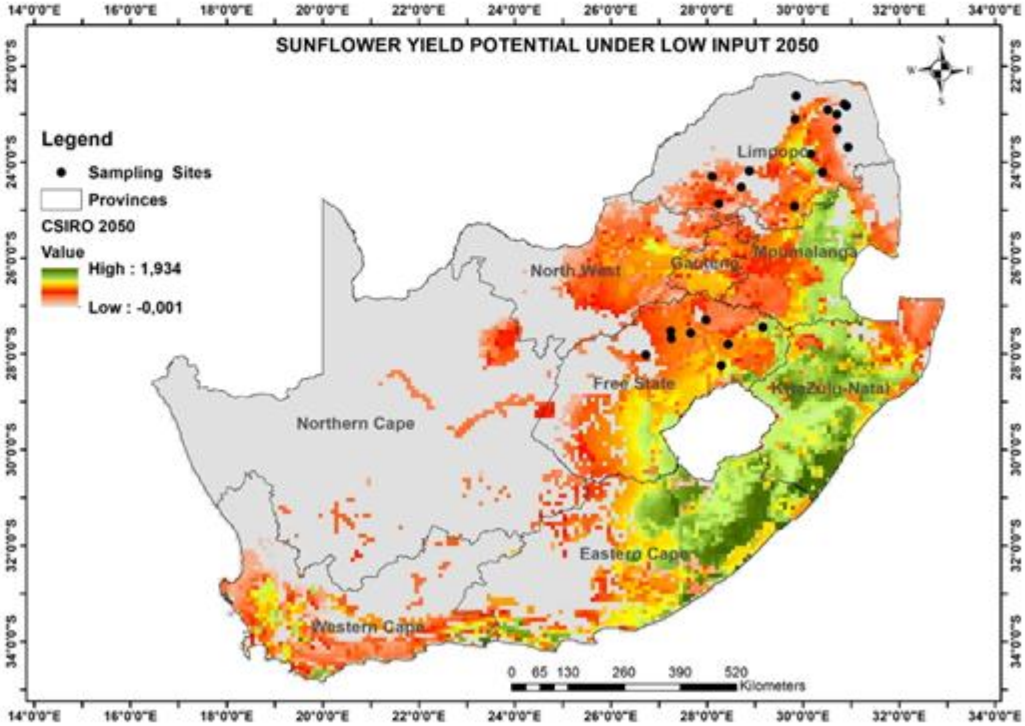


Figure 4.77a: Potential sunflower yield for low input for model CSIRO for the 2050 period (Calculated from GAEZ, 2012).

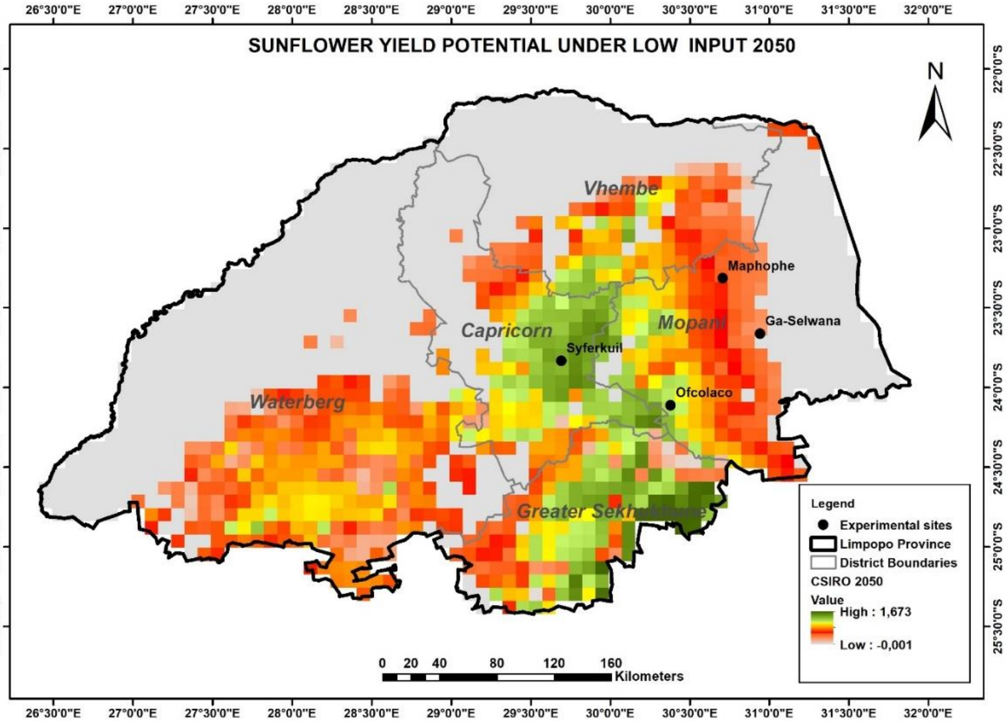


Figure 4.77a: Potential sunflower yield for low input for model CSIRO for the 2050 period (Calculated from GAEZ, 2012).

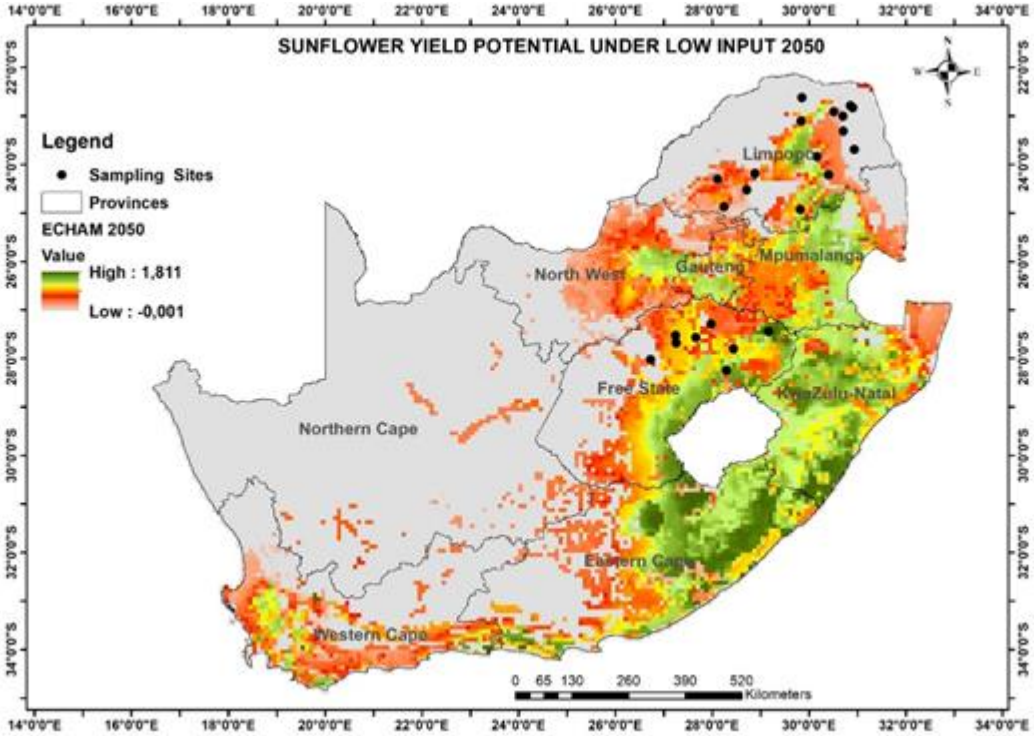


Figure 4.78a: Potential sunflower yield for low input for model ECHAM for the 2050 period (Calculated from GAEZ, 2012).

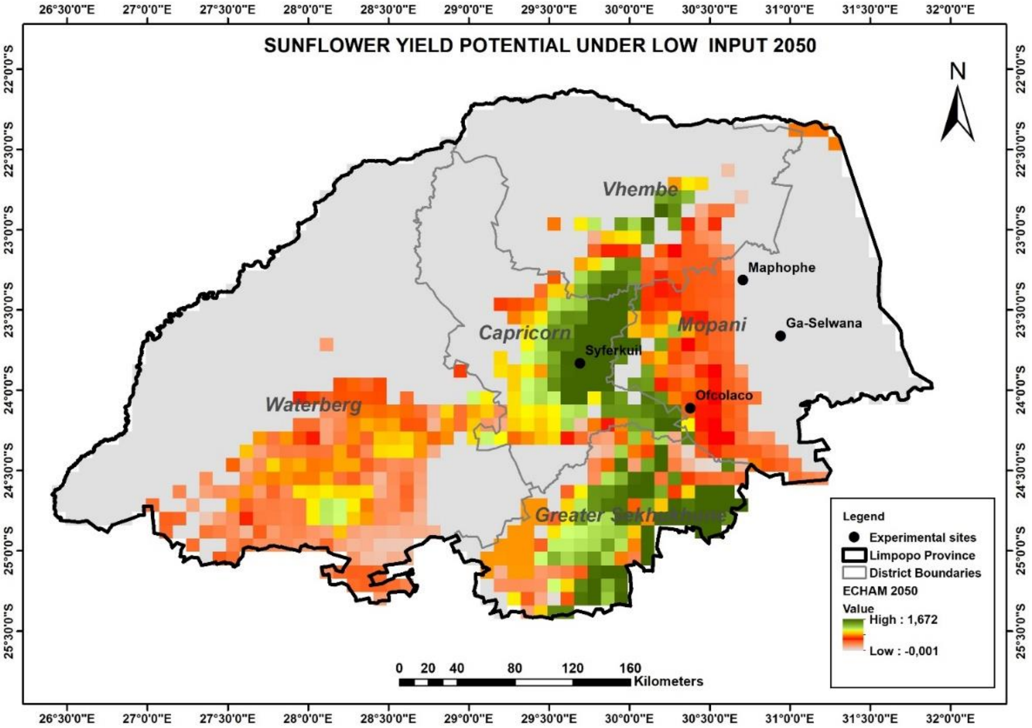


Figure 4.78b: Potential sunflower yield for low input for model ECHAM for Limpopo for the 2050 period (Calculated from GAEZ, 2012).

Under the intermediate management regimes, for the model CCCMA, as shown in Figure 4.79a, yields are up to 3 t/ha in areas like KwaZulu Natal, Eastern Cape, Limpopo and patches in the North West. In Limpopo, as seen in Figure 4.79b areas with the yields up to 3t/ha are found in the humid and Semi-arid areas.

For the CSIRO model, yields are up to 3 t/ha (Figure 4.80a) but in Limpopo, yields are up to 2.5 t/ha as opposed to what was seen in CCCMA for the province.

The ECHAM model, shows yield up to 2.9 t/ha (Figure 4.80a) while some areas in Limpopo shows yields up to 2.9 as well.

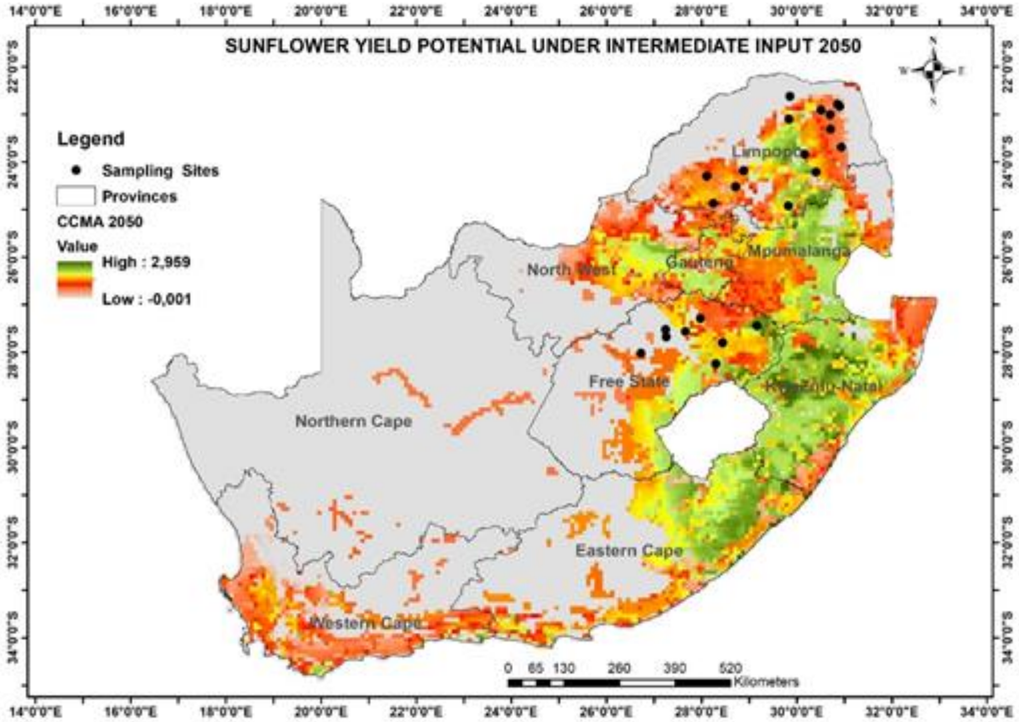


Figure 4.79a: Potential sunflower yield for intermediate input for model CCCMA for the 2050 period (Calculated from GAEZ, 2012).

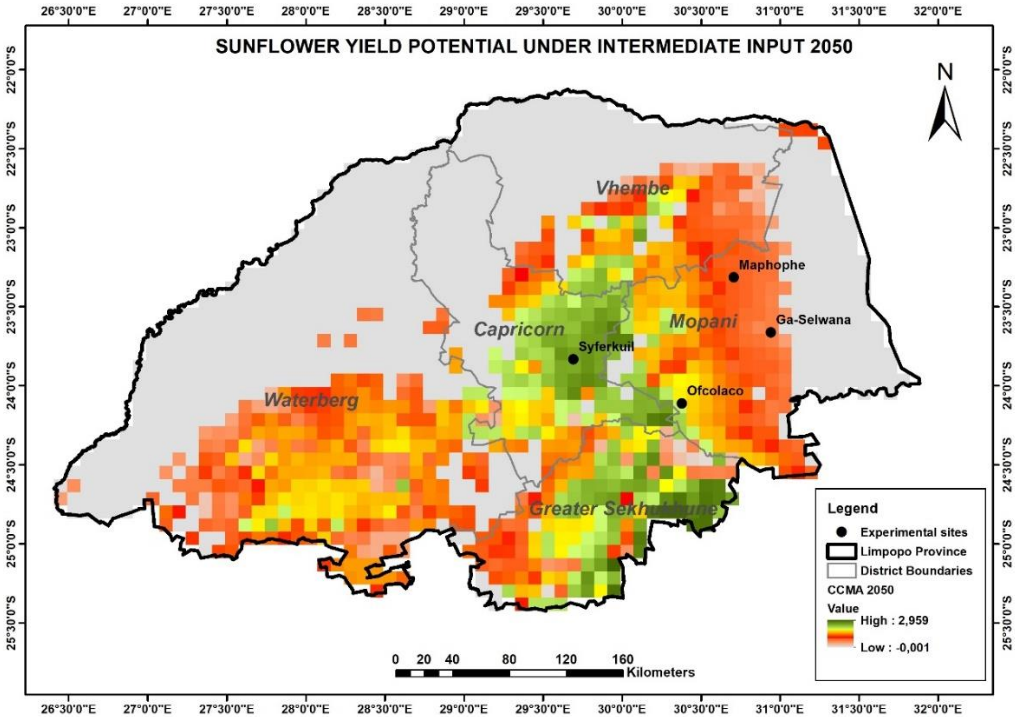


Figure 4.79b: Potential sunflower yield for intermediate input for model CCCMA for Limpopo for the 2050 period (Calculated from GAEZ, 2012).

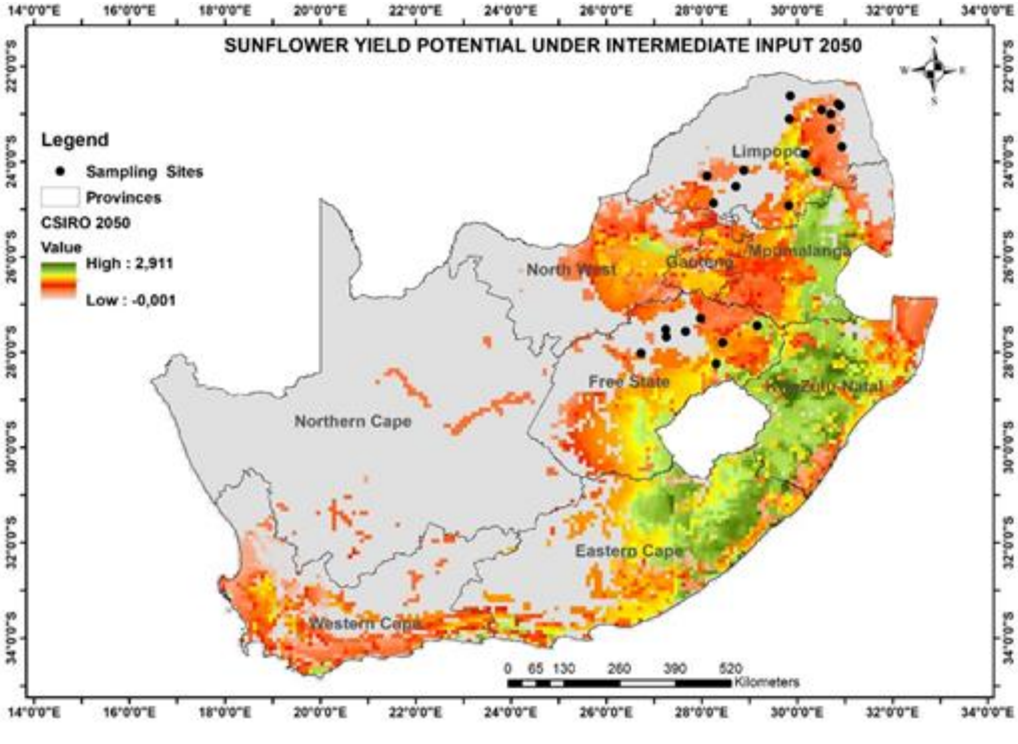


Figure 4.80a: Potential sunflower yield for intermediate input for model CSIRO for the 2050 period (Calculated from GAEZ, 2012).

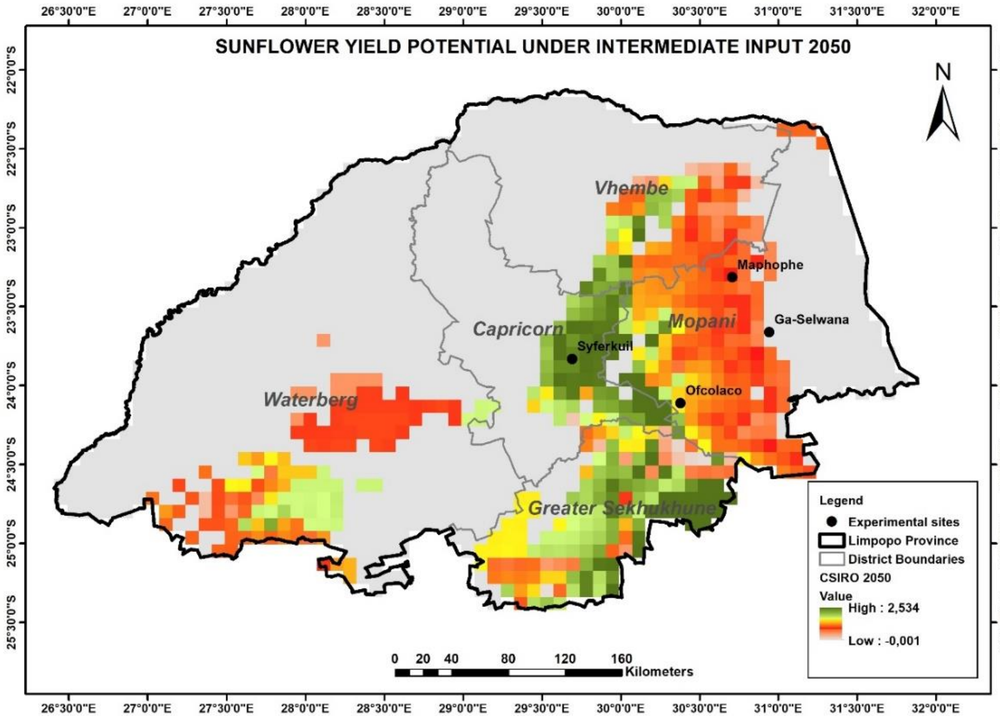


Figure 4.80b: Potential sunflower yield for intermediate input for model CSIRO for Limpopo for the 2050 period (Calculated from GAEZ, 2012).

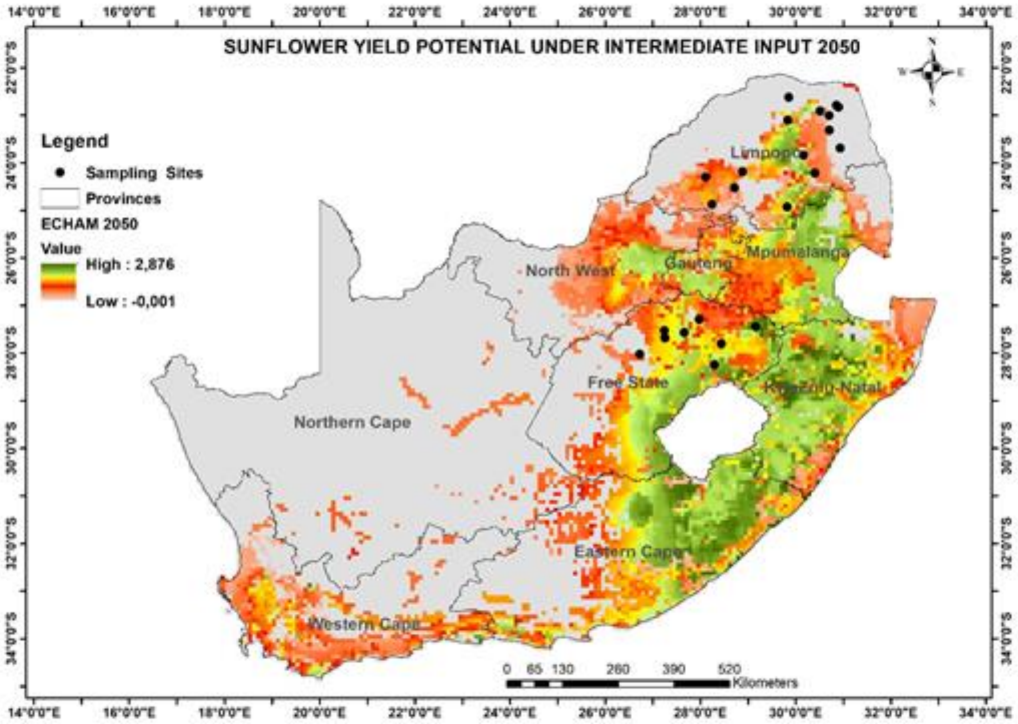


Figure 4.81a: Potential sunflower yield for intermediate input for model ECHAM for Limpopo for the 2050 period (Calculated from GAEZ, 2012).

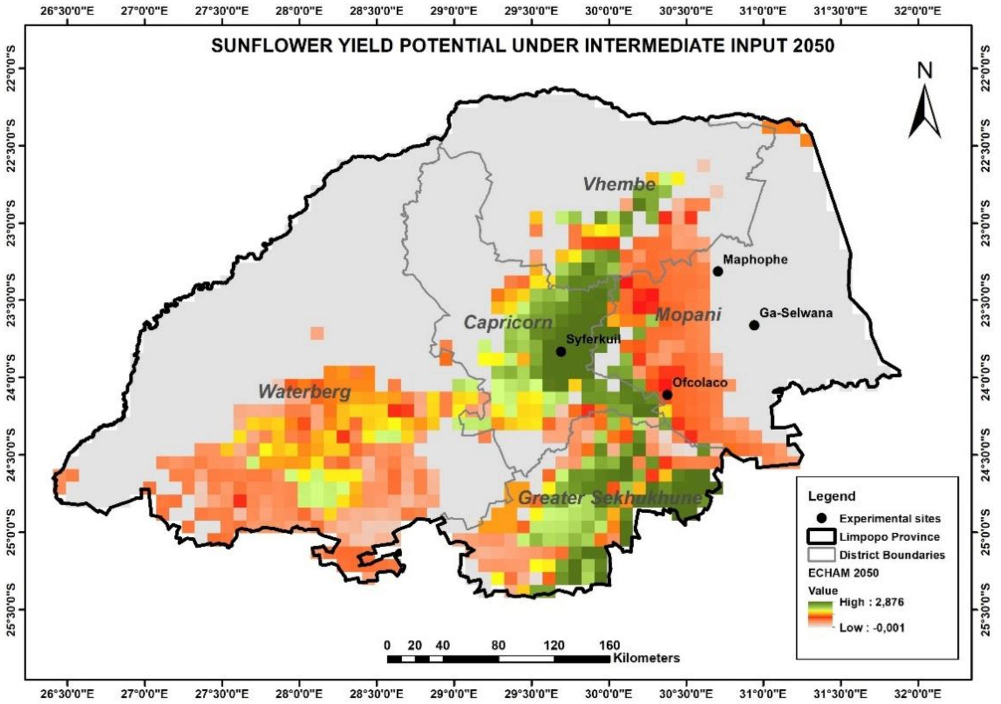


Figure 4.81b: Potential sunflower yield for intermediate input for model ECHAM for Limpopo for the 2050 period (Calculated from GAEZ, 2012).

4.4.2.4 Future potential yield output for sunflower under different climate change models for the time period uo to 2080 under the low and intermediate input scenario

Under the low input scenario, all climate models show yield output of up to 1.55t/ha as shown in Figure 4.82a to 4.84a. For the Limpopo Provinces, yields range up to1.4t/ha as seen in Figures 4.82b to 4.84b.

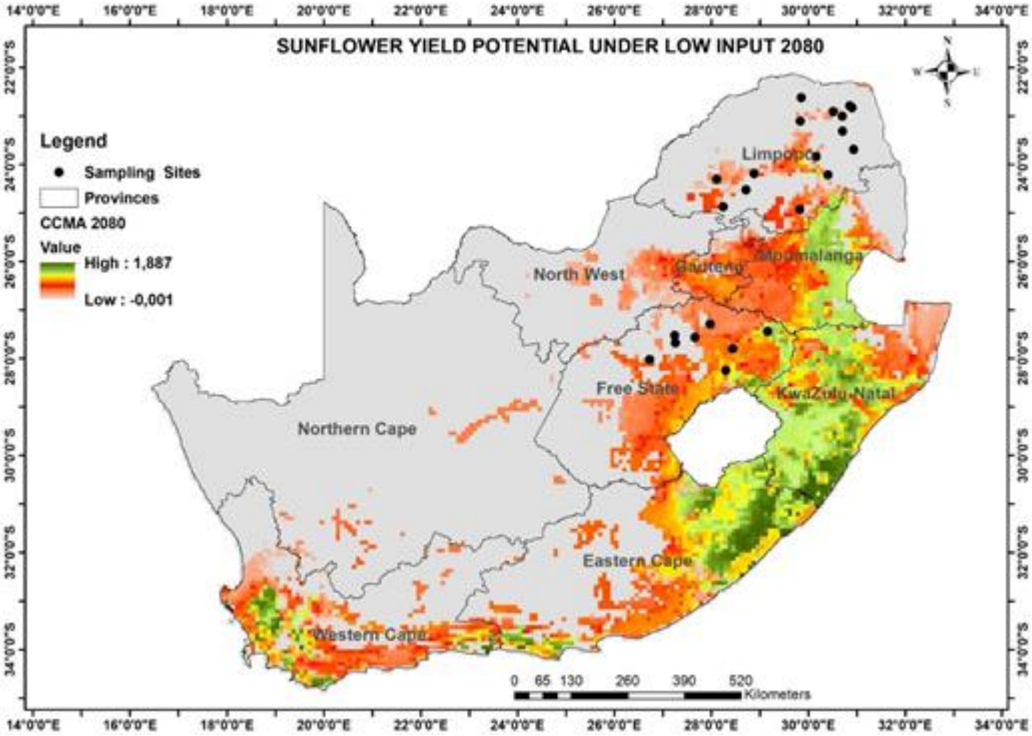


Figure 4.82a: Potential sunflower yield for low input for model CCCMA for the 2080 period (Calculated from GAEZ, 2012).

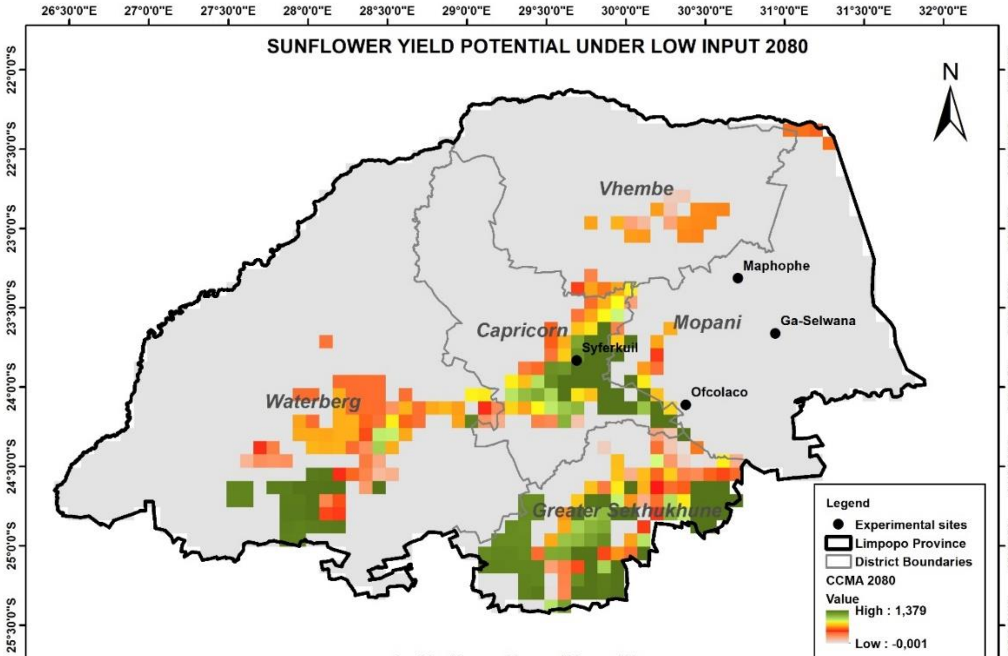


Figure 4.82b: Potential sunflower yield for low input for model CCCMA for Limpopo for the 2080 period (Calculated from GAEZ, 2012).

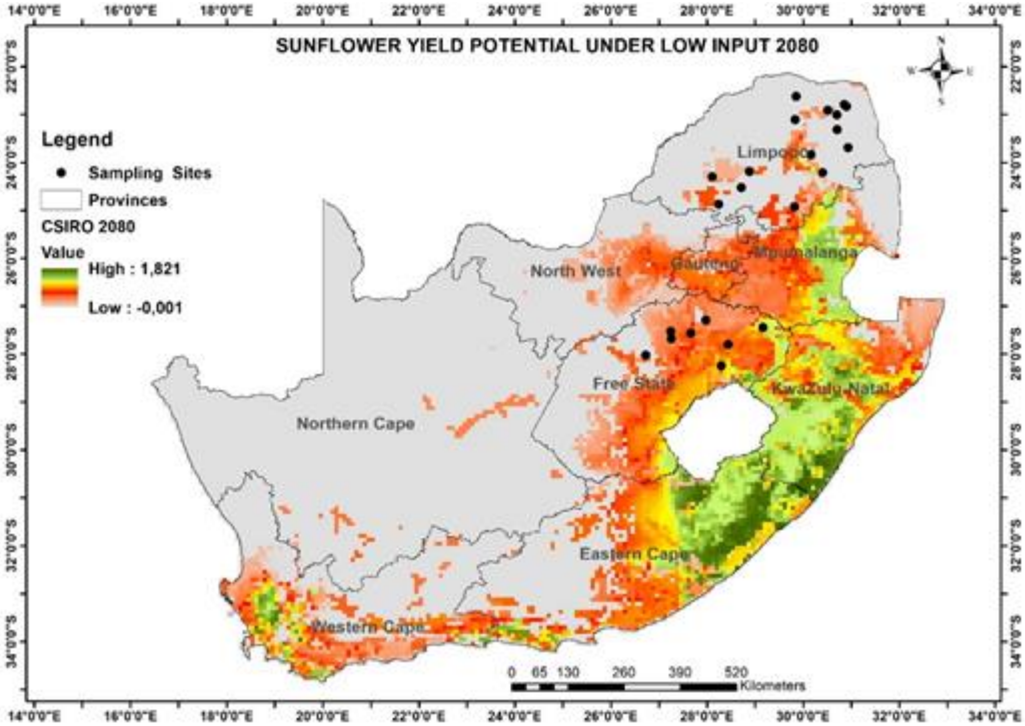


Figure 4.83a: Potential sunflower yield for low input for model CSIRO for the 2080 period (Calculated from GAEZ, 2012).

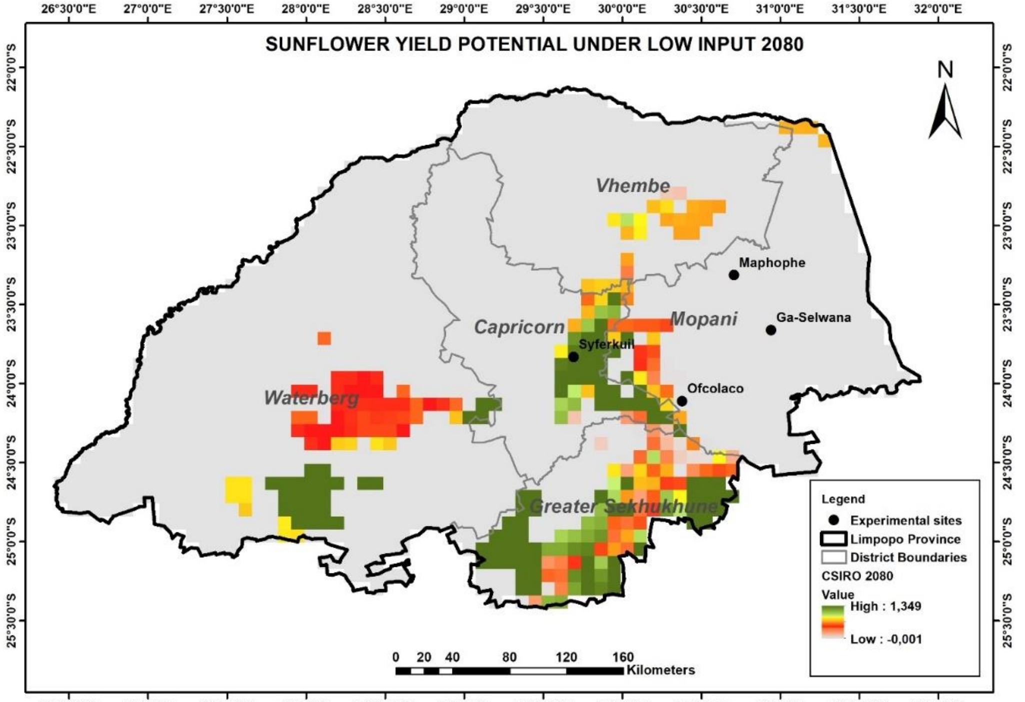


Figure 4.83b: Potential sunflower yield for low input for model CCCMA for Limpopo for the 2080 period (Calculated from GAEZ, 2012).

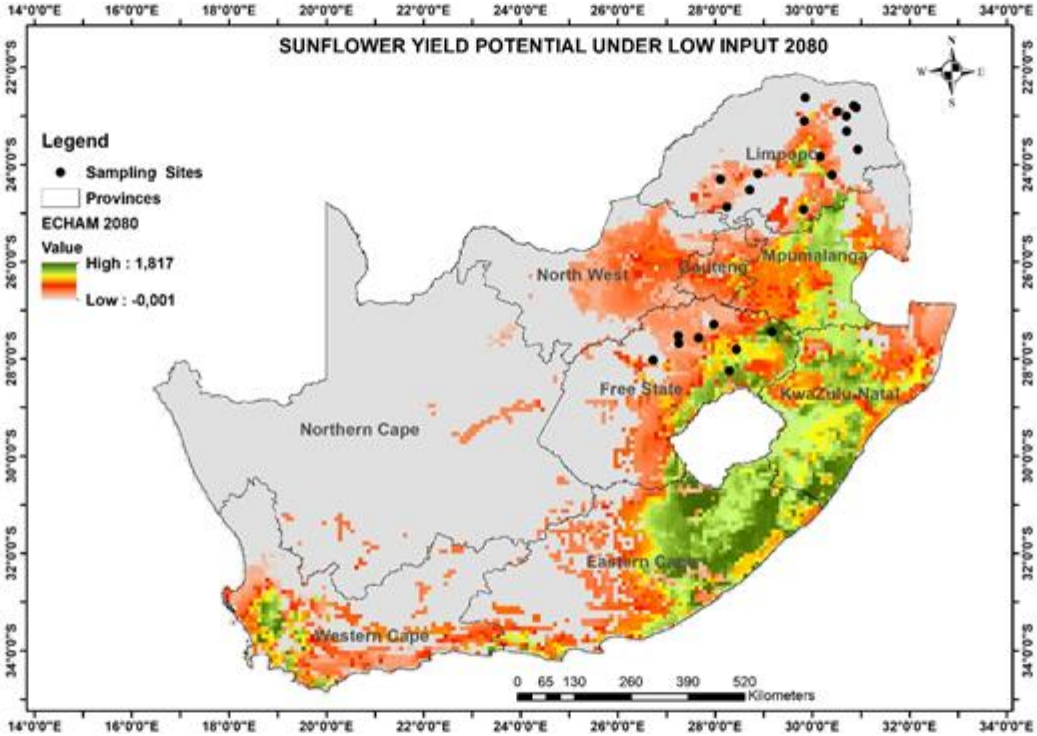


Figure 4.84a: Potential sunflower yield for low input for model ECHAM for the 2080 period (Calculated from GAEZ, 2012).

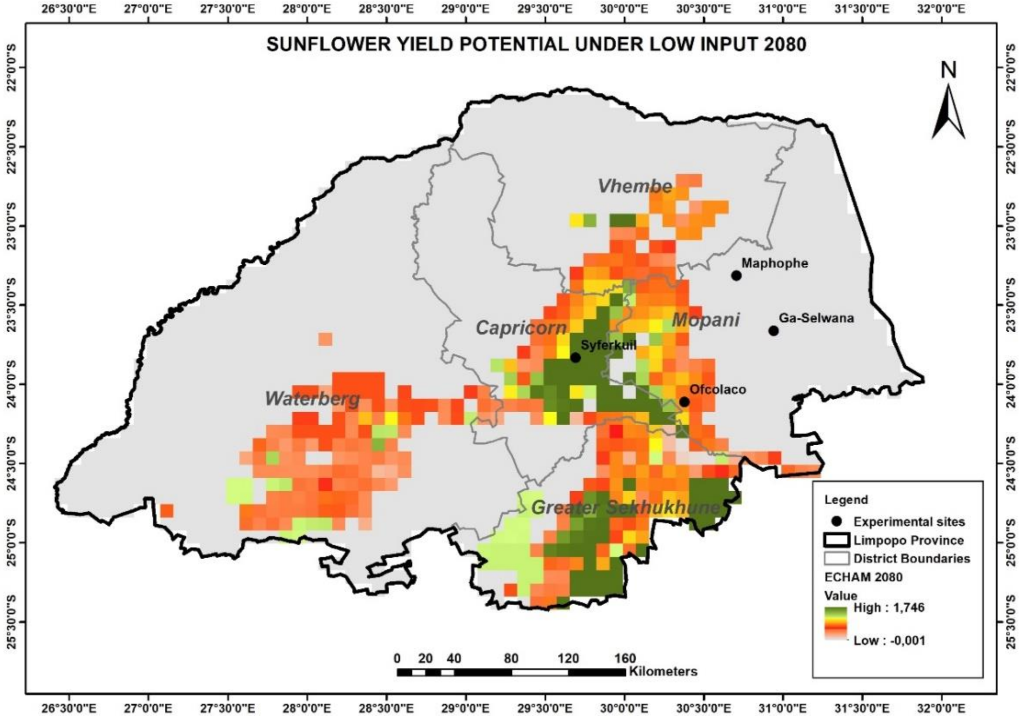


Figure 4.84b: Potential sunflower yield for low input for model ECHAM 4for Limpopo for the 2080 period (Calculated from GAEZ, 2012).

In the intermediate scenario, yield increase up to 3.1t//ha in certain areas of the summer rainfall areas for the 2080-time frame as seen in Figures 4.85a under the CCCCMA model. Such high yields are shown to be in Eastern Cape, KwaZulu Natal, and Mpumalanga. In Limpopo under the CCCMA model, maximum yields were up to 2.4 t/ha as seen in figure 4.85b. Under the CSIRO model, Figure 4.86a yields range up to 3.1 as well and in Limpopo Figure 4.86b, yields in some areas are up to 2.4 as well. In Figure 4.87and 4.87 b, yields are shown to range up to 3t/ha in both the region and in Limpopo.

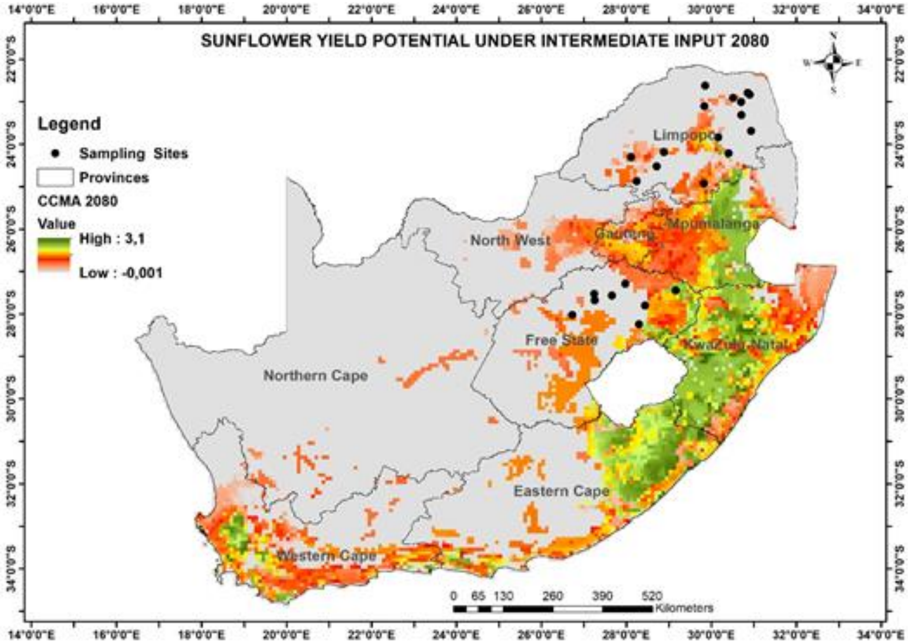


Figure 4.85a: Potential sunflower yield for low input for model CCCMA for the 2080 period (Calculated from GAEZ, 2012).

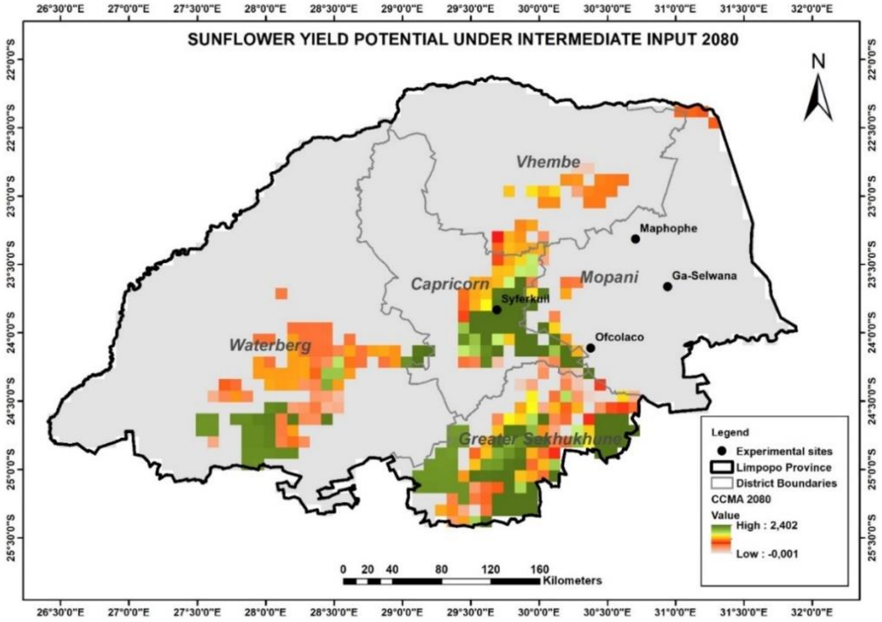


Figure 4.85b: Potential sunflower yield for intermediate input for model CCCMA for Limpopo for the 2080 period (Calculated from GAEZ, 2012).

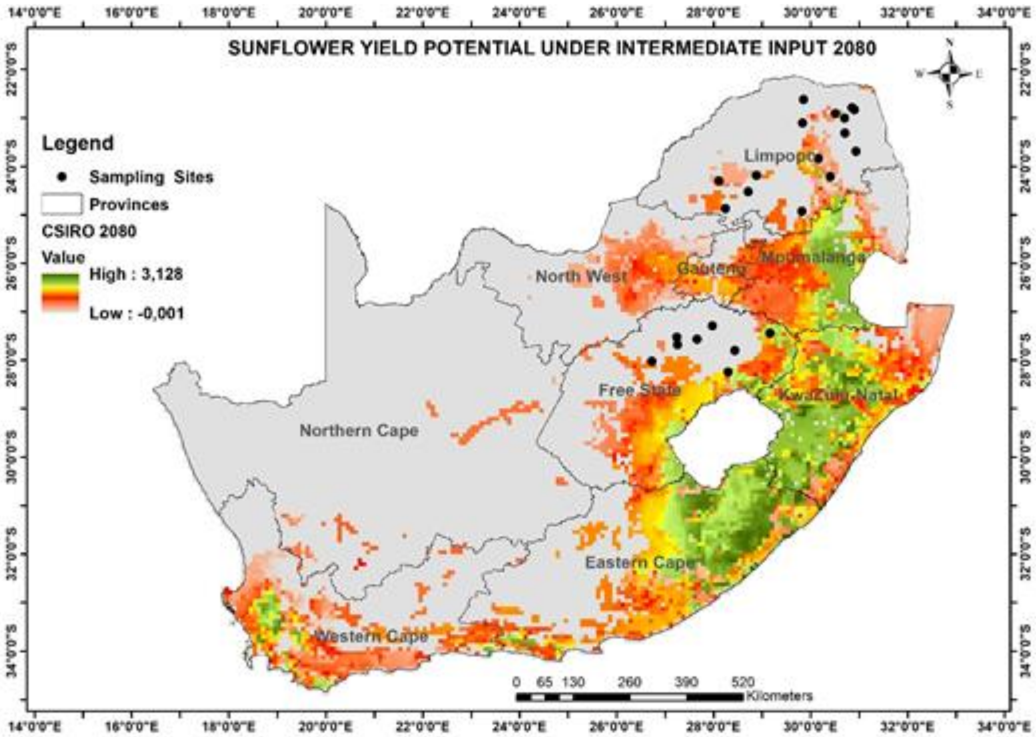


Figure 4.86a: Potential sunflower yield for low input for the model CSIRO for the 2080 period (Calculated from GAEZ, 2012).

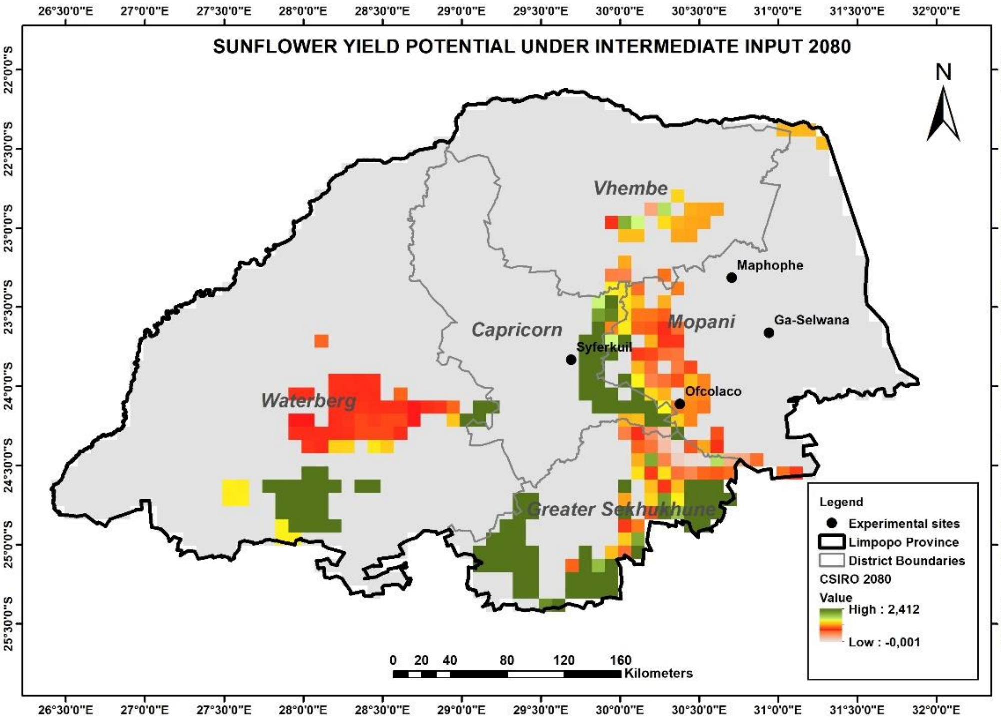


Figure 4.86b: Potential sunflower yield for intermediate input for model CSIRO for Limpopo for the 2080 period (Calculated from GAEZ, 2012).

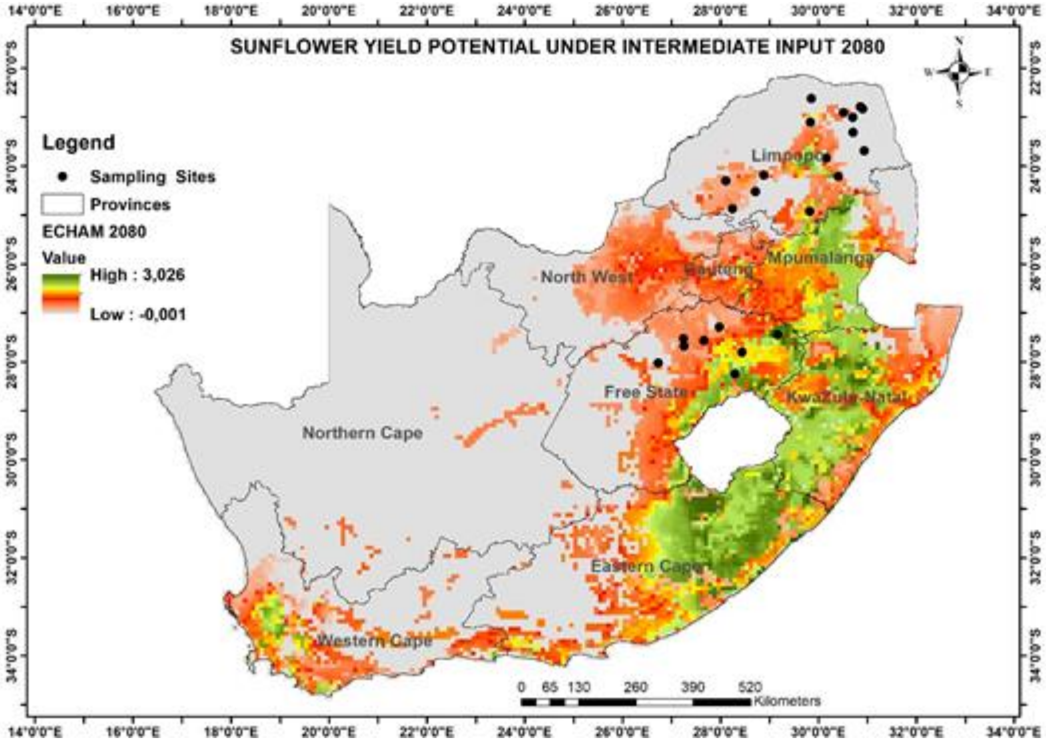


Figure 4.87a: Potential sunflower yield for intermediate input for model ECHAM for the 2080 period (Calculated from GAEZ, 2012).

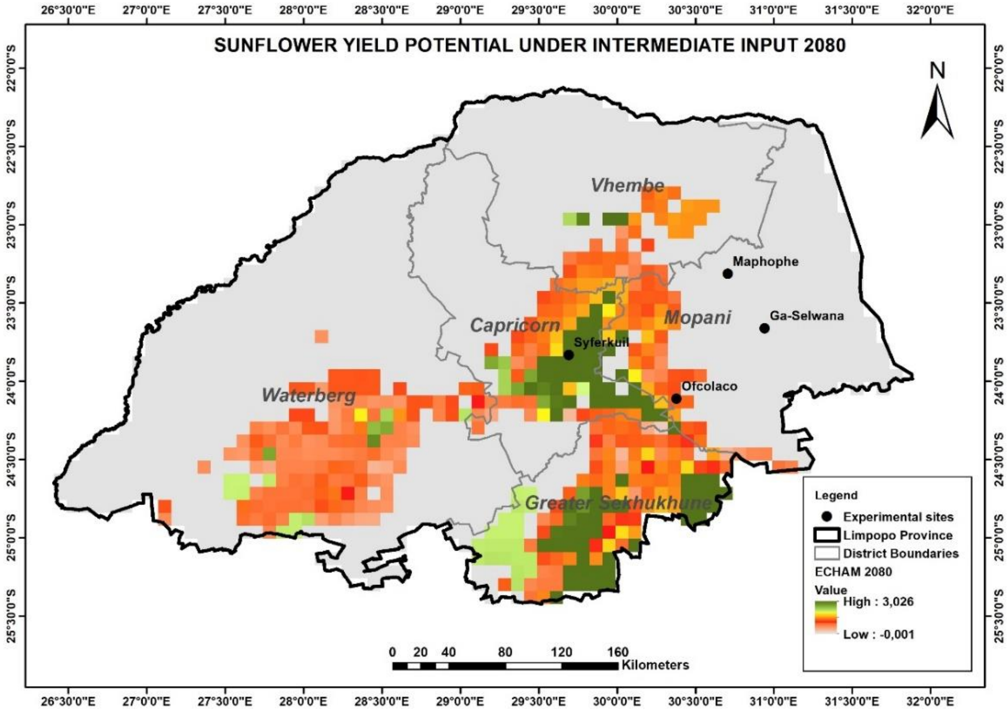


Figure 4.87b: Potential sunflower yield for intermediate input for model ECHAM for Limpopo for the 2080 period (Calculated from GAEZ, 2012).

4.4.3 Potential Crop yield variability over space and time frames for groundnut

In the low input baseline scenario, as shown in Figures 4.88a, yield output for groundnut production is up to 1.1 t/ha. Areas of the summer rainfall areas with high yields include Mpumalanga. North West and Free State all show patches with yield output ranging up to 1.1t/ha. The lower yield of about .3t/ha as seen in the Northern Cape, Eastern Cape and North West. In Limpopo as seen in Figure 4.88b, areas in the semi areas had a yield of t/ha as well as in the semi-arid and humid areas.

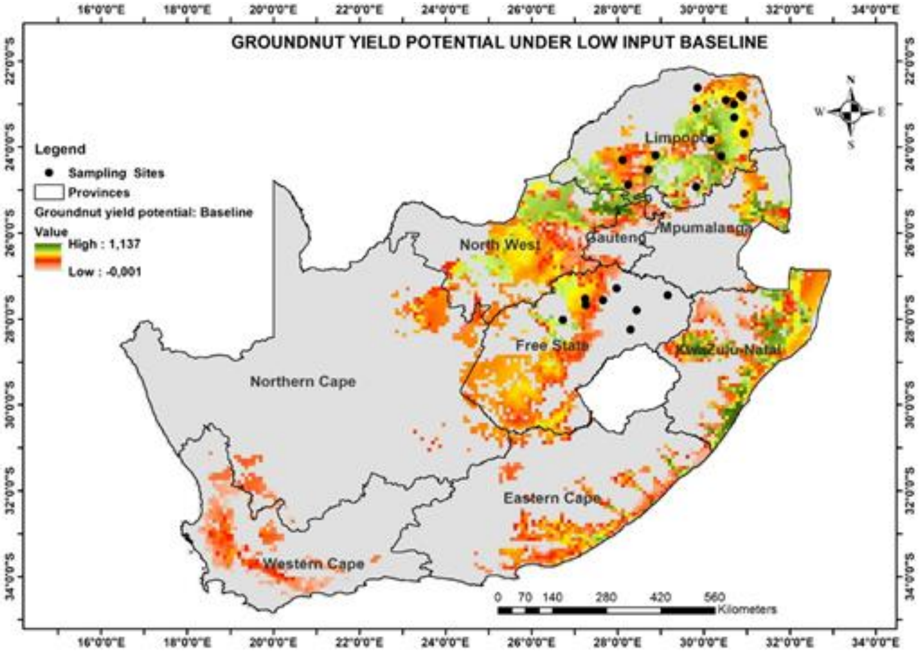


Figure 4.88a: Potential groundnut yield for low input for the baseline period (Calculated from GAEZ, 2012).

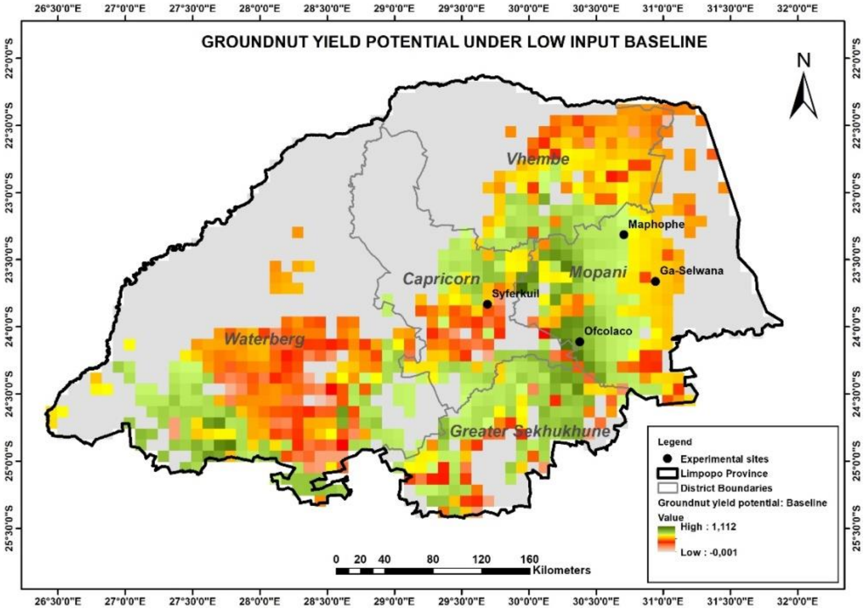


Figure 4.88b: Potential groundnut yield for low input for the baseline period for Limpopo (Calculated from GAEZ, 2012).

In the intermediate baseline scenario, as seen in Figure 4.89a, groundnut production is up to 2.5 t/ha. Areas showing a high yield of 1.8 t/ha include patches in Limpopo, Mpumalanga, KZN, North West, and Free state. Some areas in the Free State show yield of about 0.3 t/ha with other areas such as Northern and Eastern Cape showing yields of less than 0.3 t/ha.

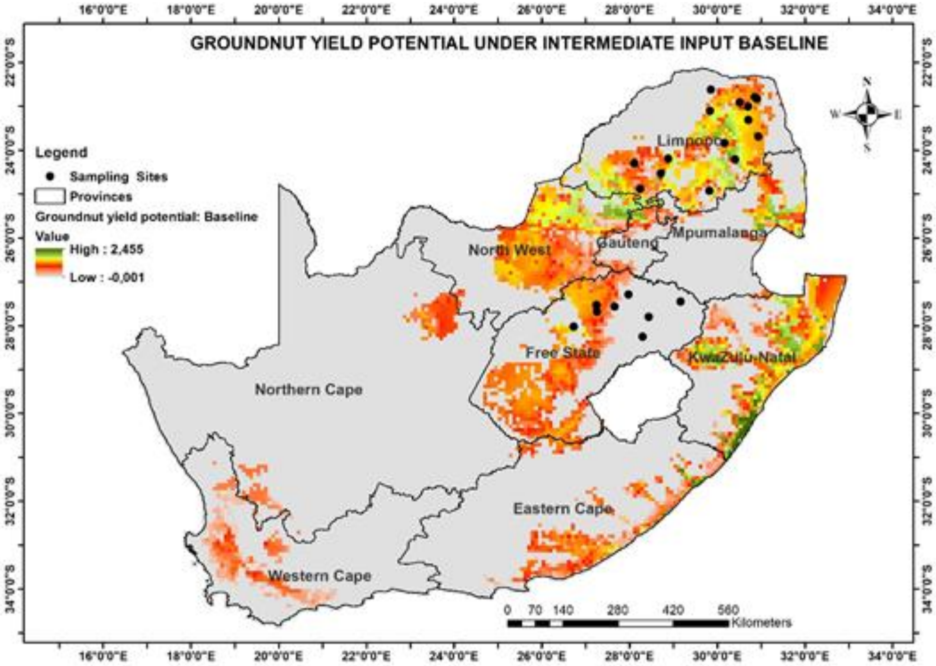


Figure 4.89a: Potential groundnut yield for intermediate input for the baseline period (Calculated from GAEZ, 2012)

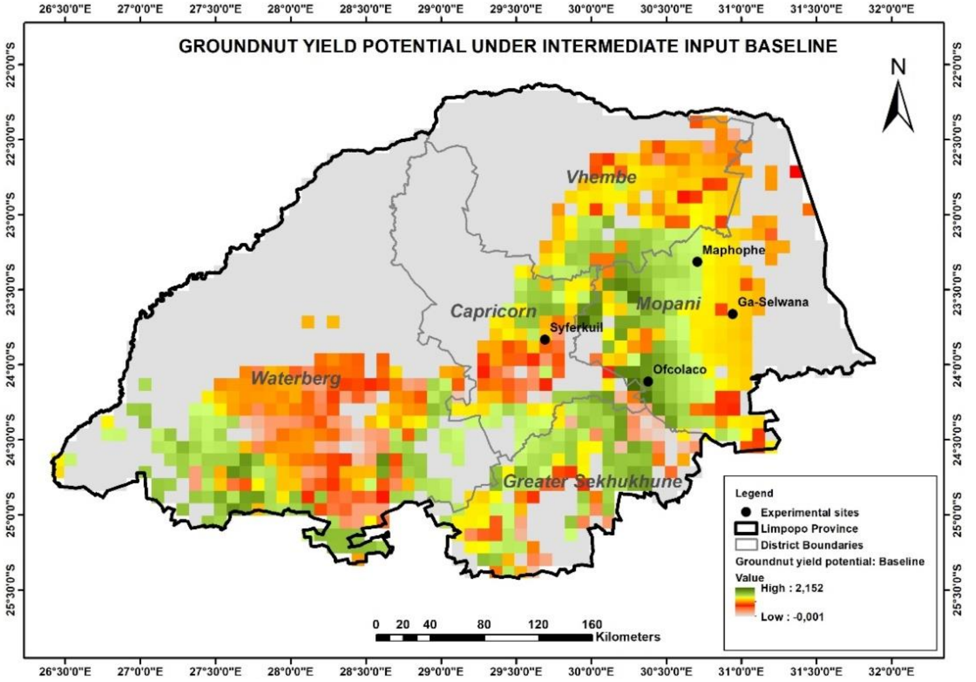


Figure 4.89b: Potential groundnut yield for low input for the baseline period for Limpopo (Calculated from GAEZ, 2012)

4.4.3.1 Future potential yield output for groundnut under different climate change models for the time period 2020 under the low input scenario

Under the low input scenario for CCCMA, yield ranges up to 1.3 t/ha. Higher yields are found in the Free State, North West, Limpopo, Mpumalanga, and KZN as shown in Figure 4.90a. Most of the areas showing production show yield output of 0.5 t/ha. In Figure 4.90, areas showing high yields can be seen in areas of the semi-arid and humid areas in the province.

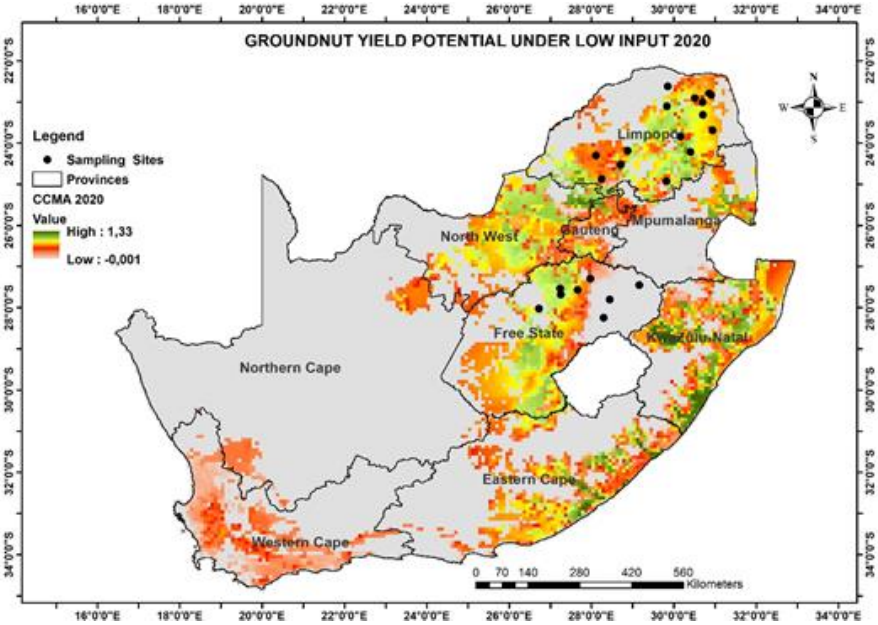


Figure 4.90a: Potential groundnut yield for low input for the CCCMA model for the 2020 period (Calculated from GAEZ, 2012)

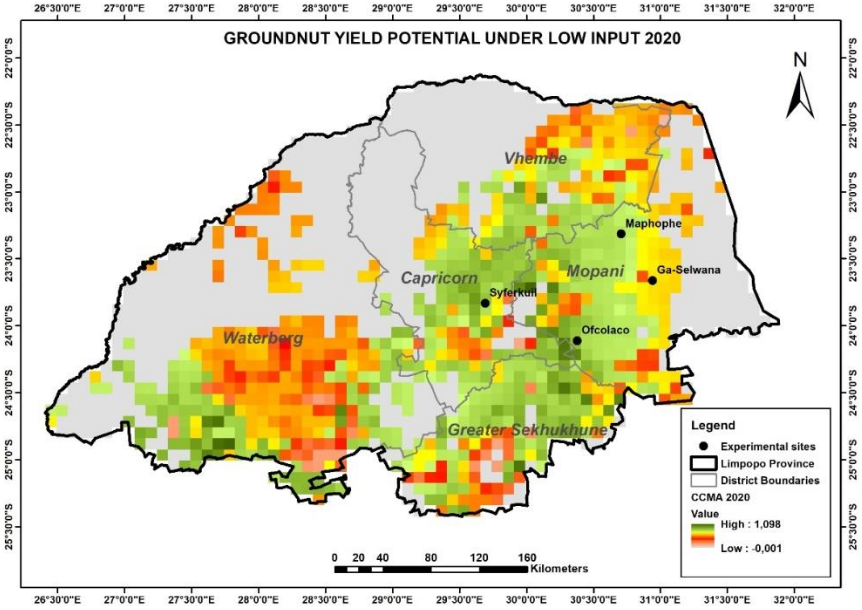


Figure 4.90b: Potential groundnut yield for low input for the CCCMA model for the 2020 period for Limpopo (Calculated from GAEZ, 2012)

Similar yield output is shown for CSIRO and ECHAM3, models with the optimum yield at 1.2 t/ha as seen in Figures 4.90a and 4.91a. As with the CCCMA model, the areas showing a yield of up to 1.2 t/ha are found in Limpopo, Mpumalanga, KZN. Figures 4.90b and 4.91b show that for the models CSIRO and ECHAM yield in Limpopo range up to 2 t/ha in humid areas.

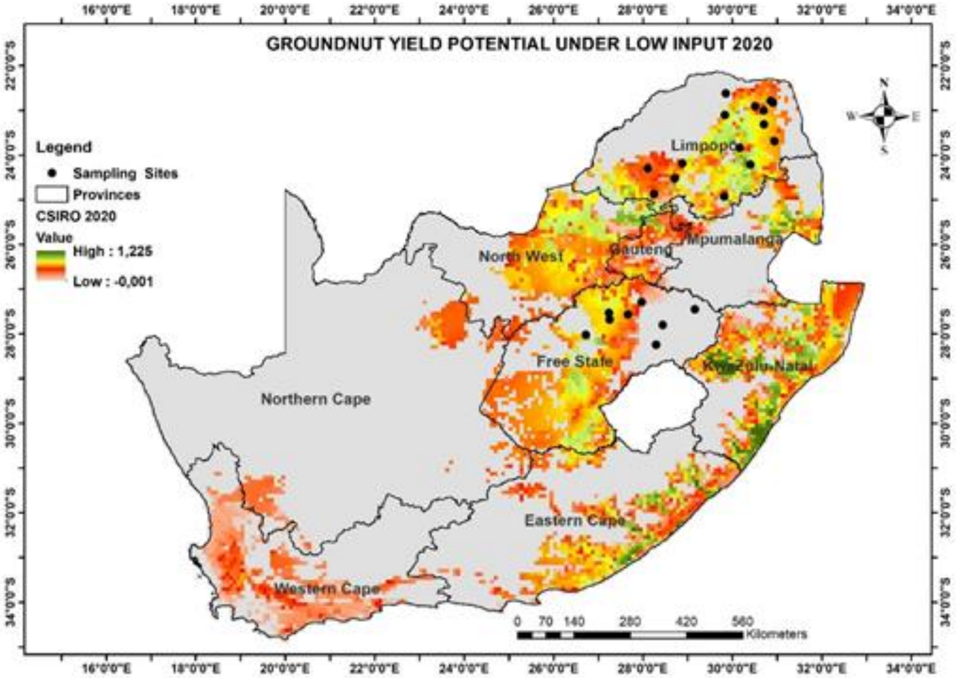


Figure 4.91a: Potential groundnut yield for low input for the CSIRO model for the 2020 period (Calculated from GAEZ, 2012).

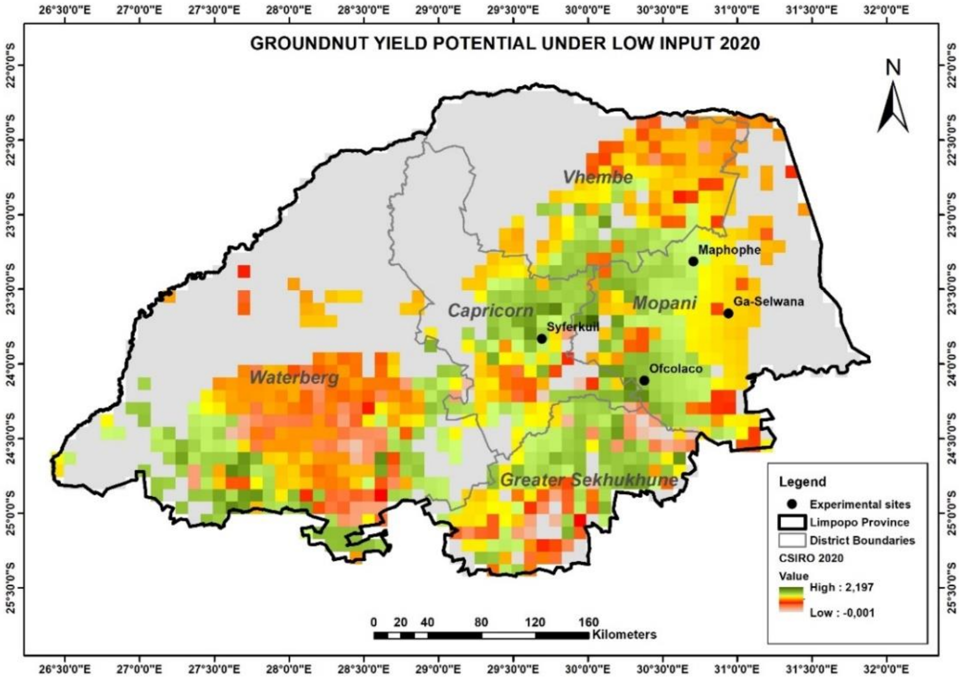


Figure 4.91b: Potential groundnut yield for low input for the CSIRO model for the 2020 period for Limpopo (Calculated from GAEZ, 2012).

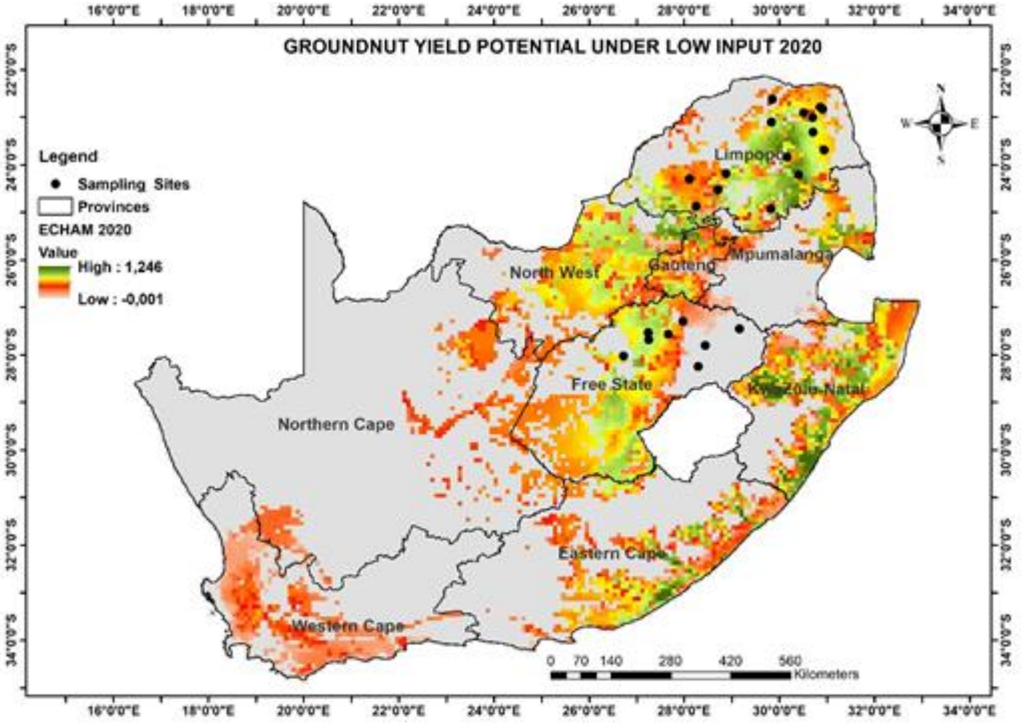


Figure 4.92a: Potential groundnut yield for low input for the ECHAM model for the 2020 period (Calculated from GAEZ, 2012).

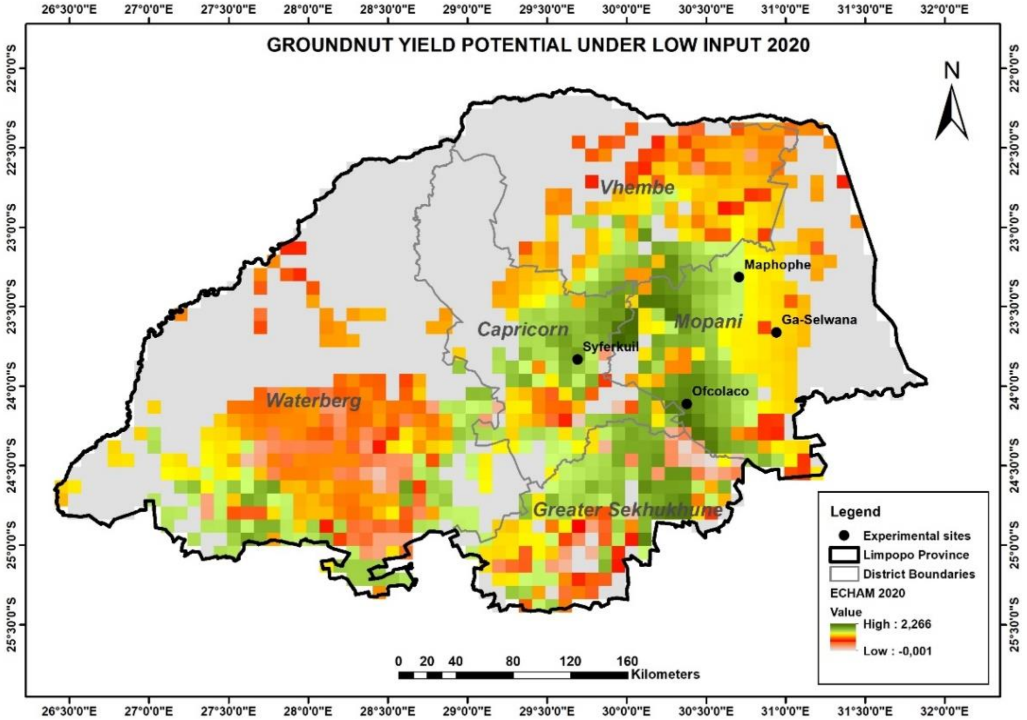


Figure 4.92b: Potential groundnut yield for low input for the ECHAM model for the 2020 period for Limpopo (Calculated from GAEZ, 2012).

4.4.3.2 Future potential yield output for groundnut under different climate change models for the time period 2020 under the intermediate input scenario

As with the low input scenario, Figure 4.93a to 4.95a shows that under the CCCMA, CSIRO and ECHAM models, maximum yield is estimated at 2.6 t/ha. All models show the highest yields are found in KwaZulu Natal. A similar pattern is sown in Limpopo as shown in Figure 4.93b to 4.95b where yields are up to 2 t/ha in areas of the semi-arid and humid areas.

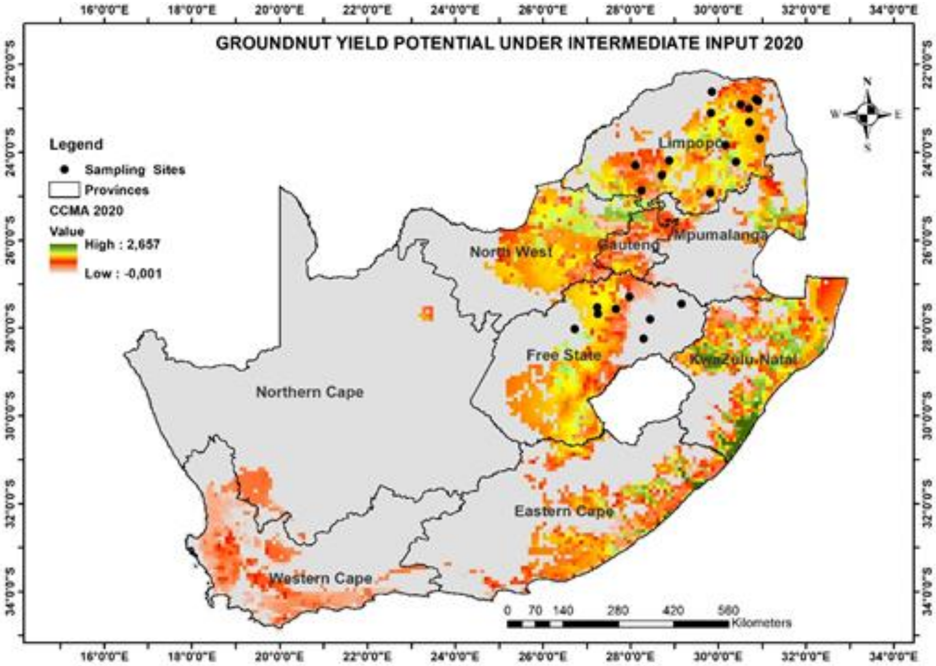


Figure 4.93a: Potential groundnut yield for intermediate input for the CCCMA model for the 2020 period (Calculated from GAEZ, 2012).

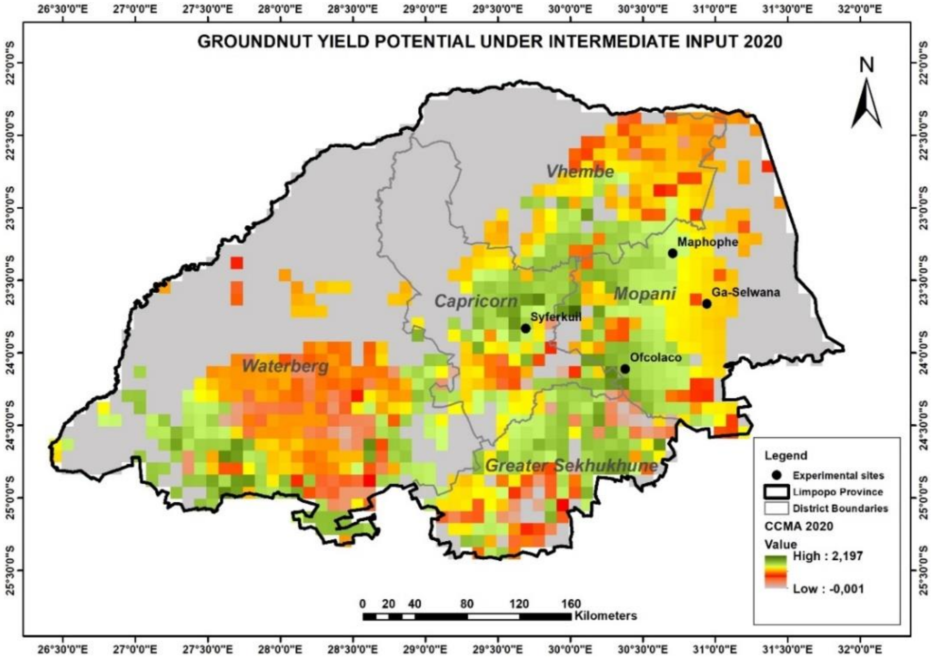


Figure 4.93b: Potential groundnut yield for intermediate input for the CCCMA model for the 2020 period for Limpopo (Calculated from GAEZ, 2012).

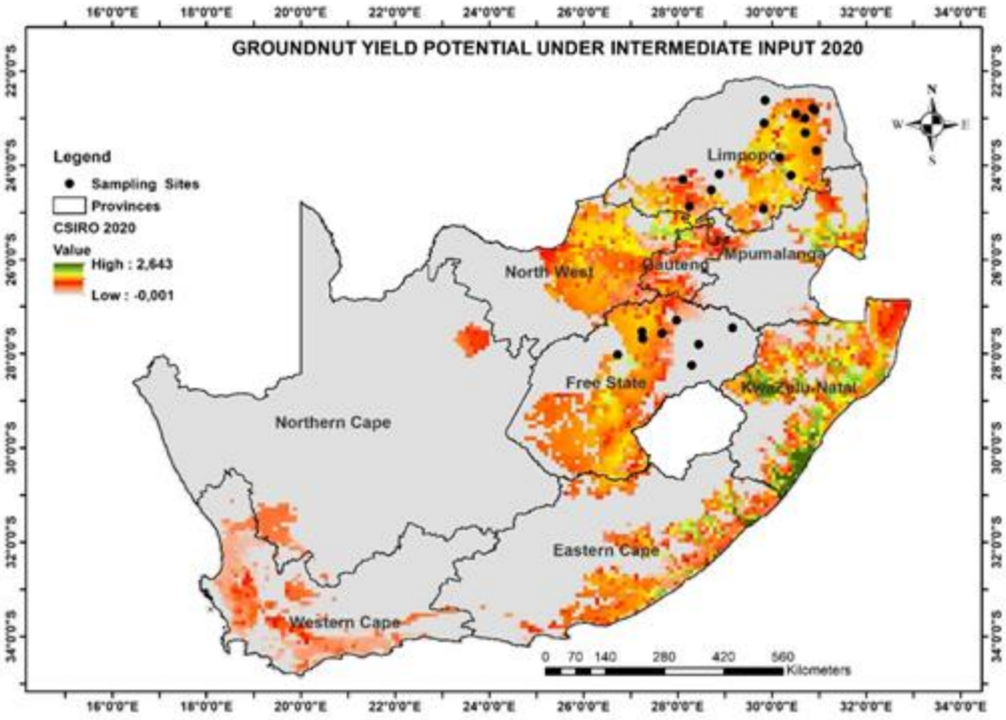


Figure 4.94a: Potential groundnut yield for intermediate input for the CSIRO model for the 2020 period (Calculated from GAEZ, 2012).

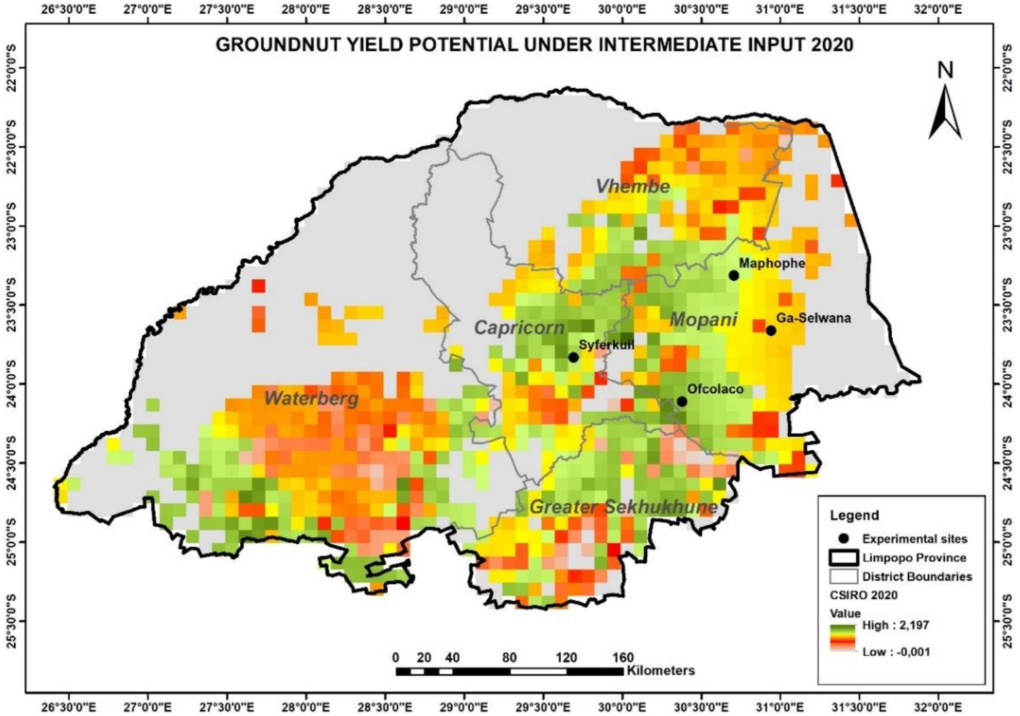


Figure 4.94b: Potential groundnut yield for intermediate input for the CSIRO model for the 2020 period for Limpopo (Calculated from GAEZ, 2012).

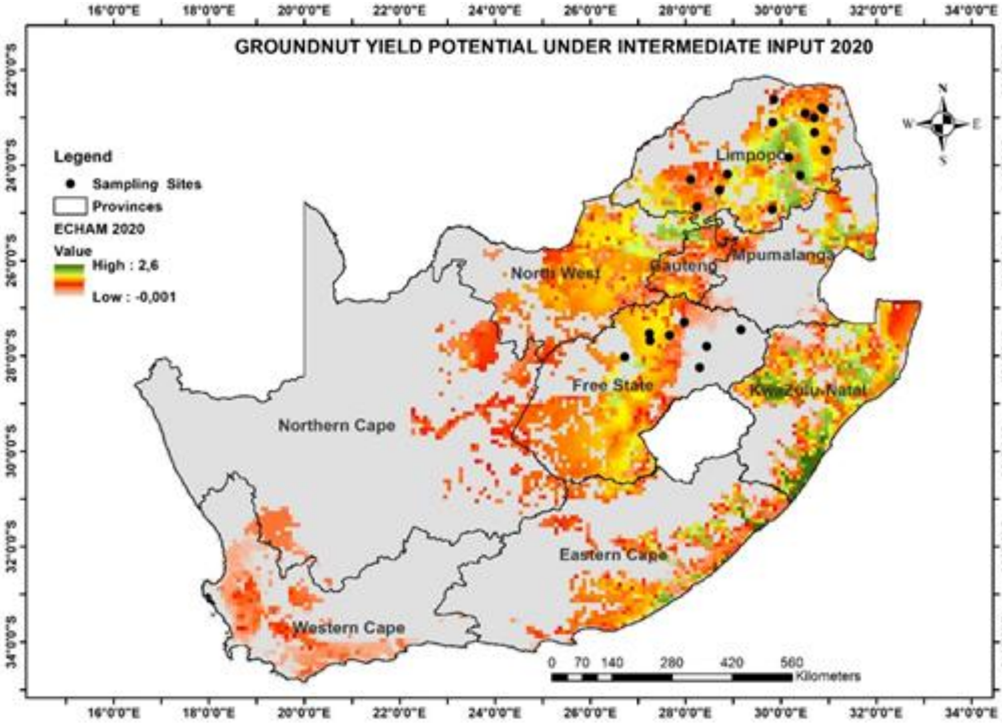


Figure 4.95a: Potential groundnut yield for intermediate input for the ECHAM model for the 2020 period (Calculated from GAEZ, 2012).

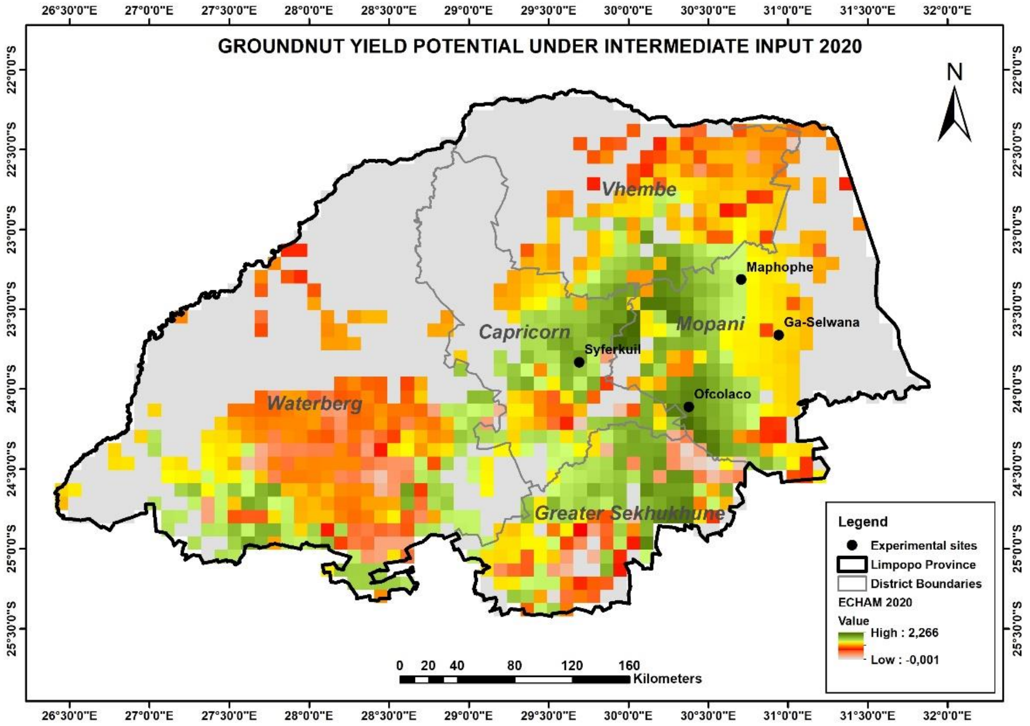


Figure 4.95b: Potential groundnut yield for intermediate input for the ECHAM model for the 2020 period for Limpopo (Calculated from GAEZ, 2012).

4.4.3.3 Future potential yield output for groundnut under different climate change models for the time period 2050 under the low and intermediate input scenario

Under the low input scenario as seen in Figures 4.96a to 4.98a, all climate models show yield output of up to 1.4t/ha. On the other hand, yields in Limpopo across the area varies across the models with 1.2 t/ha for CCCMA, 1.2 t/ha for CSIRO and 1.3 t/ha for the ECHAM model.

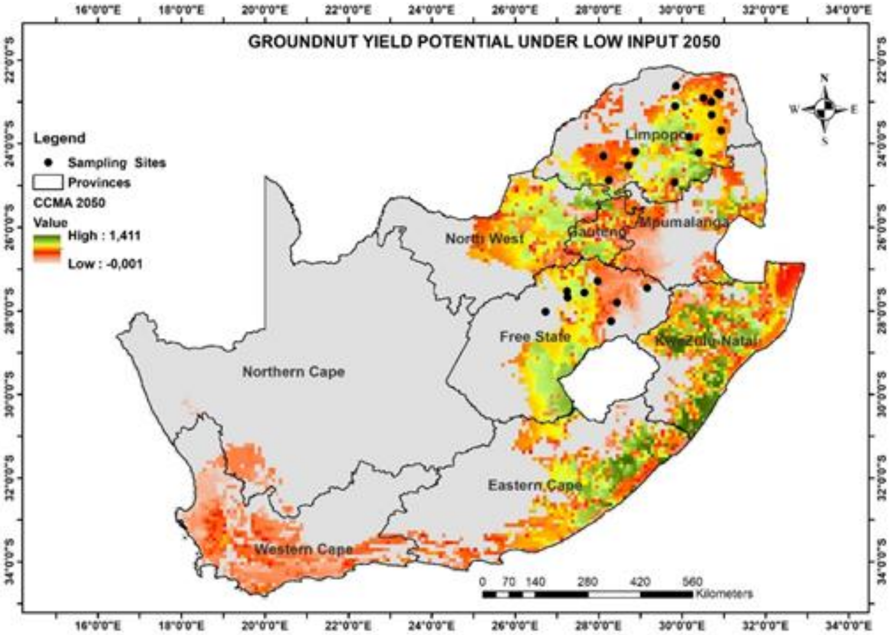


Figure 4.96a: Potential groundnut yield for intermediate input for the CCCMA model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

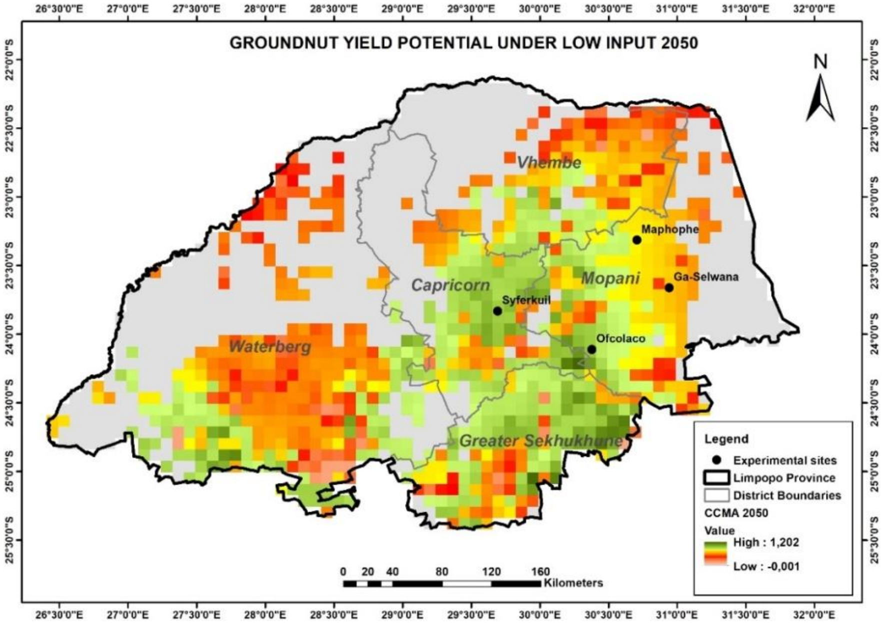


Figure 4.96b: Potential groundnut yield for intermediate input for the CCCMA model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

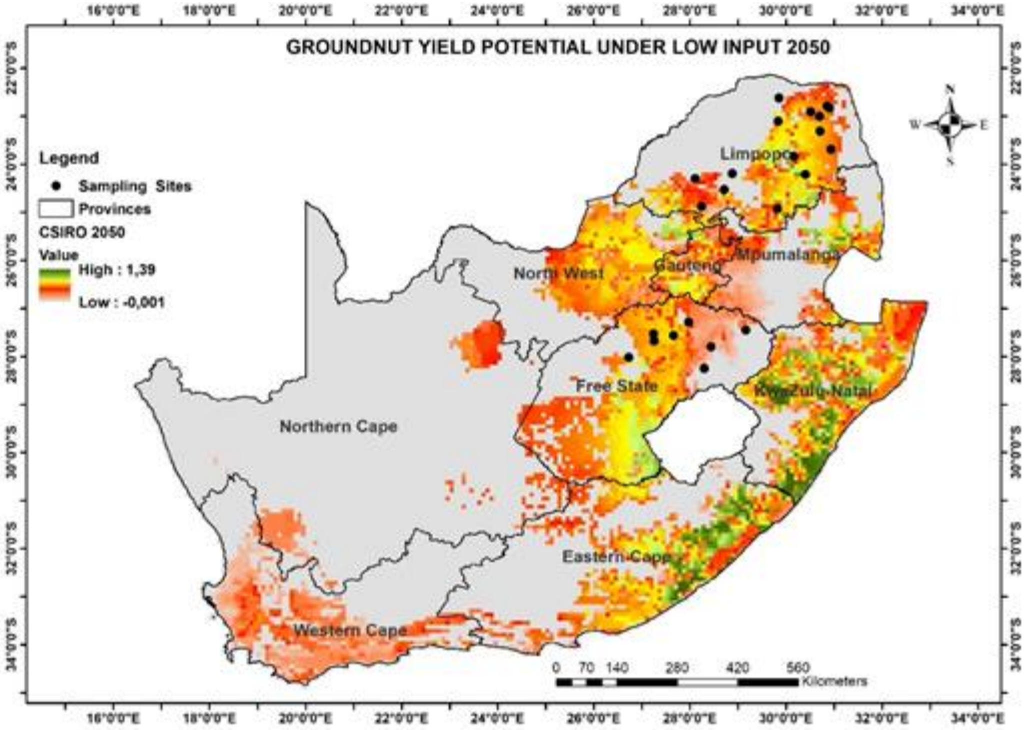


Figure 4.97a: Potential groundnut yield for intermediate input for the CSIRO model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

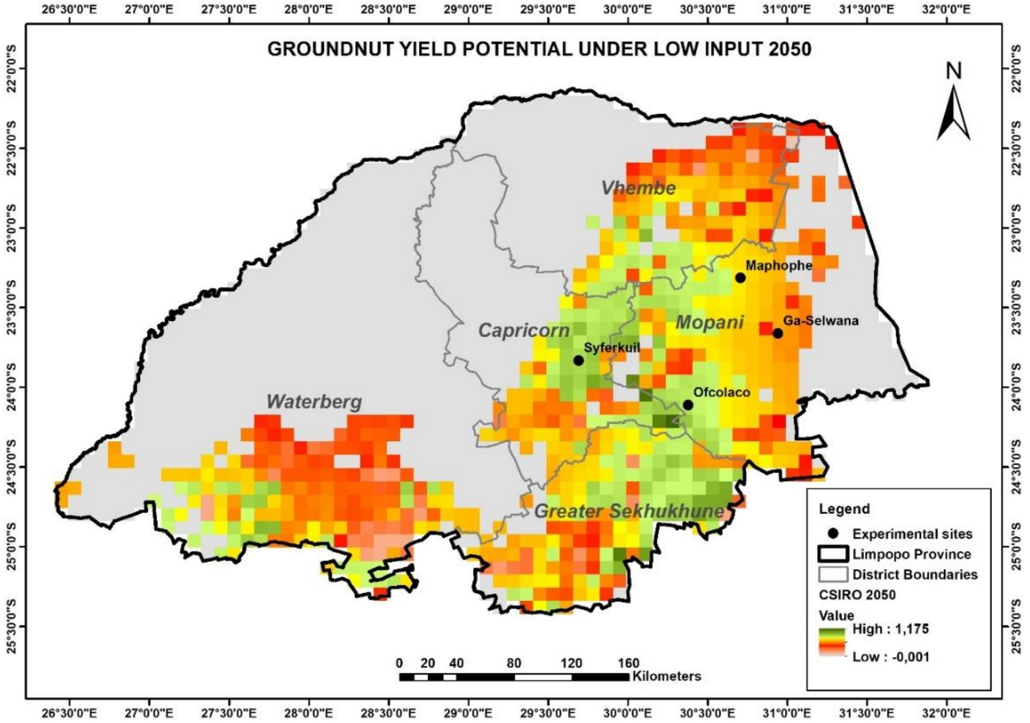


Figure 4.97b: Potential groundnut yield for intermediate input for the CSIRO model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

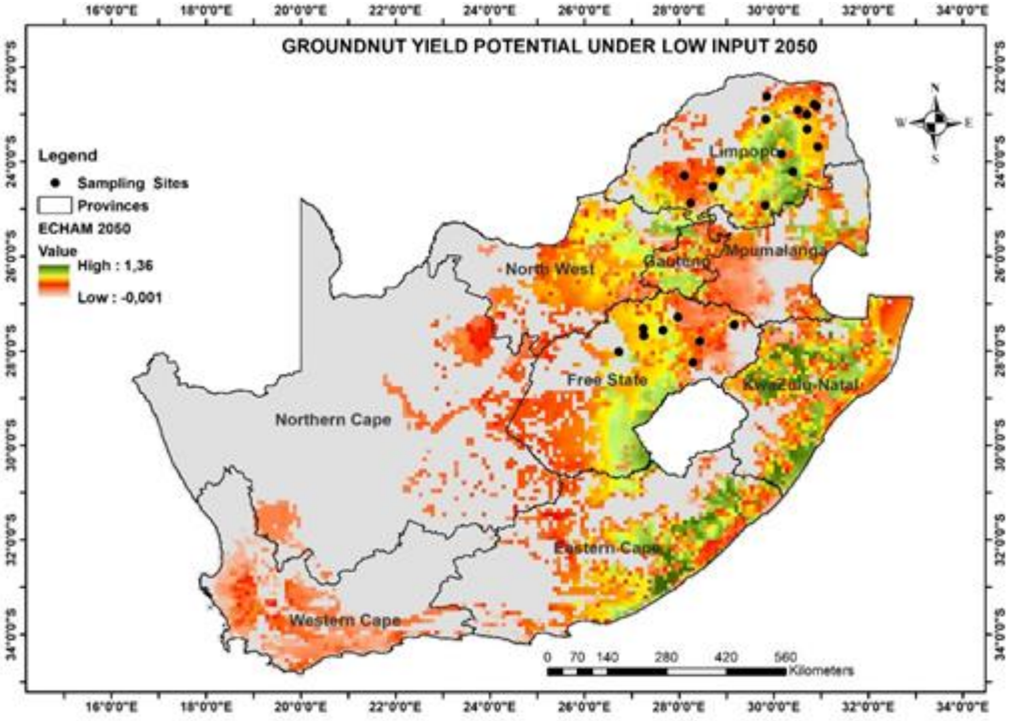


Figure 4.98a: Potential groundnut yield for intermediate input for the ECHAM model for the 2050 period (Calculated from GAEZ, 2012).

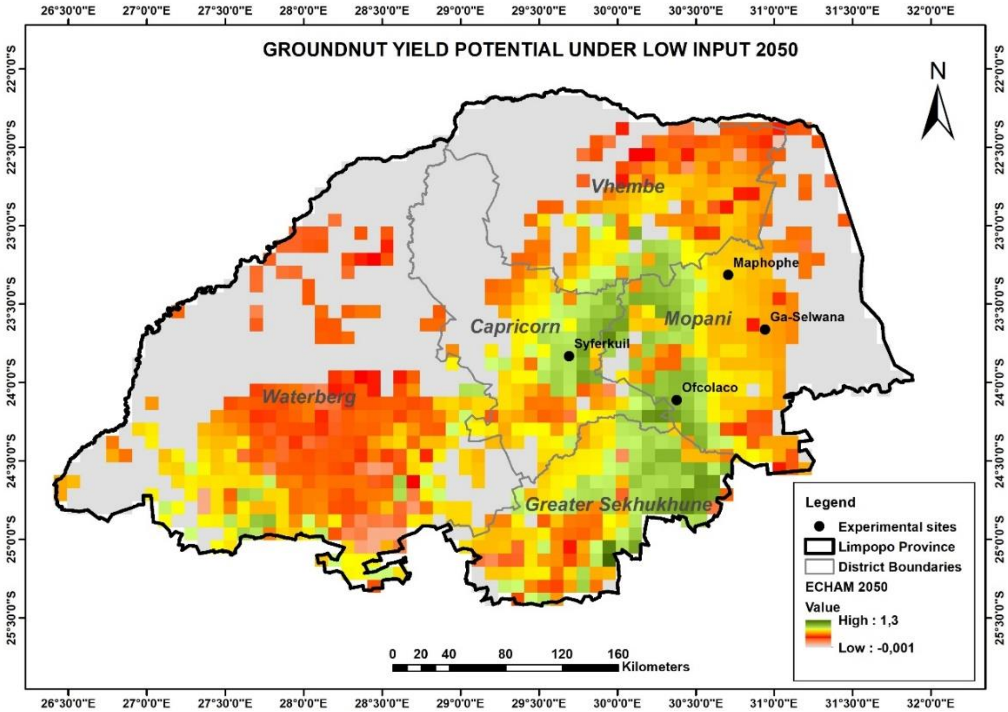


Figure 4.98b: Potential groundnut yield for low input for the ECHAM model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

In the intermediate scenario Figures, 4.99a and 4.100a show that yield gets up to 2.8 t/ha for CCCMA and CSIRO respectively. Figure 4.100a show that yield ranges up to 2.7t/ha. However, the models show that areas of KwaZulu Natal have the highest yield up to 2.7-2.8 t/ha. In Limpopo, as shown by Figure 4.99b 4.100b, and 4 101b yields for the CCCMA, CSIRO and ECHAM models range up to 2.4,2.2 and 2.1 t/ha respectively. High yields are found in the semi-arid and arid areas of the Province.

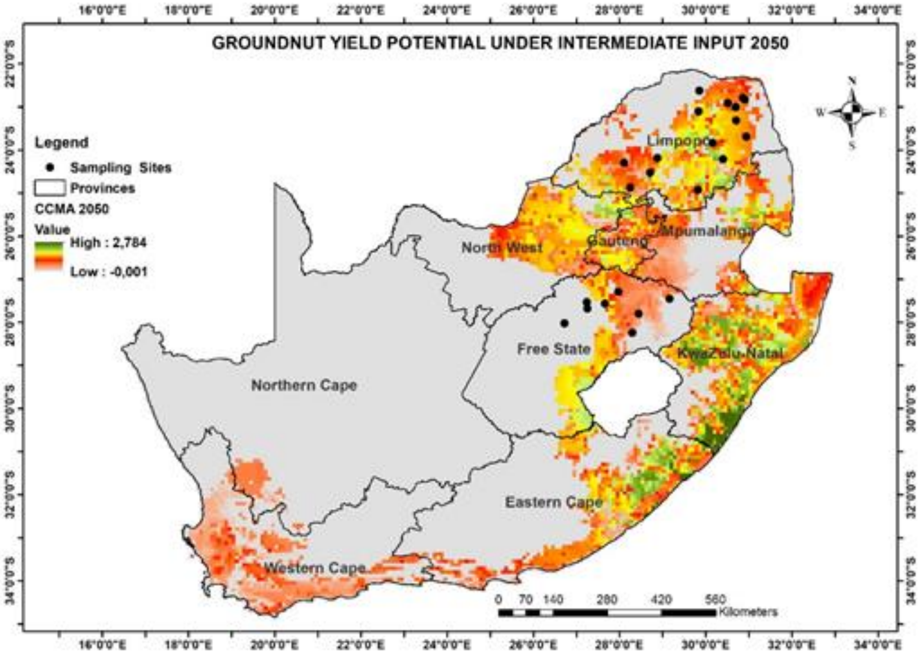


Figure 4.99a: Potential groundnut yield for intermediate input for the CCCMA model for the 2050 period (Calculated from GAEZ, 2012).

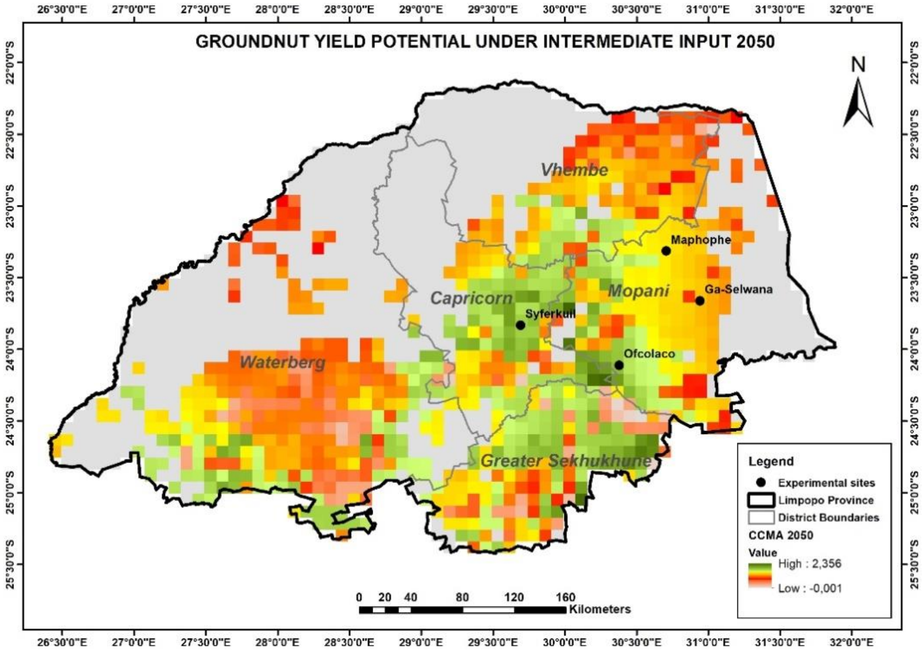


Figure 4.99b: Potential groundnut yield for intermediate input for the CCCMA model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

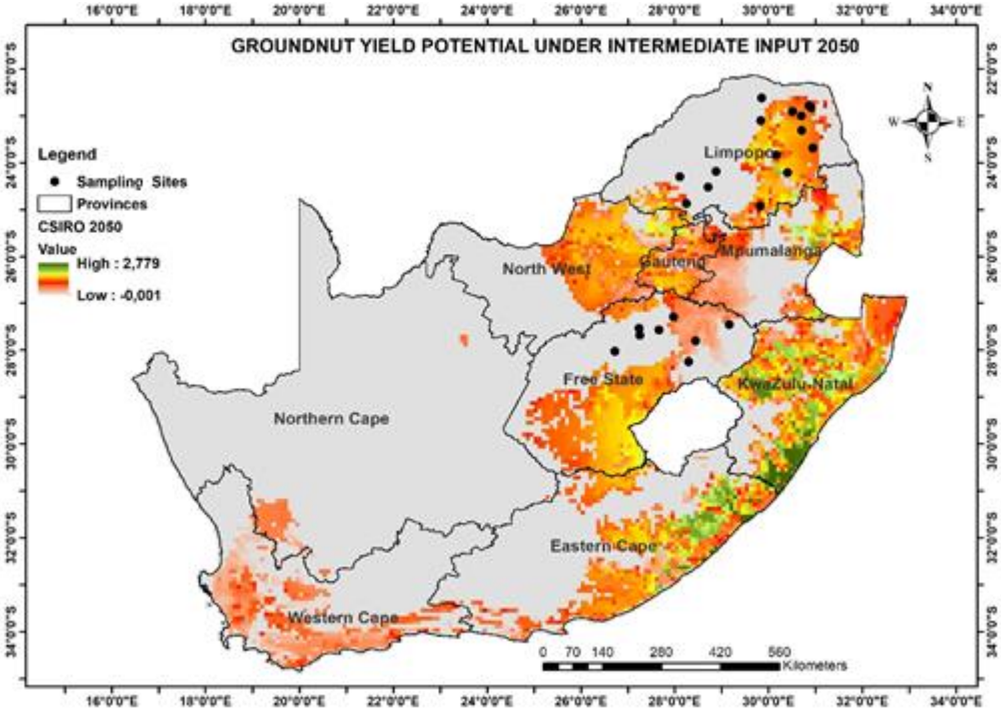


Figure 4.100a: Potential groundnut yield for intermediate input for the CSIRO model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

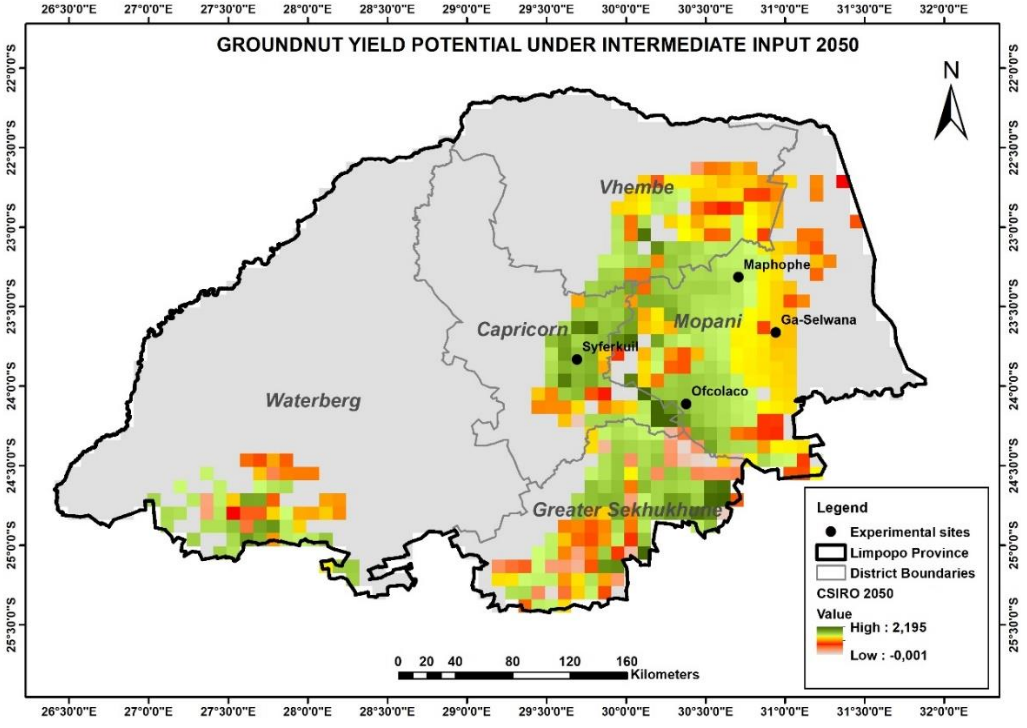


Figure 4.100b: Potential groundnut yield for intermediate input for the CSIRO model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

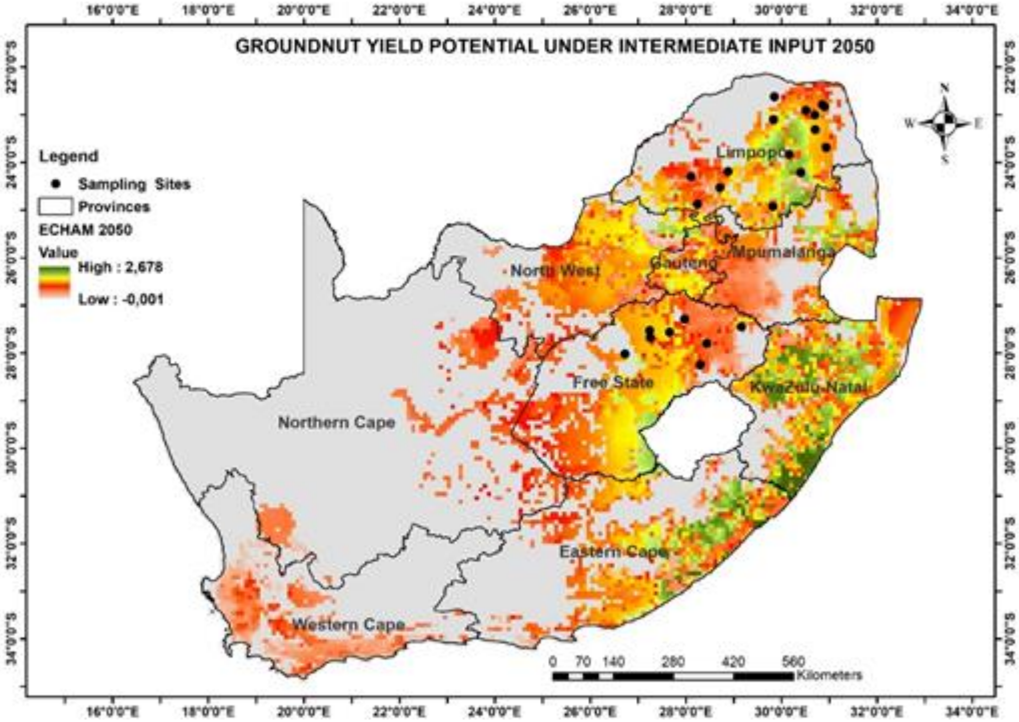


Figure 4.101a: Potential groundnut yield for intermediate input for the ECHAM model for the 2050 period (Calculated from GAEZ, 2012).

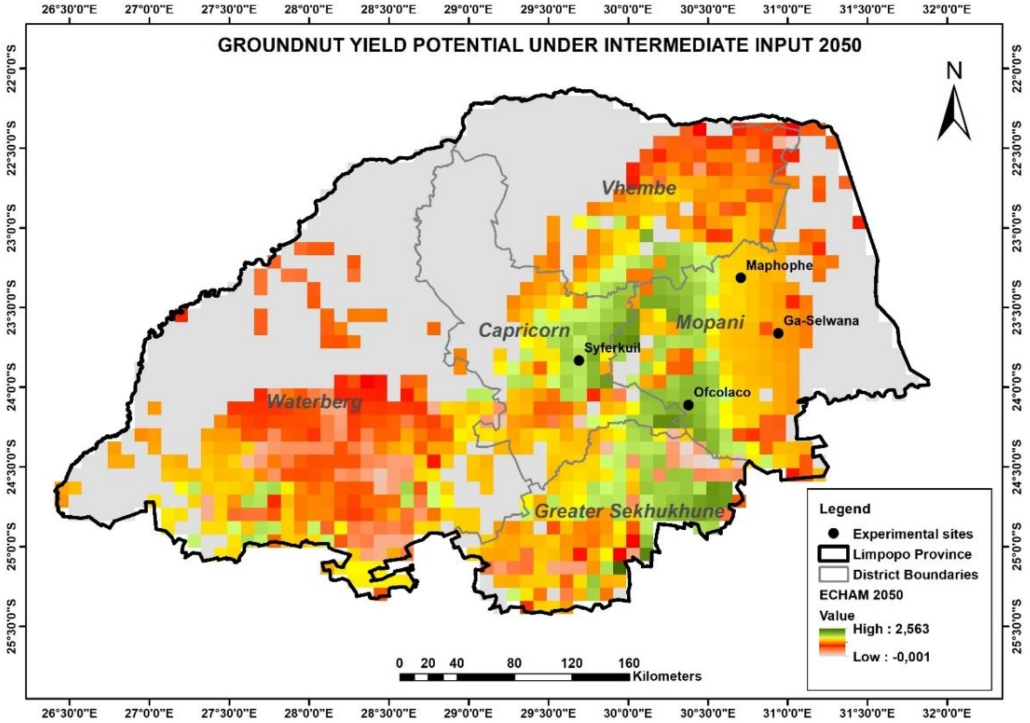


Figure 4.101b: Potential groundnut yield for intermediate input for the ECHAM model for the 2050 period for Limpopo (Calculated from GAEZ, 2012).

4.4.3.4 Future potential yield output for groundnut under different climate change models for the time period 2080 under the low and intermediate input scenario

Under the low input scenario for the time period 2080, all climate models show yield output of up to 1.5 t/ha as shown in Figures 4.102a, 4.103a and 4.104a. However, yields get up to 2 t/ha for areas in Limpopo as shown by 4.102b, 4.103b and 4.104b.

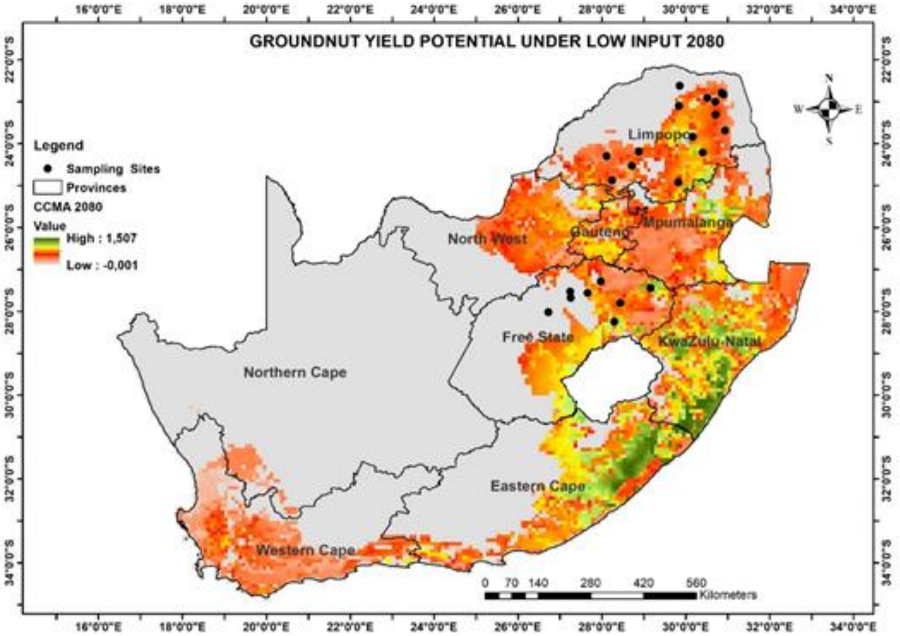


Figure 4.102a: Potential groundnut yield for low input for the CCCMA model for the 2080 period (Calculated from GAEZ, 2012).

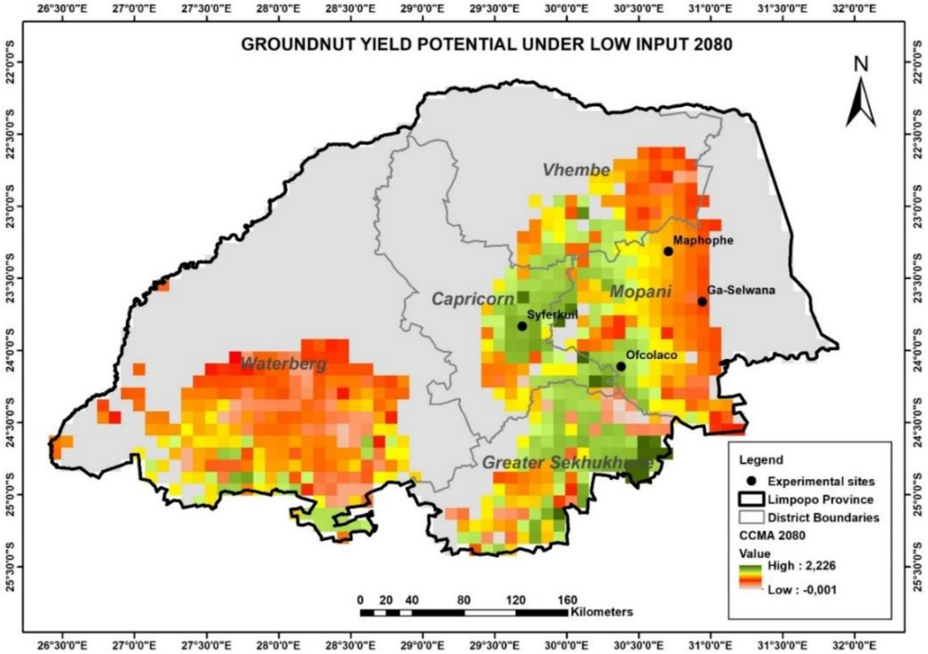


Figure 4.102b: Potential groundnut yield for low input for the CCCMA model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

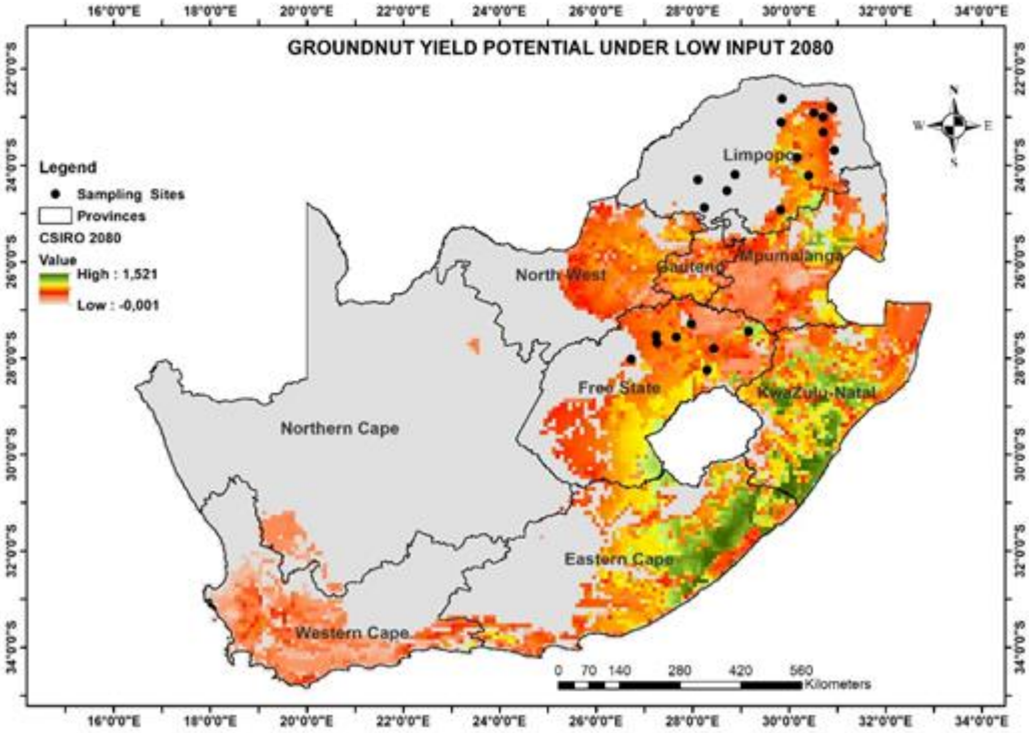


Figure 4.103a: Potential groundnut yield for low input for the CSIRO model for the 2080 period (Calculated from GAEZ, 2012).

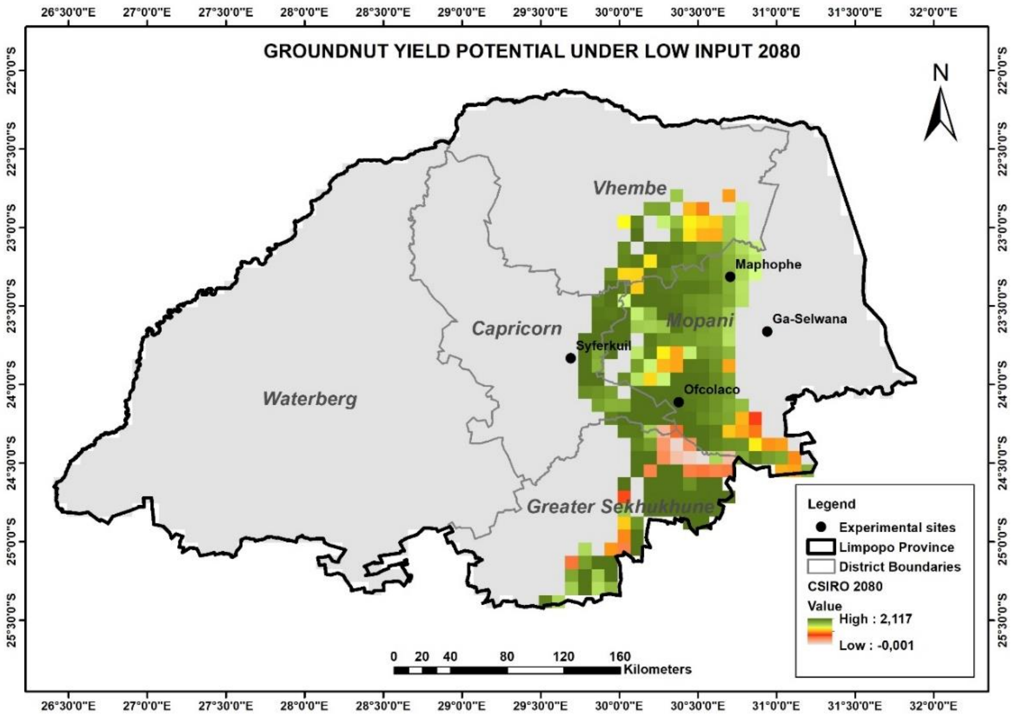


Figure 4.103b: Potential groundnut yield for low input for the CSIRO model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

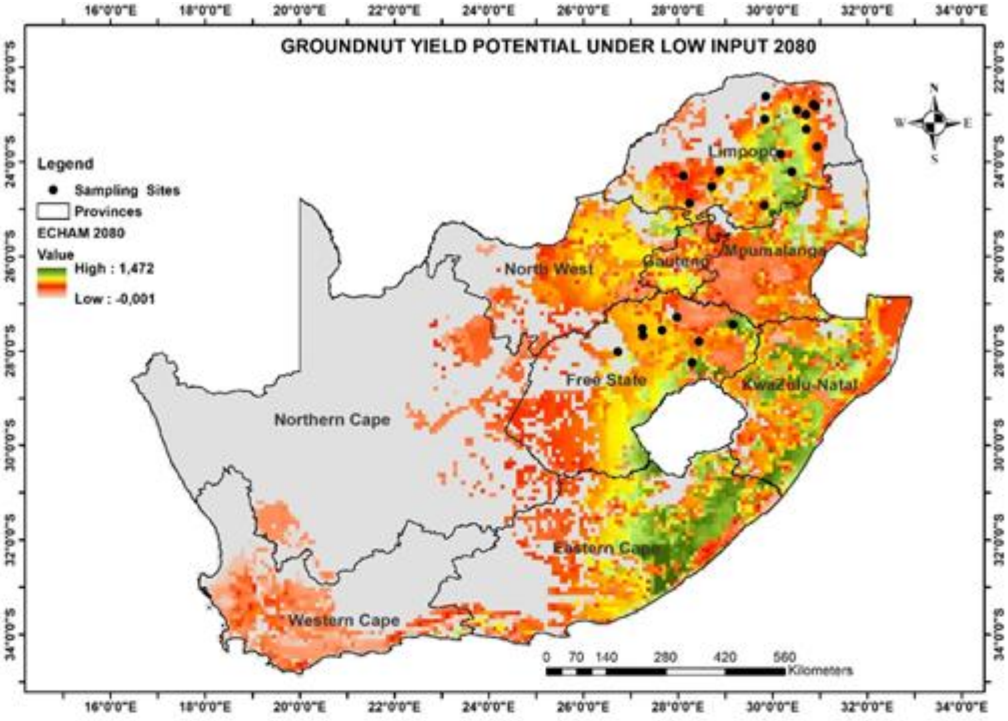


Figure 4.104a: Potential groundnut yield for low input for the ECHAM model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

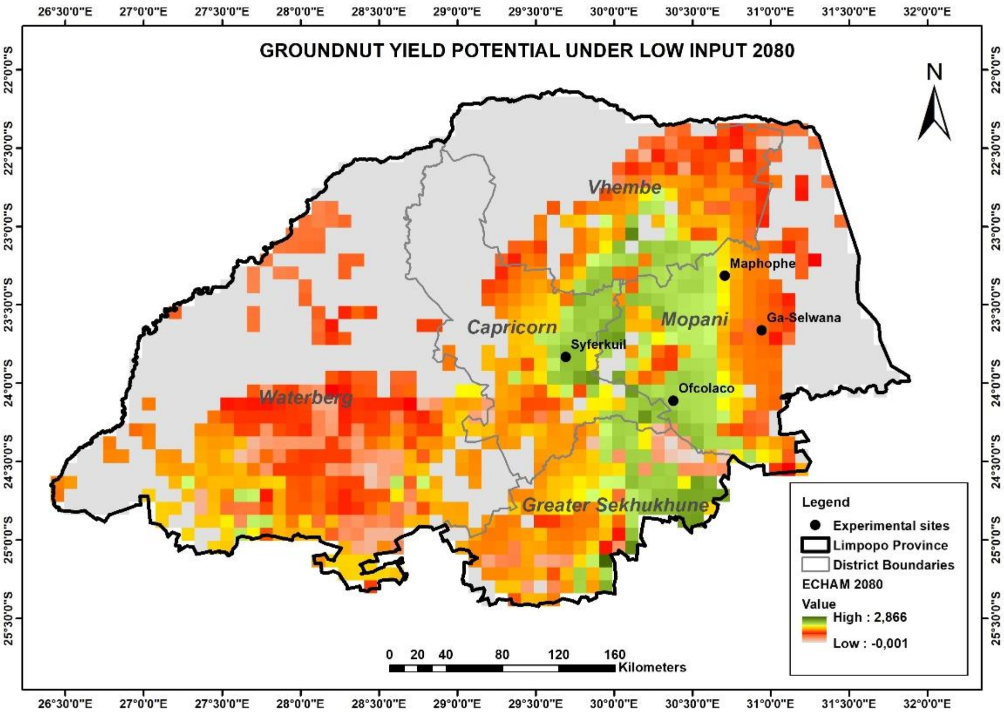


Figure 4.104b: Potential groundnut yield for low input for the ECHAM model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

In the intermediate scenario, yield range up to 2.9 t/ha for CCCMA, 3t/ha for CSIRO and ECHAM model as seen in Figures 4.105a,4.106a,14.107a respectively. Areas with such high yield from the models are found in KwaZulu Natal. In Limpopo, yields get up to 2.2 t/ha.

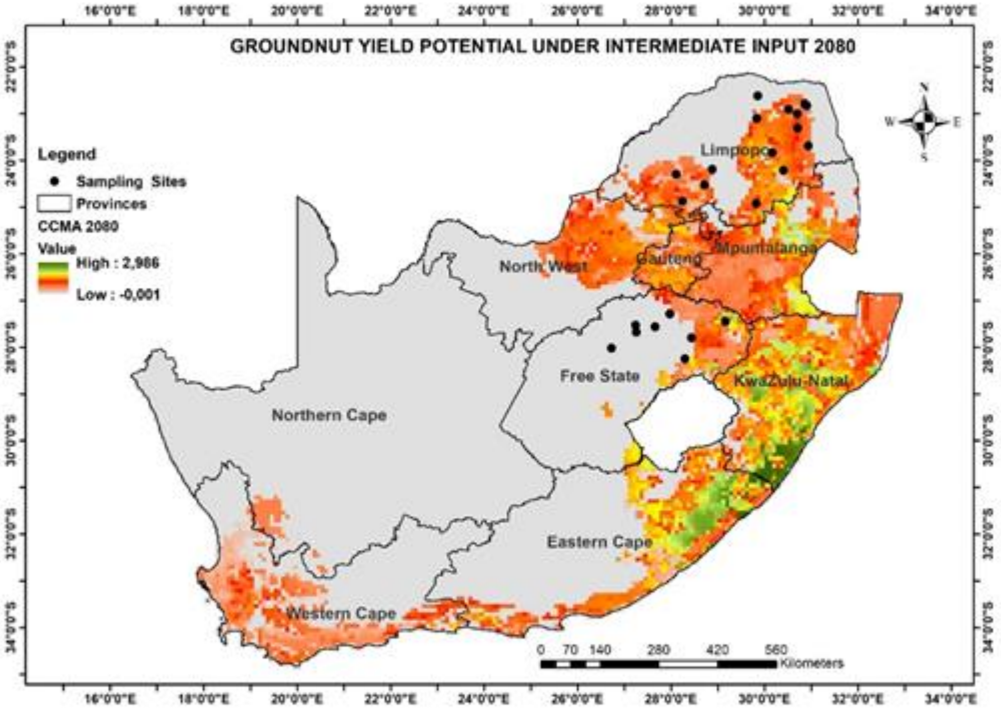


Figure 4.105a: Potential groundnut yield for intermediate input for the CCCMA model for the 2080 period (Calculated from GAEZ, 2012).

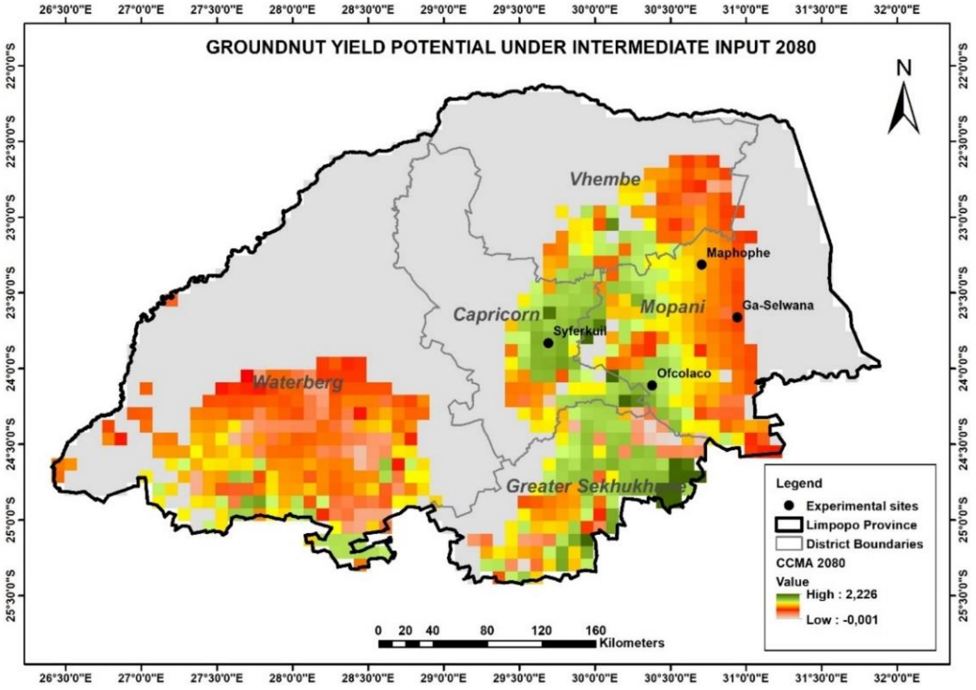


Figure 4.105b: Potential groundnut yield for intermediate input for the CCCMA model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

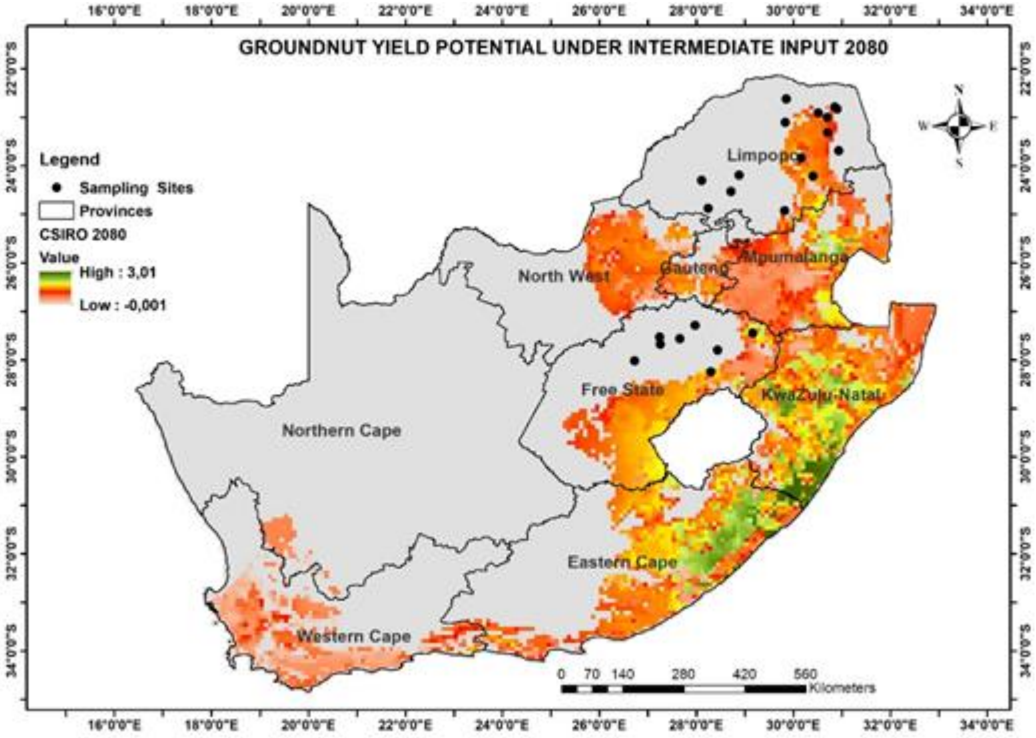


Figure 4.106a: Potential groundnut yield for intermediate input for the CSIRO model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

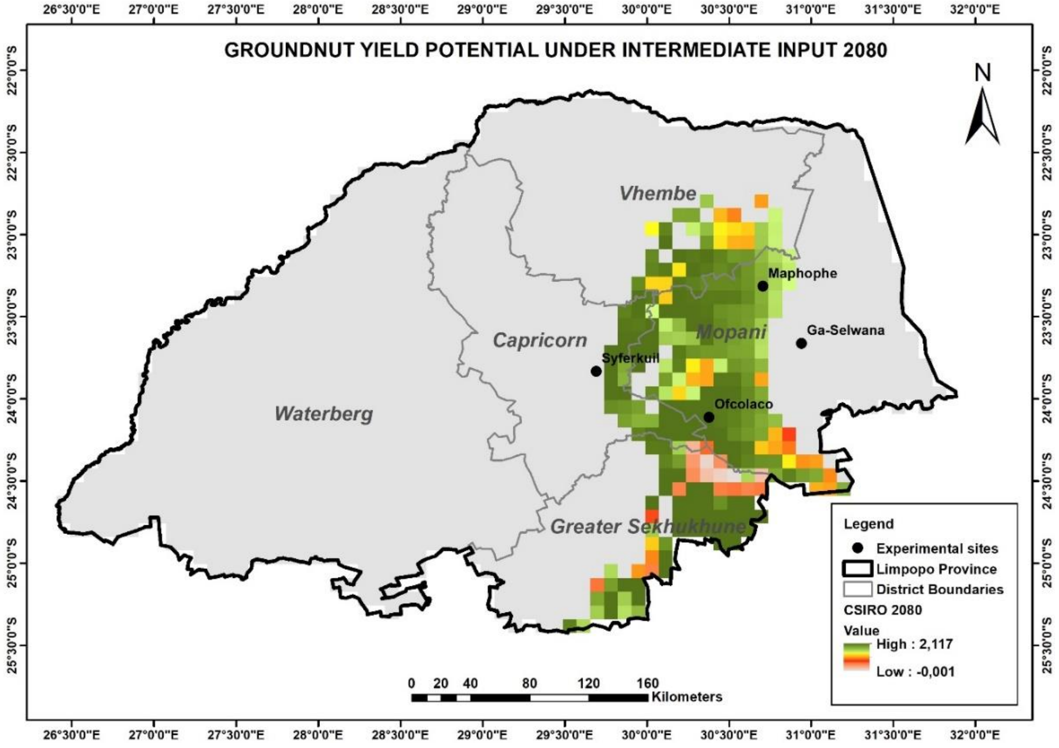


Figure 4.106b: Potential groundnut yield for intermediate input for the CSIRO model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

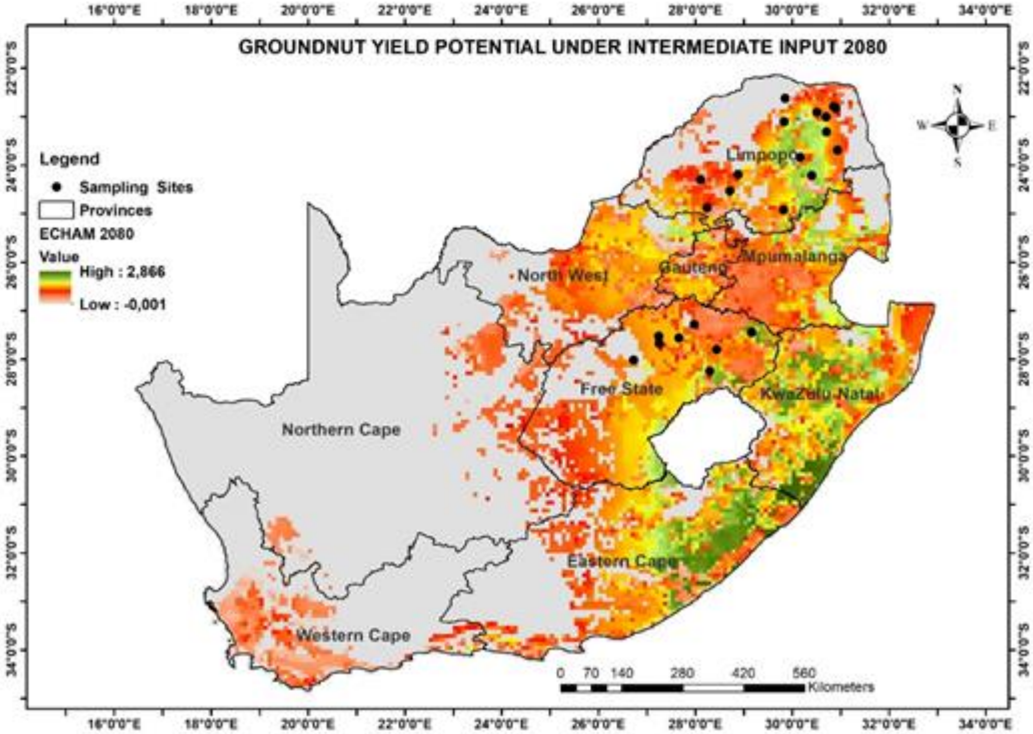


Figure 4.107a: Potential groundnut yield for intermediate input for the ECHAM model for the 2080 period (Calculated from GAEZ, 2012).

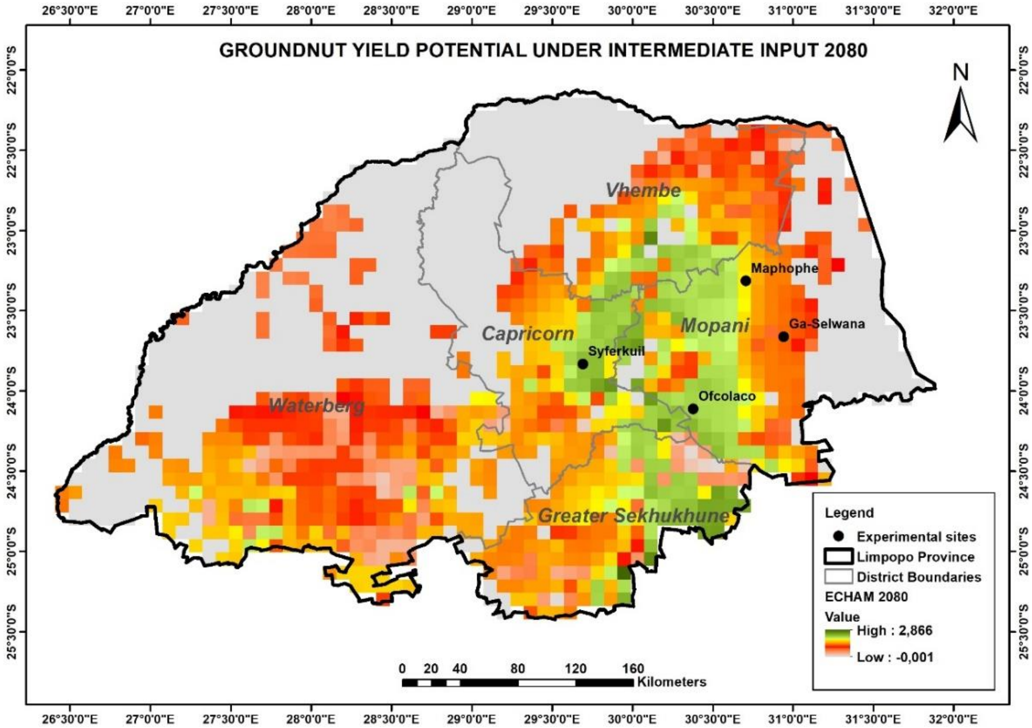


Figure 4.107b: Potential groundnut yield for intermediate input for the ECHAM model for the 2080 period for Limpopo (Calculated from GAEZ, 2012).

4.4.4 Indicators for vulnerability weighting and assessment

Given that agricultural vulnerability to climate change can be understood as an outcome of the interrelationships between hazard exposure, sensitivity, and adaptive capacity, the following sub-sections show the results of the interaction between hazard exposure (based on climate change projections), and sensitivity (based on an analysis of biophysical characteristic) and the overall vulnerability based on the extent to which these risks are mitigated or exacerbated by the presence or absence of adaptive capacity.

4.4.4.1 Hazard / Risk/ Exposure indicators

Climate extremes index or incidence of extreme weather was selected in order to determine locations that are currently prone to and will be more prone to weather events in the future and the type of weather event. In South Africa, extreme weathers often take the form of drought, flooding, frost, and hailstorms. In relation to extreme weather events, indicators were chosen that suggest changes to the incidence and intensity of flood events and droughts. Temperature and rainfall are used as indicators for exposure. Indicators include years with abnormally high rains (indicative of floods), years of abnormally low rains (indicative of drought) and heatwaves are used to show the climate extremes that will be prevalent in the study area at a point scale (hazard of place) of the experiment site as well as compared to the country scale predictions. Appendices 4.27 to 4.29 shows the climate extremes that are projected to occur at Syferkuil, and Appendices 4.30 to 4.32 shows that of Ofcolaco.

4.4.4.2 Crop Sensitivity Index

Appendices 4.33 to 4.41 shows how the suitability per indicator which varies from the micro-scale of the province to the whole country South Africa. Tables 4.54- 4.56 show the result of the crop sensitivity index calculated for the provinces. It shows that the sensitivity varies over the years and across provinces. A score of one occurs when the actual and expected yield is the same. However, a score above one indicates years in which harvest was below the expected value hence indicates a crop failure index (Simelton et al., 2008).

Table 4.54: Crop failure Index for soybean cultivation for the period 1994 to 2018 seasons.

Soybean Season	**Northern Cape**		**Crop Sensitivity Index (CSI)**	**Free State**		**CSI**	**Eastern Cape**			**KwaZulu-Natal**		
	Actual Yield	Expected Yield trend line $Y=0.388_x+2.26$		Actual Yield	Expected Yield trend line $Y=.0026_x+1.36$		Actual Yield	Expected Yield trend line $Y=0.0444_x+2.141$	CSI	Actual Yield	Expected Yield trend line $Y=0.0688_X+1.1642$	CSI
1994/95	1.262	3.01	2.381	1.086	1.362	1.255	-			1.173	1.518	1.294
1995/96	3.237	3.77	1.165	1.470	1.363	0.927	-			1.535	1.537	1.002
1996/97	3.778	3.98	1.054	1.708	1.364	0.798	-			1.807	1.552	0.859
1997/98	2.081	3.32	1.597	1.424	1.363	0.957	-			2.192	1.573	0.717
1998/99	2.417	3.45	1.429	1.267	1.362	1.076	-			2.039	1.564	0.767
1999/2000	2.600	3.52	1.356	1.657	1.363	0.823	1.500	2.209	1.472	1.967	1.561	0.794
2000/2001	2.700	3.56	1.320	1.365	1.363	0.998	2.000	2.231	1.115	2.248	1.576	0.701
2001/2002	3.872	4.02	1.038	1.364	1.363	0.999	2.333	2.246	0.962	2.311	1.579	0.683
2002/2003	5.044	4.47	0.887	1.151	1.362	1.183	3.000	2.275	0.758	1.624	1.542	0.950
2003/2004	2.344	3.43	1.461	1.349	1.363	1.010	1.333	2.201	1.651	1.900	1.557	0.819
2004/2005	3.000	3.68	1.227	1.463	1.363	0.931	2.000	2.231	1.115	2.310	1.579	0.684
2005/2006	3.000	3.68	1.227	1.711	1.364	0.797	1.500	2.209	1.472	2.500	1.589	0.636
2006/2007	3.000	3.68	1.227	0.750	1.361	1.815	2.000	2.231	1.115	2.200	1.573	0.715
2007/2008	3.500	3.87	1.107	1.344	1.363	1.014	1.500	2.209	1.472	2.514	1.590	0.632
2008/2009	3.000	3.68	1.227	1.800	1.364	0.758	2.000	2.231	1.115	2.800	1.605	0.573
2009/2010	3.000	3.68	1.227	1.599	1.363	0.852	1.500	2.209	1.472	2.450	1.586	0.648
2010/2011	3.000	3.68	1.227	1.407	1.363	0.968	1.500	2.209	1.472	2.706	1.600	0.591
2011/2012	3.000	3.68	1.227	1.100	1.362	1.238	1.500	2.209	1.472	2.400	1.584	0.660
2012/2013	3.500	3.87	1.107	1.050	1.362	1.297	1.500	2.209	1.472	2.500	1.589	0.636
2013/2014	3.600	3.91	1.087	1.751	1.364	0.779	1.800	2.222	1.234	2.800	1.605	0.573
2014/2015	3.500	3.87	1.107	1.200	1.362	1.135	1.400	2.204	1.574	2.450	1.586	0.648
2015/2016	3.400	3.84	1.128	0.851	1.361	1.600	1.400	2.204	1.574	2.357	1.581	0.671
2016/2017	3.500	3.87	1.107	2.100	1.365	0.650	1.500	2.209	1.472	2.950	1.613	0.547
2017/2018	3.500	3.87	1.107	1.600	1.363	0.852	1.000	2.187	2.187	3.100	1.621	0.523

Table 4.54 Cont.: Crop failure Index for soybean cultivation for the period 1994 to 2018 seasons.

Soybean Season Cont.	Mpumalanga		(CSI)	Limpopo		CSI	Gauteng			North West		
	Actual Yield	Expected Yield trend line $Y=0.05_x+0.64$		Actual Yield	Expected Yield trend line $Y=0.0747_X+2.27$		Actual Yield	Expected Yield trend line $Y=0.0491_X+0.89$	CSI	Actual Yield	Expected Yield trend line $Y= -.0158_x+2.3$	CSI
1994/95	0.784	0.677	0.863	0.764	2.295	3.004	0.659	0.927	1.406	0.991	2.186	2.206
1995/96	0.879	0.682	0.775	2.489	2.337	0.939	0.973	0.942	0.969	1.817	2.090	1.151
1996/97	1.059	0.691	0.652	2.429	2.336	0.962	1.127	0.950	0.843	2.143	2.052	0.958
1997/98	1.475	0.712	0.482	2.783	2.344	0.842	1.943	0.990	0.510	2.157	2.051	0.951
1998/99	1.171	0.696	0.595	2.850	2.346	0.823	1.360	0.961	0.707	2.419	2.020	0.835
1999/2000	1.345	0.705	0.524	3.111	2.353	0.756	1.556	0.971	0.624	2.484	2.013	0.810
2000/2001	1.389	0.707	0.509	3.446	2.361	0.685	1.400	0.963	0.688	2.149	2.052	0.955
2001/2002	1.600	0.718	0.449	2.889	2.347	0.812	1.818	0.984	0.541	2.200	2.046	0.930
2002/2003	1.203	0.698	0.580	2.635	2.341	0.888	1.463	0.966	0.661	2.439	2.018	0.827
2003/2004	1.498	0.713	0.476	2.203	2.330	1.058	1.560	0.971	0.622	2.364	2.027	0.857
2004/2005	1.627	0.719	0.442	2.736	2.343	0.856	1.840	0.985	0.535	2.216	2.044	0.922
2005/2006	1.500	0.713	0.475	2.650	2.341	0.883	1.651	0.976	0.591	2.700	1.988	0.736
2006/2007	0.850	0.680	0.800	2.000	2.325	1.163	0.830	0.935	1.127	2.000	2.069	1.034
2007/2008	1.561	0.716	0.459	3.000	2.350	0.783	1.618	0.974	0.602	2.500	2.011	0.804
2008/2009	2.100	0.743	0.354	2.750	2.344	0.852	1.869	0.986	0.528	2.850	1.970	0.691
2009/2010	1.652	0.721	0.436	2.800	2.345	0.837	1.700	0.978	0.575	2.700	1.988	0.736
2010/2011	1.550	0.715	0.462	2.502	2.338	0.934	1.550	0.971	0.626	2.500	2.011	0.804
2011/2012	1.315	0.704	0.535	2.300	2.333	1.014	1.500	0.968	0.645	1.500	2.127	1.418
2012/2013	1.800	0.728	0.404	2.750	2.344	0.852	1.600	0.973	0.608	0.800	2.208	2.760
2013/2014	1.650	0.720	0.437	3.000	2.350	0.783	2.368	1.011	0.427	2.000	2.069	1.034
2014/2015	1.591	0.717	0.451	3.000	2.350	0.783	2.300	1.007	0.438	1.500	2.127	1.418
2015/2016	1.700	0.723	0.425	2.400	2.335	0.973	2.200	1.003	0.456	0.910	2.195	2.413
2016/2017	2.300	0.753	0.327	3.500	2.362	0.675	2.800	1.032	0.369	2.300	2.034	0.884
2017/2018	2.200	0.748	0.340	2.800	2.345	0.837	2.050	0.995	0.485	1.700	2.104	1.237

Table 4.55: Crop failure Index for sunflower cultivation for the period 1994 to 2018 seasons.

Sunflower Season	Northern Cape			Free State			Mpumalanga			Limpopo		
	Actual Yield	Expected Yield trend liney = -0.0367x + 2.33	(CSI)	Actual Yield	Expected Yield trend line y = 0.0199x + 0.92	CSI	Actual Yield	Expected Yield trend line y = 0.0119x + 1.016	CSI	Actual Yield	Expected Yield trend line y = 0.0115x + 0.63	CSI
1990/91	6.1	2.122	0.3	0.99	1.926	2.0	1.2	1.030	0.89	0.62	0.635	1.02
1991/92	0.7	2.322	3.5	0.55	1.488	2.7	0.2	1.018	4.72	0.14	0.630	4.56
1992/93	0.6	2.325	3.8	0.82	1.758	2.1	1.0	1.027	1.07	0.55	0.634	1.15
1993/94	0.7	2.322	3.4	0.92	1.857	2.0	1.1	1.029	0.95	0.62	0.635	1.03
1994/95	1.4	2.296	1.7	0.94	1.879	2.0	1.0	1.028	0.98	0.51	0.634	1.25
1995/96	1.7	2.285	1.4	1.29	2.226	1.7	1.2	1.030	0.85	0.94	0.639	0.68
1996/97	1.3	2.299	1.7	1.01	1.944	1.9	1.0	1.027	1.08	0.74	0.636	0.87
1997/98	1.4	2.295	1.6	1.13	2.069	1.8	1.3	1.031	0.79	0.71	0.636	0.90
1998/99	2.0	2.274	1.1	1.46	2.401	1.6	1.4	1.032	0.74	0.61	0.635	1.05
1999/2000	3.7	2.211	0.6	1.46	2.399	1.6	1.1	1.029	0.94	1.20	0.642	0.53
2000/2001	2.7	2.248	0.8	1.30	2.239	1.7	1.2	1.030	0.90	0.90	0.638	0.71
2001/2002	2.0	2.274	1.1	1.45	2.393	1.6	1.8	1.037	0.59	1.25	0.642	0.51
2002/2003	2.4	2.259	0.9	1.14	2.078	1.8	1.1	1.029	0.91	0.60	0.635	1.06
2003/2004	1.5	2.291	1.5	1.30	2.238	1.7	1.4	1.032	0.76	1.48	0.645	0.44
2004/2005	2.0	2.274	1.1	1.41	2.344	1.7	1.6	1.035	0.66	0.90	0.638	0.71
2005/2006	1.5	2.292	1.5	1.21	2.153	1.8	1.2	1.031	0.82	0.91	0.638	0.70
2006/2007	1.9	2.278	1.2	1.15	2.087	1.8	1.0	1.028	1.03	0.42	0.633	1.52
2007/2008	2.3	2.264	1.0	1.70	2.639	1.6	1.5	1.034	0.69	1.10	0.641	0.58
2008/2009	2.0	2.274	1.1	1.30	2.235	1.7	1.4	1.033	0.74	1.00	0.640	0.64
2009/2010	2.0	2.274	1.1	1.30	2.239	1.7	1.6	1.035	0.65	0.90	0.638	0.71
2010/2011	1.4	2.297	1.7	1.45	2.385	1.6	1.2	1.030	0.86	1.00	0.640	0.64
2011/2012	0.3	2.337	8.2	1.30	2.239	1.7	1.4	1.032	0.76	0.85	0.638	0.75
2012/2013	0.5	2.329	4.7	1.35	2.289	1.7	1.5	1.034	0.69	0.86	0.638	0.74
2013/2014	0.5	2.329	4.7	1.60	2.539	1.6	1.3	1.031	0.79	0.85	0.638	0.75
2014/2015	1.1	2.307	2.1	1.30	2.239	1.7	1.3	1.032	0.78	0.75	0.637	0.85
2015/2016	1.7	2.285	1.3	1.10	2.039	1.9	1.1	1.029	0.94	0.75	0.637	0.85
2016/2017	2.3	2.264	1.0	1.45	2.389	1.6	1.1	1.029	0.94	0.95	0.639	0.67
2017/2018	1.2	2.303	1.9	1.55	2.489	1.6	1.0	1.027	1.08	0.80	0.637	0.80

Table 4.55 Cont: Crop failure Index for sunflower cultivation for the period 1994 to 2018 seasons.

Sunflower Season Cont.	**Gauteng**		**Crop Sensitivity Index (CSI)**	**North West**		**CSI**
	Actual Yield	Expected Yield trend line y = -0.0026x + 1.2992		Actual Yield	Expected Yield trend line y = 0.0196x + 0.7484	
1990/91	1.528	1.295	0.85	1.1	0.7692	0.7
1991/92	0.313	1.298	4.14	0.3	0.7551	2.2
1992/93	0.953	1.297	1.36	0.9	0.7652	0.9
1993/94	1.068	1.296	1.21	1.0	0.7672	0.8
1994/95	1.287	1.296	1.01	1.0	0.7672	0.8
1995/96	1.561	1.295	0.83	1.3	0.7735	0.6
1996/97	1.219	1.296	1.06	1.0	0.7680	0.8
1997/98	1.298	1.296	1.00	1.1	0.7703	0.7
1998/99	1.833	1.294	0.71	1.2	0.7719	0.6
1999/2000	1.500	1.295	0.86	1.3	0.7729	0.6
2000/2001	1.500	1.295	0.86	1.2	0.7719	0.6
2001/2002	1.500	1.295	0.86	1.3	0.7739	0.6
2002/2003	1.185	1.296	1.09	1.0	0.7682	0.8
2003/2004	1.301	1.296	1.00	1.1	0.7700	0.7
2004/2005	1.390	1.296	0.93	1.3	0.7748	0.6
2005/2006	1.350	1.296	0.96	1.0	0.7680	0.8
2006/2007	1.100	1.296	1.18	0.8	0.7650	0.9
2007/2008	1.450	1.295	0.89	1.5	0.7778	0.5
2008/2009	1.403	1.296	0.92	1.3	0.7738	0.6
2009/2010	1.400	1.296	0.93	1.3	0.7738	0.6
2010/2011	1.200	1.296	1.08	1.3	0.7748	0.6
2011/2012	1.300	1.296	1.00	1.2	0.7709	0.7
2012/2013	1.026	1.297	1.26	0.9	0.7664	0.8
2013/2014	1.300	1.296	1.00	1.3	0.7748	0.6
2014/2015	1.200	1.296	1.08	1.1	0.7700	0.7
2015/2016	1.000	1.297	1.30	1.1	0.7690	0.7
2016/2017	1.000	1.297	1.30	1.5	0.7768	0.5
2017/2018	1.000	1.297	1.30	1.4	0.7758	0.6

Table 4.56: Crop failure Index for groundnut cultivation for the period 1994 to 2018 seasons

Groundnut Season	**Northern Cape**		**(CSI)**	**Free State**		**CSI**	**KwaZulu-Natal**		
	Actual Yield	Expected Yield trend line y = 0.0433x + 1.86		Actual Yield	Expected Yield trend line y = 0.0118x +0.87		Actual Yield	Expected Yield trend line y = 0.0761x + 0.3264	CSI
1990/91	0.90	1.89	2.09	1.06	0.90	0.85	1.00	0.71	0.71
1991/92	1.53	1.92	1.26	0.38	0.89	2.36	0.52	0.69	1.32
1992/93	1.28	1.91	1.49	0.64	0.89	1.40	0.57	0.69	1.22
1993/94	2.12	1.95	0.92	0.92	0.90	0.97	0.78	0.70	0.90
1994/95	1.94	1.94	1.00	0.47	0.89	1.88	0.91	0.71	0.77
1995/96	1.84	1.94	1.05	0.90	0.90	0.99	0.65	0.70	1.08
1996/97	2.49	1.96	0.79	0.96	0.90	0.94	0.73	0.70	0.96
1997/98	2.59	1.97	0.76	1.03	0.90	0.88	1.00	0.71	0.71
1998/99	2.81	1.98	0.70	1.12	0.90	0.80	2.00	0.75	0.37
1999/2000	2.55	1.97	0.77	1.40	0.90	0.64	1.00	0.71	0.71
2000/2001	2.55	1.97	0.77	1.05	0.90	0.86	0.80	0.70	0.88
2001/2002	2.50	1.96	0.79	1.15	0.90	0.78	1.00	0.71	0.71
2002/2003	2.65	1.97	0.74	1.02	0.90	0.88	1.05	0.71	0.68
2003/2004	2.99	1.99	0.66	1.30	0.90	0.69	1.47	0.73	0.50
2004/2005	3.08	1.99	0.65	1.49	0.90	0.61	1.67	0.73	0.44
2005/2006	2.90	1.98	0.68	1.30	0.90	0.69	2.42	0.76	0.31
2006/2007	3.02	1.99	0.66	1.10	0.90	0.81	1.50	0.73	0.48
2007/2008	3.07	1.99	0.65	1.40	0.90	0.64	1.60	0.73	0.46
2008/2009	3.10	1.99	0.64	1.57	0.90	0.58			
2009/2010	2.71	1.97	0.73	1.40	0.90	0.64			
2010/2011	2.53	1.97	0.78	0.90	0.90	1.00			
2011/2012	2.60	1.97	0.76	1.09	0.90	0.82			
2012/2013	2.00	1.94	0.97	0.90	0.90	1.00			
2013/2014	2.60	1.97	0.76	1.18	0.90	0.77			
2014/2015	3.20	1.99	0.62	0.97	0.90	0.93			
2015/2016	2.00	1.94	0.97	0.45	0.89	1.98			
2016/2017	3.50	2.01	0.57	1.55	0.90	0.58			
2017/2018	2.50	1.96	0.79	0.90	0.90	1.00			

Table 4.56 Cont: Crop failure Index for groundnut cultivation for the period 1994 to 2018 seasons.

Groundnut Season Cont.	**Mpumalanga**		**(CSI)**	**Limpopo**		**CSI**	**Gauteng**			**North West**		
	Actual Yield	Expected Yield trend line Y=0.1014x + 0.57		Actual Yield	Expected Yield trend line y = 0.0266x + 0.97		Actual Yield	Expected Yield trend line y = 0.0341x + 0.53	CSI	Actual Yield	Expected Yield trend liney = 0.0167x + 0.62	CSI
1990/1991	1.00	0.68	0.68	1.000	1.17	1.17	1.00	0.56	0.56	0.800	0.633	0.79
1991/1992	0.29	0.60	2.06	0.35	1.04	2.93	0.51	0.54	1.07	0.206	0.623	3.02
1992/1993	0.76	0.65	0.86	0.67	1.11	1.64	0.55	0.54	1.00	0.391	0.626	1.60
1993/1994	1.12	0.69	0.61	1.03	1.18	1.14	0.49	0.54	1.11	0.816	0.634	0.78
1994/95	1.04	0.68	0.65	1.33	1.24	0.93	0.52	0.54	1.05	0.535	0.629	1.18
1995/96	0.98	0.67	0.69	1.12	1.20	1.07	0.45	0.54	1.20	0.859	0.634	0.74
1996/97	1.24	0.70	0.56	1.22	1.22	1.00	0.55	0.54	0.99	0.732	0.632	0.86
1997/98	1.02	0.68	0.67	1.37	1.25	0.91	1.01	0.56	0.56	0.816	0.634	0.78
1998/99	1.43	0.72	0.50	0.89	1.15	1.29	1.00	0.56	0.56	0.891	0.635	0.71
1999/2000	2.50	0.83	0.33	1.30	1.24	0.95	1.00	0.56	0.56	1.150	0.639	0.56
2000/2001	2.80	0.86	0.31	1.10	1.19	1.09	1.00	0.56	0.56	0.900	0.635	0.71
2001/2002	1.50	0.73	0.48	1.50	1.28	0.85	1.00	0.56	0.56	1.150	0.639	0.56
2002/2003	1.50	0.73	0.48	1.27	1.23	0.97	1.00	0.56	0.56	0.953	0.636	0.67
2003/2004	1.80	0.76	0.42	1.61	1.30	0.81	1.00	0.56	0.56	1.255	0.641	0.51
2004/2005	1.80	0.76	0.42	1.65	1.31	0.79	1.00	0.56	0.56	1.094	0.638	0.58
2005/2006	-			1.95	1.37	0.70	1.00	0.56	0.56	1.053	0.637	0.61
2006/2007	-			1.42	1.26	0.89	1.00	0.56	0.56	1.000	0.637	0.64
2007/2008	-			2.23	1.43	0.64	1.20	0.57	0.47	1.350	0.642	0.48
2008/2009	-			2.25	1.43	0.64	1.20	0.57	0.47	1.400	0.643	0.46
2009/2010	-			1.60	1.30	0.81	1.20	0.57	0.47	1.100	0.638	0.58
2010/2011	-			1.40	1.26	0.90				0.950	0.636	0.67
2011/2012	-			1.20	1.21	1.01				1.050	0.637	0.61
2012/2013	-			1.20	1.21	1.01				0.500	0.628	1.26
2013/2014	-			1.37	1.25	0.91				1.295	0.642	0.50
2014/2015	-			1.30	1.24	0.95				0.560	0.629	1.12
2015/2016	-			0.90	1.15	1.28				0.349	0.626	1.79
2016/2017	-			1.60	1.30	0.81				1.450	0.644	0.44
2017/2018	-			2.00	1.38	0.69				0.650	0.631	0.97

4.4.5 Adaptive Capacity

The indicators chosen focused on the following aspects of adaptive capacity to climate change: household income, gender and age profile, and education. According to literature (e.g. Gbetibouo et al., 2010), the adaptive capacity required to cope with climate change is assumed to be dependent on five livelihoods assets: financial, human, natural, physical and social capital assets. Proxy indicators of adaptive capacity considered for this study were: human capital (level of education), population size, and income level. Socioeconomic indicators were obtained from the census data by the South African statistical services (2011, 2016). In this study, human capital (literacy rate) income level, population structure is included in the sensitivity component of vulnerability. It is assumed that the greater the human capital and income levels the less the sensitivity of that region to the impacts of climate change. For the purposes of simplicity in assessing the vulnerability of the farming community, the approach has been to map the lack of adaptation capacity or social vulnerability. Figure 4.108 shows the distribution of income across households. The most highly vulnerable areas are found in the Eastern Cape, parts of North West, Northern Cape, Limpopo, and KwaZulu Natal.

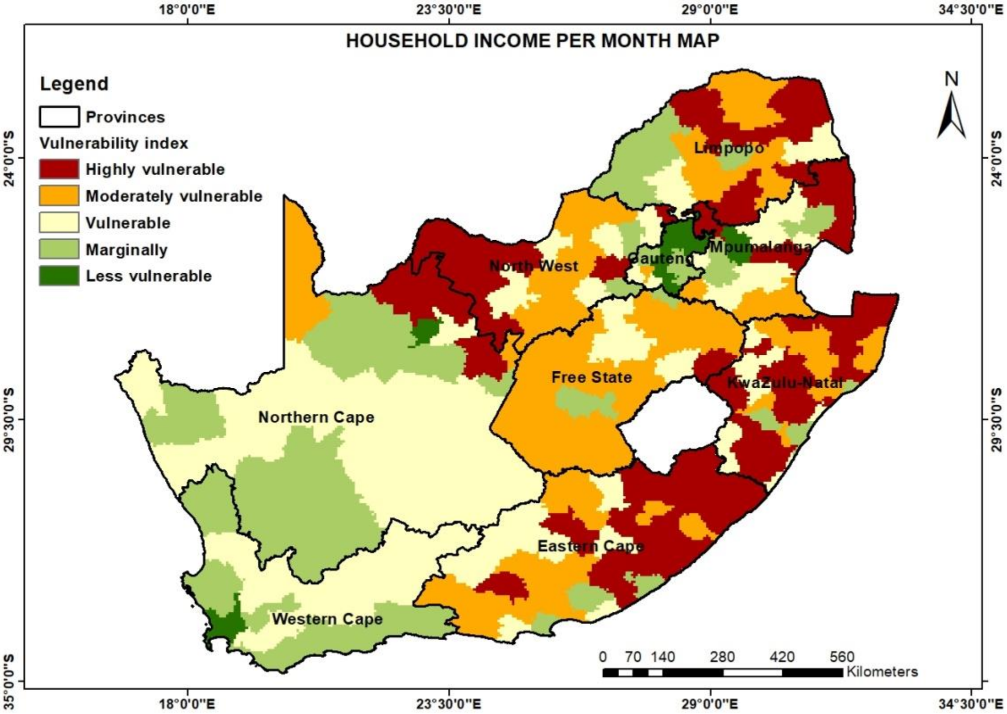


Figure 4.108: Income distribution and vulnerability of households across various provinces
Source: Calculated from Statistics from StatsSA (2011).

Figure 4.109 shows that areas with high vulnerability based on the female population are found in Free State, Limpopo, Mpumalanga, North West and KZN.

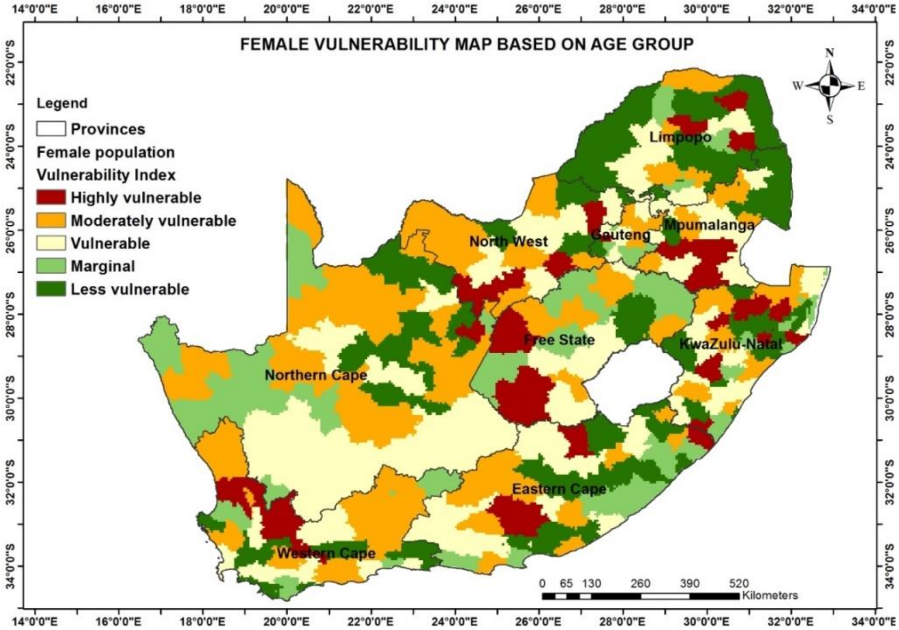


Figure 4.109: Vulnerability based on the distribution of female-headed household
Source: Calculated from Statistics from StatsSA (2016).

Figure 4.110 shows that in terms of population distribution, areas made up of mostly young and old people are highly vulnerable as in the North West, Free State, Northern and Eastern Cape.

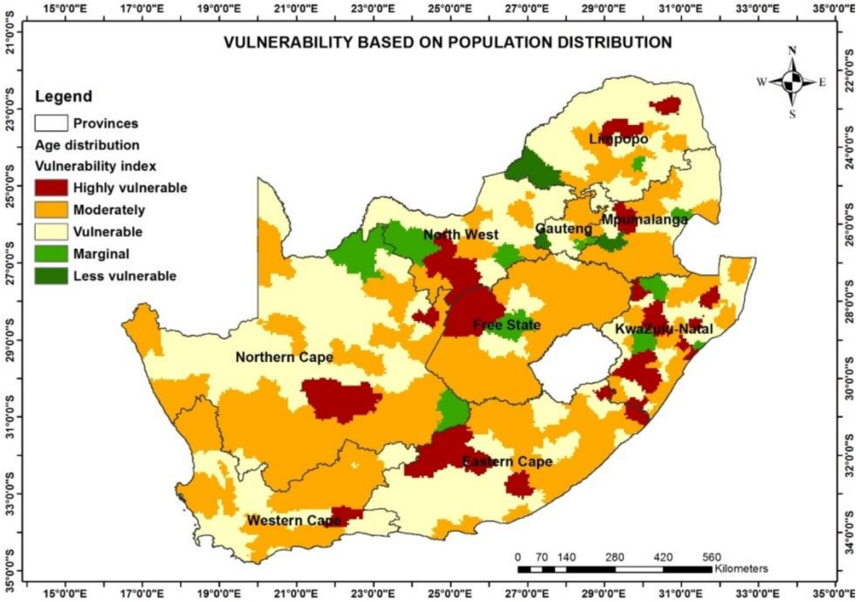


Figure 4.110: Vulnerability-based on the distribution of population distribution
Source: Calculated from Statistics from StatsSA (2016).

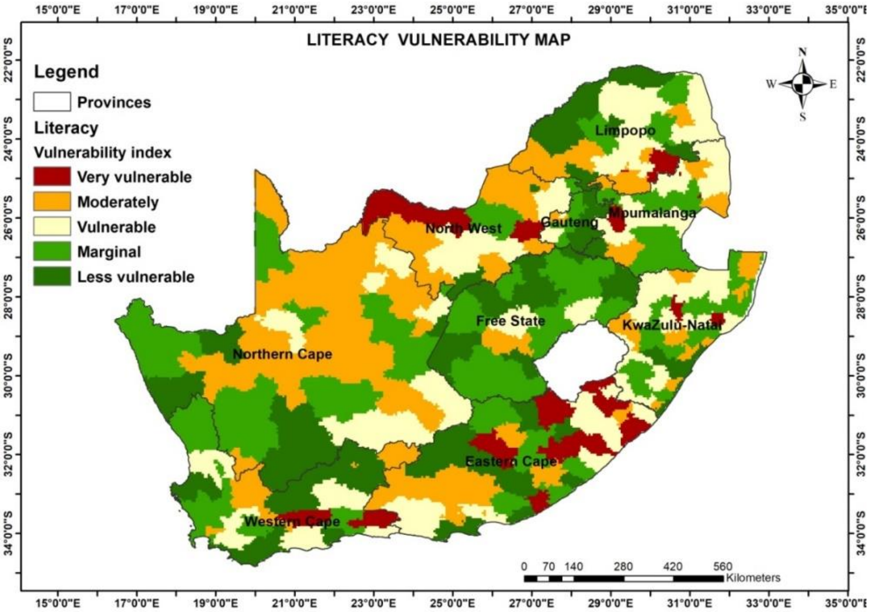


Figure 4.111: Vulnerability based on the literacy levels
Source: Calculated from Statistics from StatsSA (2016).

Figure 4.112 shows a composite of the merged social indicators and shows that areas with high vulnerability have a low adaptive capacity. It shows that areas in the North West, Northern Cape and Free State have higher adaptive capacity compared to the rest of the country which has a moderate vulnerability.

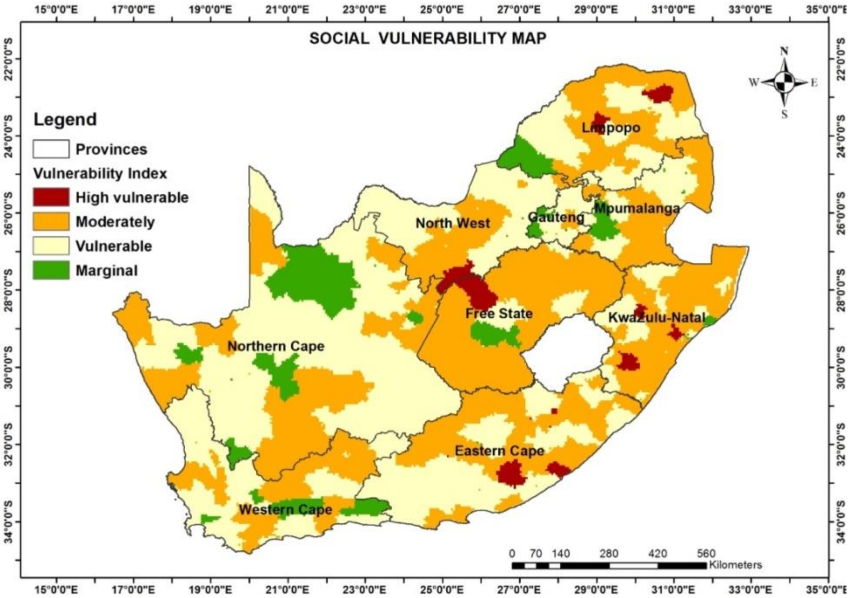


Figure 4.112: Overall adaptive capacity.

4.4.6 Vulnerability of crops

Crop vulnerability maps calculated from GAEZ are shown in Appendices 4.42 to 4.44. Appendix 4.42 shows the suitability of production of soybean based on the agro-ecological potential of South Africa. With low input level, most of the country is moderately suitable for production except for the Northern Cape Province. Areas with very high potential for production are found in Eastern Cape, North West, Limpopo and some patches in Free State and KwaZulu Natal. Production is carried out over most of the country because the degree of input used is very minimal and does not have a lot of cost implications for the farmers. Hence given that very little input is used, more farmers are producing soybean. For the medium input during the base line time frame, it can be seen that due to the addition of inputs and more market-oriented decisions, most of the provinces: Eastern Cape, KwaZulu Natal, Gauteng, Mpumalanga, Free State, North West and Limpopo are good for production. Future production for soybean the intermediate level input. Indicates that production under the CCCmaCGMa model is to be found in the KwaZulu Natal. Patches are found in Limpopo. The areas showing better results are mostly Limpopo and the Free State provinces.

In regard to the production of sunflower under various input regimes for the period 1960-1990, Appendix 4.43 shows a trend of areas of very high suitability found in the Eastern Cape and Limpopo. The northern part appears to have the greatest areas not suitable for production. For areas with high potential, Mpumalanga, Gauteng, and Free State are the most favourable.

For baseline production of groundnut Appendix 4.44, those for the low input patches of very highly suitable are Gauteng, Free State, and Limpopo. Areas not suitable can be found in parts of Eastern Cape, Mpumalanga, KwaZulu Natal, Limpopo, Free State, North West, and Northern Cape. Intermediate shows similar trend like the low input. However, the areas of very marginal found under low input decreases under the intermediate input regime showing a similar pattern but with more part of North West, Free State showing patches of very high suitability.

The various climate model show variation in terms of land used for cultivation as shown by Tables below 4.57 to 4.59.

Table 4.57: Changes in the area used for the production of soybean under various time frames and input levels.

Soybean Production: 2020 Intermediate Input

	Very High (% Land)	High (% Land)	Good (% Land)	Medium (% Land)	Moderate (% Land)	Marginal (% Land)	Very Marginal (% Land)	Not Suitable (% Land)
Baseline (1960-1990)	0.3	1.7	7	16.9	15.4	8.9	6	43.8
CCCma	0.3	2	7.7	16.1	18	8.2	5.5	45.9
Csiro	0.3	1.3	5	14.6	15	8.5	6	49.2
Echam	0.3	1.9	7.2	17.7	21.2	14	4.3	33.2
Soybean Production: 2050 Intermediate Input								
Baseline (1960-1990)	0.3	1.7	7	16.9	15.4	8.9	6	43.8
Cccma	0.2	1.8	6.9	13.2	12.9	7.6	7.4	49.8
Csiro	0.3	1.1	4.4	13.4	15.1	8.2	7.1	50.3
Echam	0.3	2	7.5	17.4	22.7	17.2	4	28.7
soybean production: 2080 Intermediate Input								
Baseline (1960-1990)	0.3	1.7	7	16.9	15.4	8.9	6	43.8
Cccma	0.1	0.8	3.2	8.9	14.6	10.1	8.1	54
Csiro	0.2	0.8	3	10.4	14.1	7.7	7.1	56.6
Echam	0.3	1.7	6.9	16.6	22.5	16.9	3.7	323

Table 4.58: Changes in the area used for the production of Sunflower under various time frames and input levels.

Sunflower Production: 2020 Intermediate Input

	Very High (% Land)	High (% Land)	Good (% Land)	Medium (% Land)	Moderate (% Land)	Marginal (% Land)	Very Marginal (% Land)	Not Suitable (% Land)
Baseline	0.4	2.1	8	17.3	16.1	8.2	5.8	42
CCCMA	0.3	2.3	8	16.5	14.8	8.9	5.7	43.4
CSIRO	0.3	1.6	6.1	15.2	16.7	8.7	6.2	45.1
ECHAM	0.3	2.3	8.3	17.5	19.9	12	4.4	35.2
Sunflower Production: 2050 Intermediate Input								
Baseline	0.4	2.1	8	17.3	16.1	8.2	5.8	42
CCCMA	0.2	1.9	6.6	12.1	12.9	9	7.4	49.8
CSIRO	0.3	1.2	4.6	12.5	15.6	10.2	7.1	48.5
ECHAM	0.3	1.8	7.2	13.1	14.9	13.5	5.2	44
Sunflower Production: 2080 Intermediate Input								
Baseline	0.4	2.1	8	17.3	16.1	8.2	5.8	42
CCCMA	0.2	0.6	3.6	3.6	7.6	9.8	8.9	60
CSIRO	0.2	0.9	3.4	8.8	11.8	9.6	7.2	57.8
ECHAM	0.3	1.3	4.7	9.2	13.2	13.9	6.1	51

Table 4.59: Changes in the area used for the production of groundnut under various time frames and input levels.

Groundnut Production: 2020 Low Input								
Model	**Very High (% Land)**	**High (% Land)**	**Good (% Land)**	**Medium (% Land)**	**Moderate (% Land)**	**Marginal (% Land)**	**VeryMarginal (% Land)**	**Not Suitable (% Land)**
Baseline	0.3	0.6	2.6	11.1	16.6	11.1	3.7	53.8
CCCMA	0	0.9	5.7	13.1	14.6	10	3.2	52.3
CSIRO	0	0.4	3.4	12.1	15.3	10.4	3.2	55
ECHAM	0	0.7	5	13.9	22.8	12.4	3.3	41.6
Groundnut Production: 2050 Low Input								
Baseline	0.3	0.6	2.6	11.1	16.6	11.1	3.7	53.8
CCCMA	0.3	0.9	5.6	11.5	14.1	10.4	3.5	53.7
CSIRO	0.1	0.6	3.7	12.9	16.5	12.1	3.5	50.3
ECHAM	0.1	0.9	5.5	15.5	27	15.2	4.1	31.6
Groundnut Production: 2080 Low Input								
BASELINE	0.3	0.6	2.6	11.1	16.6	11.1	3.7	53.8
CCCMA	0.3	0.6	2.6	11.1	16.6	11.1	3.7	53.8
CSIRO	0.3	0.6	2.8	12.4	16.7	9.4	3.7	53.8
ECHAM	0.3	1	5.2	16.6	27.7	14.6	4.8	29.5
Groundnut Production: 2020 Intermediate Input								
Model	**Very High (% Land)**	**High (% Land)**	**Good (% Land)**	**Medium (% Land)**	**Moderate (% Land)**	**Marginal (% Land)**	**VeryMarginal (% Land)**	**NotSuitable (% Land)**
Baseline	0	0.2	1.2	7	16.3	13.2	1.1	60.5
CCCMA	0	0.3	2.7	11.6	14.8	10.7	0.8	58.9
CSIRO	0	0.1	1.3	9.8	14	10.7	0.9	63.1
ECHAM	0	0.3	2.2	12.6	24.3	14.2	1.4	44.8
Groundnut Production: 2050 Intermediate Input								
Baseline	0	0.2	1.2	7	16.3	13.2	1.1	60.5
CCCMA	0	0.1	1.3	9.5	15.2	12.6	0.9	60.2
CSIRO	0	0.1	1.3	9.5	15.2	12.6	0.9	60.3
ECHAM	0	0.3	2.7	14.1	28.1	18.5	1.5	34.5
Groundnut Production: 2080 Intermediate Input								
Baseline	0	0.2	1.2	7	16.3	13.2	1.1	60.5
CCCMA	0	0.2	1.2	7	16.3	13.2	1.1	60.8
CSIRO	0.1	0.3	1.3	8.1	15.1	11.3	1.1	62.6
ECHAM	0	0.5	2.6	15.2	28.3	17.4	1.7	34.1

4.4.7 Decision Support Systems for adaptation and continual crop production in the face of climate change

Table 4.60 shows the results of the screening process which guided the formulation of various scenarios for possible production management in the face of a changing climate. Due to the emergent nature of the climate change issue, there is largely an absence of critical data gathered for South Africa to perform a classical cost-benefit analysis for most of the interventions included in this analysis. Hence the analysis is largely reliant on secondary sources of information. It is also important to highlight that due to lack of quantitative and numerical information, for some of the proposed interventions, strong non-quantitative arguments had to be used to show the perceived benefits as in literature and reports reviewed. From the literature, scenarios which can be used to improve yield and at the same time contribute to mitigations were analysed. The methods chosen for decision support are guided by cost effectiveness and the sustainability and profitability of each method of production. The results of the scenarios are looked in terms of cost benefits of using no-till soil tillage as against minimum and conventional tillage at the farm level as well as climate-smart agricultural practices.

Table 4:60: Results from the screening process for a decision support system for future crop production

Agriculture Activities/Production Stage	Mitigation Options	Adaptation Options
Land Preparation	- Minimum use of heavy machinery for land preparation	- Zero (0%) tillage - Conservation Tillage (30%) tillage - (can reduce greenhouse gases considerably while raising carbon levels in the soil increasing fertility and productivity)
Planting	- Minimum use of heavy planting equipment that is tractor drawn.	- Use of a no-till planter (causes minimum disturbance of the soil) - planting by hand using hand-held implements e.g. hoes
Irrigation	- Switching from fossil fuel-based energy for irrigation pumping to renewable energy e.g. solar panels - Use of biofuels - Use of drought-resistant crop cultivars or varieties	- Use water use efficient technologies such as drip irrigation and low-pressure pipes (saves energy, reduces water loss and avoids over-irrigation) - Use of renewable energy e.g. solar and wind energy for pumping
Fertilization	- Reduce or limit the use of synthetic fertilisers especially nitrogen-based fertilisers	- Use of crop residue left on the field after harvest - Use of natural green/organic fertilisers - Crop rotation with leguminous crops
Weeding	- Reduce use of tractor-drawn weeding implements	- Substitute tractor-drawn mechanical weeding with use of herbicides - Weeding by hand (manual labour) - Crop rotation- Rotate between crops that are planted in different seasons - Plant leguminous cover crops
Pest and disease control and management	- Reduce 100% use of synthetic pesticides and fungicides - Use of pest and diseases tolerant or resistant cultivars or varieties	- Use of integrated pest management - use of biological control - using predators and parasitoids of eggs, larvae and pupae, parasites of eggs and larvae, and caterpillar diseases - Crop rotation - Maintain farm hygiene

4.4.8 Cost-benefit analysis for Zero tillage option at Land Preparation.

At the level of land preparation, the identified options are zero (0%) tillage and conservation tillage (30%). At this stage of the aim is to promote minimum use of heavy machinery for land preparation, which can reduce greenhouse gases considerably while raising carbon levels in the soil thereby increasing fertility and productivity.

4.4.8.1 The economic case for Zero tillage option

Reduced costs of production per unit area: A lower costs of production per unit area is associated with zero tillage as against conventional tillage or conservation tillage. This is because zero tillage implies no machinery usage in land preparation hence land is not disturbed through the utilization of tractor/drought power, precision implements such as no-till planters or manual digging implements. Assuming that land clearing is not included, zero tillage, therefore, implies zero costs of land preparation, which can translate, to more than 10% reduction in costs per hectare of production thereby increasing the profitability of any agricultural enterprise.

The lower cost of production per unit area also stems from reduced maintenance costs for equipment which could have been used during land preparation. With no-till farming, the farmer only has to go over the field once to establish the crop/plant, not three to five times, which drastically reduces fuel and labour costs. Furthermore, with less equipment needed, there is less wear and tear on machinery, which directly translates to lower costs of production. In no-till production, fuel, and labour-efficiently used than in a conventional tillage production. For example, to produce a 7,5 t/ha average yield of no-till maize, 2,8l diesel/t, and 12 minutes labour per ton is needed in comparison to a 6,9t/ ha average yield of conventional tillage maize which requires 6,7l diesel/t and 19 minutes labour per ton.

Good and often higher Crop Yields/productivity: Yield output from no-till farming should at the minimum, equal or exceed those of conventional tillage, particularly if the right equipment is utilized. For example, FAO indicates that the 4-year average maize yield for no-till can be up to 41% higher than that from conventional till and average soybean yields can be 20% higher under no-till during the 4-year. In addition, FAO highlights that the emergence of soybean seedlings was better under no-till than conventional till.

4.4.8.2 Strategic case for zero tillage option

Positive impacts on carbon emissions: zero tillage can lead to 0% carbon release during land preparation as against 100% carbon release from the soil due to disking. In addition, practicing zero tillage can reduce fossil fuel emissions from machinery operation by more than 2.2 Mg CO_2ha^{-1}.

Less Soil Compaction: Multiple passes over a field with heavy farming equipment compacts the soil in the case of conventional tillage as against no-till planting. In addition, bare soil can easily become compacted by rainfall. Tillage also breaks up the soil structure (soil aggregates), which makes it more susceptible to compaction. On the other hand, ground that' is not tilled is less compacted – before, during, and after the planting process.

Less Soil Erosion: In no-till farming, because the soil is not turned over, less soil gets blown away and less soil is washed off. The vegetative cover that's left behind in no-till planting helps control the loss of topsoil on steep slopes from runoff and also helps prevent wind erosion.

Less Evaporation: Plant residues that are left behind in no-tillage also capture water, help keep the soil moist, and minimize the evaporative effects of the wind and sun. Whether dryland (rain-fed) or irrigation, this "water-saving" effect of no-till farming has considerable importance.

More Fertile Soils: Because the soil is not constantly being stirred with tillage, phosphorus(P) fertilizers remain effective for longer (many years). The more soil the P fertilizers are exposed to, the more they react chemically with the soil particles and become bound or fixed into forms that aren't available to the plant. not

Besides the strategic advantages of zero tillage, there are some aspects with significant potential negative ramifications of the practice which include:

Gullies formation: as a result of the field not continually being smoothed with tillage. This can hide how much erosion is really occurring and which can potentially get deeper by the year. However, this can be solved by using underground tile lines, cover crops, and grass waterways to intercept and carry this runoff from the field. Maintaining high amounts of mulch cover also reduces runoff and the tendency to form rills or gullies. Low-pressure radial tires, tracks, and changing up the traffic patterns across the field also reduce the tendency for gullies to form.

Potential increased in Chemical usage: While no-till farming can actually help curb fast-growing weeds, most types of no-till farming still require the use of herbicides. Some studies show that under no-till the costs of weed control are R219 /ha (R1 077 /ha) compared to conventional tillage (R858 /ha). However, by leaving weed seeds on top of the soil surface where they are prone to be eaten by insects, birds, and mice, or rot, can help keep weeds in check and reduce the use of herbicides.

4.4.8.3 The financial case for zero tillage option

The benefits of zero tillage have been shown to outweigh the costs of production. However, the initial investment in no-till equipment and replacement parts can be one of the major deterrents to switching from conventional tilling to no-till farming practices. This, the cost can in future be recouped through higher crop yields, labour savings and the non-utilization of no-till machinery. It has been shown that the overall machinery costs for no-till are +R638/ha less, with a fuel cost difference of +R298/ha, depreciation, and repair cost difference of +R332/ha and an operator cost difference of +R8/ha compared to conventional tillage. Based on all of the production costs in the trials against the net profits, the Return to Investment (ROI) for the no-till maize was 32%, in comparison with the 19% ROI for the conventional tillage maize.

4.4.8.4 Commercial case for zero tillage option

No-till equipments are readily available in most places in South Africa. It should be noted that the total machinery overhead for no-till is not any more than that used in conventional in a tillage regime.

4.4.8.5 Management case for zero tillage option

Learning Curve for No-till Planting: farmers can be hesitant in learning the new techniques of no-till farming, preferring to stick with conventional tillage. But there are numerous resources and products being developed which can assist farmers to make the transition from conventional to no-till practices. With increased and more efficient farmer advisory, there is huge potential for widespread adoption of zero tillage.

4.4.9 Cost-benefit analysis for conservation tillage (30%) option at land preparation

A well-accepted operational definition of Conservation Tillage (CT) is tillage and planting combination that retains a 30% or greater cover of crop residue on the soil surface. Generally, there are four main types of CT: mulch tillage, ridge tillage, zone tillage, and no-tillage. A main variant of the latter is direct drilling (sometimes termed zero-tillage which has been treated separately in the preceding section), while other variants of CT are reduced tillage and minimum tillage. Conservation tillage, a crop production system involving the management of surface residues, prevents degradative processes, restores, and improves soil productivity. Major advantages of CT are given for the following scenarios:

4.4.9.1 Economic case for conservation tillage (30%) option

Reduced Costs of production per unit area: CT practices leads to lower cost of production per unit area compared to conventional tillage. The application of CT technology (30%) implies more than a 70% reduction in the cost of land preparation. This could translate to a significant reduction in the total production cost.

Good and often higher Crop Yields/productivity: Crop yields with CT 30% farming should at the minimum equal or exceed those of conventional tillage, particularly if the right equipment is applied. For example, Agri-Tech has seen both yield and net return advantages from strip-till. Comparisons of conventional tillage (fall chisel followed by spring disking), no-till, fall strip-till with fall-with applications of anhydrous ammonia (N) and fall strip-till with spring-applied 28% N. The strip-till with spring-applied N posted the highest yield at 11.1t/ha and highest net return at ZAR3830/ha. No-till came in second at a yield of 10.1/ha and net return of ZAR2908/ha. Conventional tillage was third with 9.88t/ha and an R2553 /ha net return.

4.4.9.2 Strategic case for conservation tillage (30%) option

Positive impacts on carbon emissions: In comparison to conventional ploughing practices such as disking and ridging that can lead up to 100% carbon release from the soil, CT can lead to 70% reduction in emissions from fuel use and up to 70% reduction in GHG emissions from soil disturbance. Furthermore, CT can reduce fossil fuel emissions from machinery operation by more than 39.48 kg CO2e ha^{-1}. CT tillage systems have been shown to have no soil crusting, earthworms abounding, improved aggregation of soil particles, increased humus content, no compaction, improved soil tilth, retention of moisture and vastly improved fertility with a high build-up of diverse good soil bacteria and mycorrhiza. The soil system thus created can provide the crop planted with nutrients over the whole season and produce highly profitable crops. Because the soil is not constantly being stirred with tillage, phosphorus fertilizers remain effective for longer periods over farming seasons unlike in the conventional systems.

Strategic benefits of CT No-Till Systems: Strip tillage encourages more favourable soil temperature, moisture and aeration conditions for germinating seeds and seedling plants. This can translate to improved crop establishment and early season performance. Strip-till also offers the opportunity to place fertilizers directly into the root zone, away from crop residues that could otherwise intercept or immobilize nutrients.

Strategic benefits of CT Over Conventional Tillage Systems: Strip-till can provide conservation and efficiency benefits over conventional tillage practices. By leaving the inter-row untilled, crop residues are retained on the soil surface providing increased erosion resistance and organic inputs.

Less Evaporation: The 70% plant residues that are left behind in no-tillage also capture water, help keep the soil moist, and minimize the evaporative effects of the wind and sun. Whether dryland (rain-fed) or irrigation, this “water-saving” effect of CT farming has considerable importance.

However, besides these positive strategic advantages of CT, potential increased chemical use could happen. While CT can actually help curb fast-growing weeds, most types of CT farming still require the use of herbicides.

4.4.9.3 The financial case for CT tillage option

A three-year trial compared strip-till, no-till, conventional tillage (disk ripper in the fall; one field cultivator pass in the spring) and spring conventional tillage (one field cultivator pass). Overall, strip-till tended to have both the highest average maize yields and highest average net profit (Profit was calculated for a three-year maize/soybean/corn rotation.). A three-year rotation of fall strip-till corn/no-till, narrow-row soybeans/fall strip-till maize averaged 9.8t/ha in maize yield. It garnered about ZAR4008/ha annual profit. The next most profitable system was continuous no-till, at about ZAR3960/ha. Average no-till maize yield was 9.38t/ha. The least profitable system was fall conventional tillage for maize and conventional-till, narrow-row soybeans, at ZAR3301/ha. Average corn yield was 9.1t/ha.

4.4.9.4 Commercial case for CT tillage option

The initial cost of switching from conventional to CT practices are usually high which can act as a deterrent. However, this cost is quickly recovered from increased yields, lower labour and machinery cost, as well as fuel consumption.

4.4.9.5 Management case for CT tillage option

The success of CT tillage is based on the creation of an environment where all the information required about the technology is provided to farmers through different ways that will make management decisions easier. When they adopted the technology themselves, then they experienced the technology and brought changes as per the need of their environment.

Table 4.61 shows a comparison between no-till, minimum-till and conventional tillage. It is shown that the labour and fuel costs decline as tillage is reduced, while the herbicide cost is typically expected to increase. However, from the analysis, it can be concluded that no-till requires less capital outlay, labour, and fuel than the other tillage systems because less equipment and operations are used. The time spent in land preparation and planting of the no-till crop is less than with the other tillage systems. The additional nitrogen and herbicide costs required for No-till resulted in a similar establishment cost to the Chisel Plough and Disc system. However, the benefits obtained from conserving soil, nutrients and soil moisture with No-till outweigh those of the conventional ploughing systems. The higher levels of soil moisture conserved with No-till can result in yield benefits of ≥ 2 t/ha in dry seasons.

Table 4.61: Comparison of benefits and cost of Conservation till (30%), Zero Tillage and conventional tillage.

Option	**Costs**	**Benefits**		
		Yields/ productivity/ profitability	Fossil Fuel Emissions	Carbon Release
Zero Tillage	• Zero Cost. • Practice implies farmer may incur a higher cost of weed control	Yields Can be 41% higher than conventional	• Zero emissions	Zero Carbon Release
Conservation Tillage (30%)	• 70% Reduction in land preparation costs • Practice implies farmer may incur a higher cost of weed control	Yields are at minimum equal or exceed those of conventional tillage	• Can reduce by more than 39.48 kg CO2e ha^{-1}	70% reduction in GHG emissions from soil disturbance
Conventional tillage (100%)	• 100% tillage costs	Yields/productivity Equal or less than Conservation till and zero tillage	Highest Fossil fuel emissions	100% carbon release from soil

4.4.10 Cost-Benefit Analysis of No-till interventions at planting

4.4.10.1 The economic case for no-till interventions at planting

Reduced costs of planting: the efficiency and higher work rate of direct drilling and strip tillage bring about the benefit of lower cost, in terms of both labour and machinery. The high level of accuracy brought by direct drilling and strip tillage means less soil damage and less wasted resources, resulting in lower costs. By using the quicker and more efficient systems of direct drilling and strip tillage the wear and tear of the more traditional plough-based and min-till crop establishment systems are minimized.

Quicker crop establishment: direct drilling makes it easier and quicker for crop establishment than traditional systems and methods because it combines the job of soil preparation with the distribution of seeds. This method ensures much root growth happens. When modern no-till planters are used, farmers not only benefit from the speed of the machinery but also its high level of accuracy when it comes to seed placement.

Good and often higher Crop Yields/productivity: crop yields under conservation farming should at the minimum equal or exceed those of conventional tillage, particularly if the right equipment is applied.

4.4.10.2 Strategic Case for no-till planting option

The efficiency of no-till planting not only benefits those that use them but also the environment due to their lower energy inputs and the fact that fewer resources are used (or wasted) in the process. No-till planting preserves the soil as best as possible. There are positive effects on the root and crop growth, and also promotes the ideal circumstances for the beneficial habitation of invertebrates and earthworms. With the system’s minimum soil disturbance as well as its accurate and consistent distribution of seeds, farmers benefit from enhanced root growth and development, with no problems of overcrowding or nutrients-shortage. The system also reduces the risk of issues such as capping, leaching and compacting which are common with more traditional designs. Combining its efficiency, its accuracy, and its money-saving ability-till planting/ direct drilling/strip tilling promotes stronger and happier crop—which is a very strong strategic case.

4.4.10.3 The financial case for no-till planting option

Advanced No-till seeders and planters often are much more expensive than conventional ones. Therefore, the investment in a no-till seeder or planter might create some obstacle for the transition process towards no-till planting. In many cases, the old conventional seed-drills or planters can be converted at low cost into no-till seeders or planters, either by the farmers themselves or by mechanical R19 workshops. However, the market also offers adapted Economy No-till Maize Planters that can be ox-drawn. These are much more affordable with a single unit costing 999 and set of six would, therefore, cost less than R120 000 which is much cheaper than the large, imported planters that does just about the same thing.

4.4.10.4 Commercial case for no-till planting option

Initial set up cost for CT can be recouped through higher crop yields, labour savings and selling off of old tillage equipment and downsizing tractors or eliminating extra tractors that are no longer needed. Basing on the analysis carried out by farmers weekly, the overall machinery costs for no-till are +R638/ha less, with a fuel cost difference of +R298/ha, depreciation and repair cost difference of +R332/ha and an operator cost difference of +R8/ha compared to conventional tillage. Based on all of the production costs in the trials against the net profits, the Return to Investment (ROI) for the no-till maize was 32%, in comparison with the 19% ROI for the conventional tillage maize.

4.4.10.5 Management case for no-till planting option

Most no-till planters on the market today work well under good soil and residue conditions. However, most will need some adjustments and even modifications when working in heavy residues, compacted or wet soils, on sod fields, or in other difficult situations.

4.4.10.6 Cost-benefit analysis for Precision planting option

In precision planting, single seeds, or a predetermined number of seeds, are placed at an equal predetermined distance within the row. This method is usually used for row crops like soybean, beans, groundnut, sunflower. The number of seeds per planting hole and the distance between each planting location is determined by seed plates, which have cells or chambers to meter the seed. Precision seeding has many advantages for the seeds and consequent yield for farmers.

4.4.10.7 The economic case for precision planting

Although seeding accuracy is not a substitute for proper land preparation and other crop management practices necessary to obtain a good yield, precision seeding simply allows the farmer to reduce cost and increase the reliability of his crop production. Some of the advantages of precision seeding are:

- Reduced seed costs, because the only seed that is needed is sown.
- Greater crop uniformity, because the seed is equally spaced. This often leads to uniform and high-quality produce, fewer harvests, and greater yield. Uniformity is particularly important when once-over harvest is practised.
- Improved yields of 20 to 50% because each plant has an optimum space for growth and development.
- More uniform planting depth and less scatter because seeds are dropped shorter distances.
- Reduced or eliminated thinning.

Precision seeding has some strict criteria which have to meet for the success of the practice as well as some aspects which can dither the productivity. Some of the aspects include:

- Seedbed preparation is critical.
- The seed must be more vigorous because each seed must emerge and does not have the benefit of many seedlings pushing upward to break soil.
- More management is required.
- Equipment (seeders) costs are increased.
- Equipment parts may not be readily available.

4.4.10.8 The strategic case for precision planting

It has been widely reported that precision seed drill on the soil surface has many benefits. It conserves soil moisture, moderate temperature, suppresses weeds, improves soil physicochemical properties and helps make the system sustainable.

4.4.10.9 Commercial case for precision planting

The introduction of new technology requires complex farm-management decisions, including the consideration of economic correlations (costs-yield-income). There are 6 types of precision seeders applicable across all crop ranges which can be imported into South

Africa namely, Belt type, Plate type, Vacuum-type, Spoon type, Pneumatic type, and Grooved cylinder type.

4.4.10.10 Management case for precision planting.

Precision farming technology should not be considered as only the latest plant production technology or only a new agro-management tool. It is achieved only when the results of electronics and IT equipment are realized in the variable rate treatments zone-by-zone. The advantages and disadvantages of this technology highly depend on the heterogeneity of soil, the knowledge and attitude of the manager and the staff. Before buying a precision seeder, evaluate all other aspects of crop production to ensure that they are being managed to the fullest. Precision seeding requires good seedbed preparation to provide a uniform environment for the seed to swell, germinate and emerge. Bed shaping is generally considered essential for precision seeding. Irrigation is also important because lack of moisture may stall or stop seedling emergence and reduce uniformity. Good, quality seed should be purchased. Precision seeding is no substitute for good, uniform germination. Weed and other pest management are more critical with precision seeding because crops are seeded at exact populations for maximum yields. Deviations from this population can result in reduced yields. Speed of planting will depend on the seeder, but the operation of a seeder above recommended speeds results in reduced uniformity, seed scatter, and poor stands.

4.9.4 Cost-benefit analysis of Natural green/organic fertilizers option

Organic fertilizers are fertilizers derived from animal matter, animal excreta (manure), human excreta, and vegetable matter (e.g. compost and crop residues). Naturally, occurring organic fertilizers include animal wastes from meat processing, peat, manure, slurry, and guano. In contrast, the majority of fertilizers used in commercial farming are extracted from minerals (e.g., phosphate rock) or produced industrially (e.g., ammonia). Organic agriculture, a system of farming, allows for certain fertilizers and amendments and disallows others.

4.9.4.1 The strategic case for Natural green/organic fertilizers option

Potential for integrating crop and livestock systems: Integration of crop, pasture, and livestock is mutually beneficial to each other since crop residues can be used as animal feed, while animal manure can be utilized to enhance soil tilth, fertility, and carbon sequestration that can enhance agricultural productivity. The combined system enhances soil biological activity and nutrient recycling, improves profits, increases crop yields, intensifies land use, prevents soil erosion, reduces poverty and malnutrition, and strengthens environmental sustainability.

4.10 Summary

This section presents the various results of the study. Presented results show the temporal and spatial variability of crops to climate change in Limpopo in particular and the summer rainfall areas in general. The next section deal with the discussions of the results and findings and answers the research objectives and hypothesis.

Chapter Five

Findings and Discussions

5.1 Introduction

As shown in previous chapters, this study examines the risk and vulnerability of dryland agriculture in relation to specific crops (sunflower, soybean, and groundnut) to projected climate and various adaptive responses in the summer rainfall areas of South Africa. In order to achieve the research objectives, the following assessments were carried out: Determine the risk of dryland crop production under projected future climate change scenarios; Model and map the vulnerability of selected dryland crops (sunflower, soybean, and groundnut) to climate change; Assess the response of selected crops (sunflower, soybean, and groundnut) in relation to their current production areas; Examine the vulnerability of smallholder farmers producing sunflower, soybean, and groundnut to a changing climate; Develop coping and adaptation strategies and recommend alternative production options; Develop a decision support system for production regimes under the changed climate. The decision support section examines the hazard occurrences, together with the physical (in relation to crops) and social characteristics (in relation to farmers engaged in the production of selected crops) to determine place vulnerability. The overall place vulnerability maps as shown in the previous section identify areas which are vulnerable to the future production of selected crops. The following sections address the research objectives.

5.2 The response of selected crops to their current production areas

Crop yield per area can be defined as the total amount of crop harvested per amount of land planted, is the most common indicator to measure agricultural productivity. Crop yields are affected by several factors amongst which are the weather, cost of production input, changes in farming practices, amounts of fertilizer used, quality of seed varieties, and use of irrigation. In assessing the response of sunflower, soybean, and groundnut crop production, a field experiment was carried out in Limpopo following three fertilizer treatments across three different agro-ecological zones of Limpopo. The results showed that the fertilizer treatment affected the variability in the yields achieved. It was however noticed that for N fertilizer for sunflower and P for soybean and groundnut, above the P 75 kg/ha and N30 kg the yield did not increase in relation to the amount of fertilizer applied. It, however, did affect the days to flowering as seen in Table 4.39. Given that similar management practices were employed in Ofcolaco, Syferkuil, and Punda Maria, the variation witnessed in yield output can be attributed to other factors such as soils and climate. In relation to soybean, there was a significant variation in the yield between Ofcolaco and Punda Maria (Table 4.44), and for groundnut between Syferkuil and Pu nda Maria (Table 4.46). Yield ranged from 1100 kg/ha to 2119.8 kg/ha for sunflower; 900 kg/ha to 2500 kg/ha for soybean and 1100kg to 1700 kg/ha for groundnut.

A comparison of recorded soybean yields by small scale farmers interviewed (Table 4.23) was 1600 kg/ha in the humid, 1800 kg/ha in the semi-arid and 1100 kg/ha in the arid as against 1100-1223.1kg/ha in Ofcolaco (Figure 4.41a) and 1000-2004.4 kg/ha in Syferkuil (Figure 4.41b).

Sunflower yields for the cropping season 2016/2017 (Table 4.22) by farmers in the humid (2370kg) semi-arid (980kg/ha) and arid (1200kg/ha) were different from those from the experiments in Ofcolaco and Syferkuil which registered 1100-1600kg/ha (Figure 4.42a) and 1000-1601.1kg/ha (Figure4.42b) respectively.

Groundnut yields recorded by farmers (Table 4.24) in Limpopo for the 2016/2017 season, showed that in the humid area, yield was measured at 2900kg/ha, semi-arid was 2300kg/ha and arid is 1690kg/ha as against those of the experiments in 2016/2017 season where yield for groundnut ranged from 2000-2200kg/ha in Ofcolaco (Figure 4.43a) and 1200-1500kg/ha in Syferkuil (Figure 4.43b).

The yields obtained from small scale farmers (Table 4.22 - 4.44) and field experiments when compared against the provincial yields in Limpopo (Table 4.22 – 4.44) showed that yields from farmers and field experiments were lower than the provincial as well as the ones from the field experiments were lower than those from the farmers. This can be as a result of economies of scale.

Similarly, spatial results of potential yields using different climate models and various input regimes show differences in potential future yields for the periods 2020,2050 and 2080, The presentation of such comparisons between the various production sites is believed to give a bird's eye view on whether or not the farming practices enhanced crop yield or the contribution of both climate and agronomic practices have brought the variation over the year of production. The results of such comparison are believed to serve as problem area indicators for place-specific climate and agronomic practices and for the concerned stakeholders to develop and implement corrective measures, so as continue sustainable farming practices. The variation in yield can also be as a result of using a one method fits all in the trial sites. Farming and agronomic practices should be place specific given that the impact of climate change is place-specific and are felt differently across sites. From the above discussion, the null hypothesis that sunflower, soybean, and groundnut respond to agronomic factors in their current production areas is accepted.

5.3 Assessing the risk of dryland crop production under climate change

In addition to its spatial component, place vulnerability also has a specific time component (Dow, 1992; Kienberger et al., 2013). Thus, a strong relationship exists with regards to the seasonal variations and changes associated with natural hazard occurrences and the elements at risk. There is a distinct seasonality to risk and exposure posed by droughts, floods, strong winds, severe frost and heavy rainfall to crops in South Africa. For instance, the highlands are at great risk from frost while the lowlands and river valleys are at great risk of flooding. As shown by results in section 4.2.10, the arid zone in Limpopo is the area affected by the incidence of frost and floods, hail and waterlogging as compared to the other areas. Attention is thus warranted, not only on "hot spots" but also on "hot-seasons" of extremes. Information on seasonal risk from different hazards is useful for risk management in agriculture, therefore it is acknowledged that the temporal characteristics of natural hazards shape the temporal scale at which vulnerability could be understood, and account for the role of the hazard in revealing, triggering or causing place vulnerability (Kienberger et al., 2013). A compounding issue impacting seasonal place vulnerability in the agricultural setting in Limpopo is the issue of 'wrong' hazard events that occur during the 'wrong' season. For instance, section 4.2.9 shows the issues of mid-season dry spells, higher than usual rainfall and the abrupt end of the season. The occurrence of the higher than normal rainfall during the farming season can lead to grain loss if such events took place during the flowering period for either soybean or groundnut. In the event of such occurrences, there is an element of societal unpreparedness, which consequently exacerbates the vulnerability of the farmers. A crop sensitivity index was calculated for the provinces producing sunflower, soybean, and groundnut. Section 4.6.2 presents the results which show that there were years where production was below the expected yield.

A look at crop yield and climate data for experimental sites Ofcolaco and Syferkuil for the cropping seasons 1998/1999 to 2002; 2000 to 2001, 2012-2013; 2015-2016 shows there was crop failure, which corresponds to the extreme climatic regime for the indicative years. This corresponds to crop failure for groundnuts in these time frames and for sunflower, the time frames were 1990 to 1995; 1998/1999, 2002/2003. Appendix 4.33 to 4.38 shows the extreme events during the time frames corresponding to crop failure. This, therefore, means sunflower, soybean, and groundnut responds differently to climate extremes as indicated by the crop failure index. The crop sensitivity index shows the vulnerability of the crop to a changing climate. Therefore, the null hypothesis which states dryland crop production of sunflower, soybean, and groundnut face risk from future climate change is accepted.

5.4 Modelling and mapping the vulnerability of selected crops

As seen in section 4.7, the distribution of sunflower, soybean, and groundnut vary over time and space. As the climate changes, so too do suitable bioclimatic ranges. Based on the changing distribution over space and time, the null hypothesis that summer rainfall areas may be vulnerable to future climatic change conditions is accepted. To emphasise this point, results from section 4.6.2 shows crop failure index across the provinces. Appendices 4.42 to 4.44 show the distribution of crops over time. The hypothesis that dryland crop production under projected future climate change scenarios face risk is accepted.

5.5 Examining the vulnerability of subsistence and smallholder farmers to a changing climate

The spatial distribution of various aspects of vulnerability differs across regions as shown in Section 4.5.3. The significance of geography has been emphasized in an analysis of disaster hotspots by Dilley et al. (2005); Peduzziet al. (2009). In the case of the summer rainfall areas, there are differences between the crops cultivated and areas of cultivation as well as in terms of accessing resources and services, demographic variations, economic conditions, literacy levels, all of which play a role in determining place vulnerability. The benefits of certain places, and environments, as well as their related physical features such as soils, climate, terrain supporting the livelihoods in certain areas, are in many ways associated to hazard (Turner Li, 2010; Preston, 2013; Maloney & Benjamin,2014; Absar, & Benjamin, 2015). Flat and fertile floodplains, for instance, have globally been attractive for human activities such as agriculture (Brémond et al., 2013). Additionally, there are also spatial variations of social vulnerability in the study region and in the South Africa summer region as a whole. The most vulnerable areas are associated with areas characterized by high percentages of poor households, the elderly and female-headed households dependent on farming. In addition, vulnerability is determined by historical, political, cultural and institutional and natural resource processes that shape the social and environmental conditions people find themselves existing within (IPCC, 2012) as seen in the following paragraphs.

5.5.1 Population dynamics affecting the vulnerability of farmers.

Social vulnerability is likely to change over time, depending on socioeconomic and infrastructural development efforts in the study region. For instance, introducing diverse livelihood options in the study area can reduce household vulnerability to natural hazards and poverty by increasing household income, while construction of roads and bridges in the rural areas can increase accessibility and facilitate economic activities. Thus, vulnerability is manifested in specific places at specific times (Adger, 2006).

The underlying crop vulnerability varies across the study region, with high crop vulnerability and social vulnerability levels emerging in the areas of the Northern Cape, Limpopo, North West. Results from the survey, Table 4.1 and Table 4.23 showed that in all the agro-ecological regions there was a higher percentage of women involved in agriculture relative to men. The survey results concur with other studies denoting that women dominate the agricultural sector (e.g. Dankelman, 2011; Teklewold, 2013). The dominance of woman participating in agricultural activities signifies that this farming population is vulnerable to the adversities of climate change as corraborated in studies such as Resurrección(2013); Twyman et al. (2014) . This is because the literature has shown that the effects of climate change affect men and women differently (e.g. Goh,2012; Rahman,2013; Kakota et al.,2011; Habtezion, 2013 cited in Chanana-Nag & Aggarwal, 2018; Mersha & Frank Van Laerhoven,2016). Women, children and the elderly are found to be the most vulnerable to climate change impacts, mainly because women play a crucial role in providing food security for their families (Cherotich *et al*., 2012; Arora-Jonsson, 2011; Alexander *et al.,* 2011). Also, women constitute the majority of the world’s poor and are more dependent on natural resources for their livelihood that is threatened by climate change (Dankelman, 2011; Teklewold, 2013; Wong,2014) and livelihood in most instances being agriculture. Furthermore, women face social, economic and political barriers that limit their coping capacity as cited by Ubisi (2016) because the social power and freedoms attributed to the men are higher than that attributed to women and in some cases their exposure to agriculture extension and training programs and resources which can have a positive influence on choosing appropriate coping mechanisms, are not always to them (Mehar, Mittal, & Prasad, 2016). For example, men can migrate as an adaptation method from drought-stricken areas, as they are more detached from family responsibility than women (Okali & Naess, 2013 cited in Amikuzuno, Kuwornu, & Osman,2019; Benhin, 2008).

Contrary to this view that a higher population of female involved in farming increases the vulnerability of the area, some studies (e.g. Bayard et al., 2007, Nhemachena & Hassan, 2007) are of the opinion that a higher female population in agricultural activities is good. They posit that gender is an important variable affecting adaptation decisions at the farm level. Even though female farmers are the most vulnerable to climate change and variability, according to Bayard et al., (2007) they are more likely to adapt to natural resource management and conservation practices. Nhemachena and Hassan (2007), goes on to say the possible reason for the female farmers to adapt is that in most rural smallholder farming communities, males are more often based in towns, and much of the agricultural work is done by a female. Consequently, female farmers have more farming experience and information on various management practices and how to change them, based on the available information (Anim, 2005). That notwithstanding, these aspects on their own does not guarantee the capacity of women to adapt in this area to climate change because adaptation is a component of both socio, economic and biophysical factors.

A further look at the population dynamics in regard to age distribution revealed that the most active age group in farming were elderly respondents between the ages of 57- 66 followed by the ages 67-76 and 37-46 years. Given the labor-intensive nature of agriculture, it would have been thought that the more youthful population should be dominant in this sector. Consequently, it can be presumed that there is a risk in the total output of agricultural produce given that human labor efficiency is on the decline. This is because the predominant age group involved in the production is not as physically strong as the younger age group. Furthermore, there is the risk of agricultural knowledge disappearing with the old since they are the most involved in agriculture and as the older generation is the custodians of information.

The population dynamic of South Africa shows a youthful population. But unfortunately, these populations as shown by the distribution of farmers in the study area are not involved in agricultural activities. This leaves the sector with an ageing population which might not be open to new farming methods and technology. This aspect heightens the vulnerability of the farmers given that their reluctance to implement changes to their farming practices could place their livelihood at risk from climate change and create more food security issues.

5.5.2 Farm management and agronomic practices employed by farmers

Farmer’s decisions with regards to farm management and agronomics play a role in the overall vulnerability of the farming systems to a changing climate. Tillage practices, planting dates, choice of crops, water harvesting, fertilizer application, planting densities are some of the management decisions which affect yield output and plays a role in the vulnerability of agricultural production in the study area as seen in the following paragraphs.

5.5.2.1 Choice of tillage practices employed by farmers

As shown in section 4.2.3, conventional tillage is a common practice amongst the smallholder farmers in the study region in Limpopo, unlike their Free State counterparts (section 4.3.3.3). Unfortunately conventional tillage practices create hard panswhich impede soil infiltration and root penetration as well as causing accelerated oxidation of organic matter due to the frequent soil disturbance (Rockstrom et al., 2003; Johansen et al.,2012); delay seed emergence and compromise plant growth (Rockstrom & Falkenmark, 2010); reduction in soil particle infiltration and the resultant slow water infiltration (Johansen et al., 2012); reduced porosity and increased surface runoff (Wani et al, 2009); reduced water holding capacity (Johansen et al., 2012) and aeration. As documented, this practice causes more harm than good and studies such that of Pittelkow et al. (2010); has linked yield decline to conventional tillage. In the sampled areas of Limpopo, 71% of the farmers were observed to practice conventional tillage. In accordance with the literature (Okai, 1997 cited in Asuming-Brempong,2010), this percentage of farmers are not producing optimally due to the choice of tillage practices. The continual use of conventional practices can only lead to decreasing fertility and increases the vulnerability of the soils to climatic impacts and consequent yield reductions (Kosgei,2007; Pittelkow et al.,2010) as well as the disturbance of the storage of soil carbon (e.g Dikgwatlhe et al., 2014, Chen et al.,2015;).

5.5.2.2 Farmers decisions on fertilizer application

With regards to fertilizer application (type, rate, and timing) section 4.2.3 showed that most farmers used organic sources of fertilization in Limpopo rather than the mineral fertilizers used by their Free State counterparts. The choice of fertilizers can affect the total yield output. This is because the supply of nutrients from the application of mineral fertilizers on conventional farms is easily available to the crop needs than when some organic forms of fertilizers are used. For example, the nitrogen (N) released from applied organic materials or incorporated residues may not necessarily translate into crop uptake because of the management and environment interactions (e.g. Chen et al.,2014). The disparity between N availability and supply may in the short and the long-term lead to yield losses, inadequate grain quality, and the loss of N from the system through leaching (Stopes et al., 2002) or emissions (Brozyna et al., 2013). The literature on the effect of residue management on nitrogen (N) or phosphorus (P) uptake by plant is equally dispersed with no effects for nitrogen Brennan et al. (2014); positive effect of N in Malhi et al., (2011) positive for P in Noack et al. 2014) or negative for N (Soon & Lupwayi, 2012) and for P (Damon et al., 2014). These differences are generally attributed to differences in soil texture and/or initial nutrient status or residue quality (Chen et al., 2014). Hence knowledge of these factors will enhance the effective choice and application of fertilizers by farmers.

5.5.2.3 Farmers knowledge of crop variety

The choice of crop variety should be influenced by various factors prevailing in a specific farming system. It was noted that farmers in the sampled localities selected their groundnuts and soybean variety based on the availability and familiarity of the seed. Hence most of them farmers in Limpopo (about 68.6 % - groundnut, 90% -soybean and 75% sunflower) could not remember the names of the cultivar they had planted. Furthermore, they didn’t have any idea of the specific characteristics of the cultivar which could have played a role in influencing their choice. Lack of information about the particular variety of crops planted could increase the vulnerability of the farmer to the changing climate. For crops such as maize and soybean, they could identify some of the cultivar traits and names. The Department of Agriculture publishes production guides which indicate what types of crop cultivars are suitable for which specific area. If a farmer plants a type of cultivar which is not suitable for Limpopo, the farmer might end up with no yield or poor yield. Switching from one crop variety to another in response to climatic stresses and changes will help farmers to improve yield.

5.5.2.4 Farmers decisions on cropping pattern

The farmers generally planted the same type of crops every year on the same piece of land. This was the case especially with the smallholder farmers who were in the processes of emerging to commercial farmers. It has been shown that year in and year out, the cultivation of certain crops such as soybean leads to a decline in certain soil nutrients. For the cropping season 2014-2017, 100% of the farmers who cultivated groundnuts, soybean, and sunflower did so, on the same piece of land. Without remedial actions in place, such practices will lead to declining soil nutrients and consequently will have an effect on the quantity and quality of the yield. According to Lin (2011), crop diversification can improve resilience by engendering a greater ability to suppress pest outbreaks and dampen pathogen transmission, which may worsen under future climate scenarios, as well as by buffering crop production from the effects of greater climate variability and extreme events.

5.5.2.5 Farmer's decision on planting density

With regards to planting density and row spacing, 90% of the farmers in Limpopo used random planting for groundnuts, 40% for soybeans and 30% for sunflower. Even though they spaced the seeds, it was not done following the planting guidelines or a regular pattern. Not following planting guidelines could lead to overcrowding or sub-optimum plant populations.

5.5.2.6 Weed management

Weed-crop competition caused by inefficient weed control can affect biomass and total yield. Weed management challenges in the smallholder farming sector have been reported as one of the major causes of low grain yields in southern Africa (Shrestha et al., 2002). This is because weeds are more efficient in competing with crops for nutrients, water, and space, and harbor pest and diseases that all have negative effects on yields obtained (Shrestha et al., 2002). In Limpopo (section 4.2.4.9) 75% of the farmers practised weed control on their farms and the rest (25%) do not bother about weeding. As to the degree of effectiveness of weed control, 31% of the farmers had very effective weeding results while 66.75% say their methods are somewhat effective and 2.25% not effective at all. This degree of effectiveness could be attributed to the number of times the farmers weeded their farms. For example, Table 4.9 shows the number of times farmers who planted groundnut, soybean and sunflower weeded their farms. The majority of them weeded their farms once. The number of times the farmers weeded could be associated with the type of weeding method employed. It was seen that 60% of the farmers used only hand hoes, while 20% used tractors, 11% used herbicides, 5% used herbicides and hand hoes, 4% used both tractors and hand hoes. The methods employed were either labour intensive as seen by their preference for hand hoes or had cost implications which some of the farmers were not willing to bear more than once. The common practice of utilizing hand hoes often leads to reduced crop yields (Mashingaidze et al., 2012). This can be attributed to the fact that weeding with the hoe is labour intensive and given the age of most of the farmers, weeding is most likely undertaken once. This will lead to a situation of poor weed management and for weeds to be in direct competition with crops, leading to a decline in yield.

Appendix 4.45 shows the results of the factor analysis carried out to determine the most influential factors contributing to the decline in crop yields amongst the farmers in the study region. Factors included improper water management techniques, followed by poor rates of herbicide applications, no utilization of different crop varieties and poor fungicide application. Most of the contributing factors on the first loading were poor farm management practices. These factors accounted for 70.80% of the decline in crop yield.

5.5.3 Availability of institutional support to the farmers

Agricultural support from various levels of government has been shown to operate concurrently and sometimes share the responsibility between national and provincial governments as well as non-governmental institutions. This means that various institutions have programmes in agriculture gearing towards the support of farmers. For example, DAFF provides conditional grants for provinces to carry out national programmes. DAFF’s Programme 3: Food Security and Agrarian Reform has the provision of production inputs, such as seed and fertilizer, as one of its medium-term objectives to increase the number of households currently benefiting to 200,000 by March 2021; and ii) cultivate 360,000 ha of underutilized land in communal areas and land reform projects for food (National Treasury, 2018). Several programmes such as the Comprehensive Agricultural Support Programme (CASP) and Revitalization of small-scale Irrigation Schemes (RESIS) initiated by the South African government have the intentions to assist farmers through one type of support or another. Besides these production inputs support, DAFF sees extension services as an important unit that ‘coordinates information and advisory services needed and demanded by farmers' (DAFF, 2011). The effectiveness of extension services in supporting smallholder farmers should be seen in the context of mobilization of the social capital of communities (Ferris, Robbins, Best, Seville, Buxton, Shriver & Wei, 2014 as cited in Ncube,2017).

Section 4.2.15 and 4.3.15 show that most of the supports received are from DAFF. In spite of the various types of supports available, farmers receive mostly seeds from support systems.With more resources at their disposal, farmers can alter their management practices in response to changing climatic and other factors. This will enable them to make use of all the available information they might have on changing conditions, both climatic and other socioeconomic factors. For instance, with financial resources and access to markets, farmers can change their cropping calendar, chose appropriate cultivars, crop varieties, invest in new irrigation technologies, and other important inputs to suit prevailing and forecasted climatic conditions. Unfortunately, the farmers in the study area do not receive adequate support.

Section 4.2.17.1 shows the cost of producing soybean, groundnut, and sunflower. The summary table shows that the cost of production could be a lesser burden to the farmers if various stakeholder institutions could offset the cost of farm inputs such as fertilizers, seeds, herbicides, and pesticides. If that were to happen then the breakeven yield and selling price will be greatly reduced.

5.5.4 Monetary support and the ease of acquiring loans – accessibility to credit facilities

There is no consensus on the extent to which monetary support as well as financial service provision such as credit, can help farmers adapt to a changing climate. This may be caused by the difficulty in measuring the impact of credit on poverty reduction. However, it is generally accepted that monetary support and financial services may assist farmers either directly or indirectly thereby having a spill down effect to the challenges faced by farmers in a changing climate. Zeller and Sharma (1998) are of the opinion that credit facilities may assist smallholder farmers to tap financial resources beyond their own means thereby taking advantage of potentially profitable small business opportunities.

However, the difficulty of smallholder farmers worldwide to access credit diminishes their opportunities for investment in the long term and eventually their ability to compete and improve their livelihoods (World Bank, 2009) and adaptive capacity. The inability to get adequate financial support places significant constraints for these farmers in both the opportunities forgone and their inability to mitigate risk and adapt to climate change. With respect to how easy it was for the farmers in Limpopo and Free State to access finance are shown in 4.2.16 and 4.3.16. Results indicate that is not easy for farmers to gain access to credit facilities. Differential access to credit enhances the farmer's vulnerability to climate change given the fact that adaptation requires a significant up-front investment in resource and technology that may have to be leveraged with credit. Therefore, easy access to credit may offset the effects of climate and play a crucial role in making the difference between being vulnerable and not. Improved access to agricultural credit and savings may help those with limited access to invest in agricultural technology or land improvements, such as high-yielding seeds and chemical inputs that increase incomes. This opinion has been echoed by Asiedu and Fosu, (2008) who acknowledged credit as a very important component in the modernization of agricultural activities. Furthermore, credit is seen as the backbone of many businesses, especially in the agricultural sector, which has traditionally been a non-monetary activity for the rural population (Abedullah, et al.,2009). Hence agricultural credit should be an integral part of the process of the modernization of agriculture.

Results in this study concur with other studies which reported that smallholder farmers without off-farm income may find it difficult to borrow funds in the formal sector (Lugemwa & Darroch, 1995). Smallholder farmers thus must rely on informal credit markets where interest rates are higher. Furthermore, this constraint has proved to impede the farmers' ability to innovate (Griffin et al., 2001) and hence can be concluded that they will not be open to suggestions of adaptation. According to Kandlinkar and Risbey (2000), Khapayi and Celliers, (2016), most farmers in Africa operate under financial resource limitations, vis: lack of credit, subsidies, and insurance, and this will accelerate farmers' failure to meet transaction costs necessary to acquire adaptation measures resulting from unexpected weather patterns.

5.5.5 Income and livelihood of farmers

As indicated by the farmers in Limpopo, their principal livelihood was in agriculture. They carried out other activities to supplement household income. If the various institutions were to consistently assist farmers with inputs such as fertilizers and seeds, production cost will be reduced, and break-even yields will be reduced as well as seen in section 4.2.17.1.

A combination of the above factors will enhance the vulnerability of the farmers to climate change. A look at the vulnerability map in section 4.6.3 shows that areas of higher vulnerability have a lower adaptive capacity. For example, areas such as Limpopo, Northern Cape, Eastern Cape North West have a lower adaptive capacity than the Free State and KwaZulu Natal. Given the poor level of adaptive capacity in Limpopo, it is worth noting that the farmers have recognized priority areas which can assist them in the future to cope with climate change as seen in the following paragraphs.In view of the theory and characteristics that influence place vulnerability, it has been established that places with high levels of physical vulnerability sustain greater losses and damages, from the natural hazard (Papathoma-Kohle et al., 2011; Wang et al., 2013). Equally, natural hazards disproportionally affect communities and farming population with high levels of physical and social vulnerability because an increase in exposure (elements at risk) coupled with limited capability of the farmers in such areas to buffer the risk increase farmer’s vulnerability.

5.6 Developing coping and adaptation strategies with recommend alternative production options for subsistence and smallholder farmers

Analyzing vulnerability in agricultural production systems involve the identification of both the threat and resilience of the community to exploit opportunities and resist or recover from associated negative impacts (Khazai, 2013). Adaptive capacity is an important factor in characterizing vulnerability. Adaptive has been shown to be influenced by factors such as the availability, accessibility, and quality of resources, infrastructure, and services available to an area. Hence a farming community with high adaptive capacity will have low levels of social vulnerability to climate change and vice versa. Some of the indicators used to express the adaptive capacity include population age profile, annual household income, employment status of household head, the gender of head of households, access to basic services, tenure status, type of dwelling, HIV prevalence, % agriculture GDP and dominant crop areas.

According to literature (e.g. Gbetibouo et al., 2010), the adaptive capacity required to cope with climate change is assumed to be dependent on five livelihoods assets: financial, human, natural, physical and social capital assets. Proxy indicators of adaptive capacity used in the study as seen in section 4.2.13 and 4.3.10 show cover adaptation at farm levels in relation to biophysical parameters and sections 4.6.3 shows various indicators of adaptive capacity. The capacity to adapt to natural hazards is context-specific and differs from place to place. This notion is similar to that of IPCC (2014) which states that adaptation is highly context-specific, and no single approach for reducing risk is appropriate across all regions, sectors, and settings. Farmers can adapt to some changes, but there is a limit to what can be managed. In order to maintain high levels of food production and yield quality, it is necessary for farmers to access all the required inputs and all available support. As shown by other studies (e.g. Makhura, 2001, Mpandeli & Maponya, 2012), the majority of people residing in the Limpopo Province are poor and hence, do not have the needed capital to explore more costly adaptation options. These collaborate with results in section 4.5.3. However, in the face of a changing climate, farmers in the study area proposed a couple of changes which to them will bring about a change in their level of vulnerability. Such adaptation options were categorized in relation to on-farm management, new technologies, conservation agriculture, diversification on and beyond farm and different dating of farming practices as seen in 4.2.16 and 4.2.15.

5.5.6 Types and number of support available to farmers

It was established as shown in Appendix 27 that the more support the farmers in the AEZ of Limpopo received, the more yield they produced. This also aligns with the results in 4.2.17.1 which shows a drop in the breakeven yield and cost of production for the major crops produced in the study area. Hence where the farmers receive more support types, their cost of production will reduce thereby leaving them with more revenue to either increase the scale of production or try new adaptation techniques.

Vulnerability is determined by historical, political, cultural and institutional and natural resource processes that shape the social and environmental conditions people find themselves existing within (IPCC, 2012). The ‘starting point’ approach of vulnerability adopted in this study views vulnerability as a dynamic process, continually transforming with changing biophysical and social processes that shape local conditions and the ability of communities to cope with shocks (Abson et al., 2012). In the study region, extreme natural hazards such as drought, floods, severe frost, simply reveal the underlying vulnerabilities in the farming communities and concur with studies such as that of Gwimbi et al., 2012; Matarira et al., 2013 which shows that vulnerability is not caused by natural climate extremes alone, but by a combination of various forces acting within a particular place. Emerging from the current study is that socioeconomic conditions heighten the farmer's vulnerability and more attention should be paid to the development of human resources to be better placed to adapt to climate change. Even though vulnerability is place specific, in South Africa, some factors such as poverty, lack of government support and social networks often affect and exacerbate vulnerability levels regardless of the type of hazard or location.

Further examination of how changing local climatic conditions and human characteristics are influencing the pattern of the crop as well as social vulnerability taking place within the summer rainfall areas and their implications on future climate adaptation and development initiatives needs to be addressed. The following paragraph will deal with these aspects and further recommendations.

5.6 Developing a decision support system for production regimes under the changing climate.

For farmers to be able to overcome the inherent challenges brought on by a changing climate, crop production has to be carried out in a proactive manner with the aim of achieving high yield and low cost of production. By improving and eventualy re-configuring the crop production processes at farm levels, there can be a positive change in production efficiency as well as in the responsiveness of the production system to climate change. Due to the linkages between crop production and meteorological conditions, weather and climate variability must be considered within the framework of applications dedicated to decision-supporting crop production management. This is particularly indispensable in terms of requirements imposed on crop quality and sustainability.

In light of the above observations and in order to confront the challenges facing agricultural sector (e.g. floods, waterlogging, drought, hail, pest), operational research tools and techniques combined with simulation modelling are proving to be very amenable and efficient for crop supply chains management. Moreover, scenario analysis and system performance measurement enable the investigation and evaluation of agricultural production for an eventual enhancement or redesign if necessary. In addition, models are being used as decision support systems at the farm level to optimize resource management.

A Decision Support System (DSS) is very helpful in creating plausible scenarios about a crop’s response to environmental factors, management decision as well as in complying with governmental regulations. Furthermore, the ability to compare the probable outcomes of different decisions can help smallholder and subsistence farmers make more informed decisions about their production regimes which can go a long way in reducing risk in the face of future uncertainties. One of the major reasons to develop and to apply DSS in farm management is to increase profit and manage resources. Furthermore, such a decision should be taken with consideration of sustainability and mitigation for future crop production as well as combating climate change.

Several factors can guide the decision process. Following this line of thought, Waha et al. (2013) highlighted the importance of incorporating farmers past decision making such as the choice of crops, cropping systems, sowing dates, etc. in climate change impact studies so as to develop adaptation strategies which will be geared towards addressing gaps in on-farm management practices in order to alleviate climate-related risks and vulnerabilities. Climate change impact assessment on smallholder farmers, in this study, was carried out by assessing how the smallholder crop farming systems are affected by climate change and the suitability of crops to a changing climate based on survey and GIS as well as modelling the response of crops in terms of yield output to future climatic conditions. This information played a role in creating scenarios for decision support systems. Decision-support tools are essential to assist relevant stakeholders to prioritize appropriate strategic decisions to improve the resilience, adaptability, and efficiency of agriculture and rural livelihoods in the face of a changing climate (CGAIR, 2015b).

Looking at the adaptation options for future production suggested by farmers in Limpopo, the farmers opted with regards to farm management for crop residues to be fed to the livestock (Table 4.19) thereby suggesting a mixed system of crop-livestock farming. This is followed by applying fertilizers that breaks down and releases nutrients slowly. This might be in the case of floods or erosion, where the fertilizer applied will not all be washed away. With regards to new technologies, the majority of the farmers chose drought tolerant and fast-maturing cultivars to be the most important, followed by flood-tolerant cultivars and lastly changing farming tools.

With regards to conservation agriculture, 75% of the farmers chose ripper tillage production as the most important factors to be adopted in the face of climate, followed by a 20% who opted for applying residue as mulch to bare soil and lastly the 5% for the adoption of no-till production. This implied the farmers were willing to take on practices such as conservation agriculture, which in the long run will be beneficial to them.

On the aspect of diversification on and beyond the farm 30.79% farmers ranked shift from farming to non-farming activities as the most important, followed by 28.33% ranking intercrop with legumes, 21.63% ranked apply crop residue as a mulch to bare soil and 19.25% ranked intercrop with trees as the important adaptation options. On farming dates, all the farmers (100%) ranked it as the most important.

In the Free State, farmers suggestions showed that the important farm management practice to be prioritized will be to apply fertilizers that break down and release nutrients, followed by feeding crop residues to the livestock. The results showed that with regards to conservation agriculture, ripper tillage production is preferred by most farmers, followed by the application of residue as mulch to bare soil and lastly the adoption of no-till production. With respect to diversification on and beyond the farm, farmers preferred changing from crop production to livestock and dairy production, followed by intercrop with legumes, intercropping with trees and lastly changing to non-farming activities.

With regards to new technologies, farmers choose drought tolerant and fast-maturing cultivars to be the most important, followed by changing tools for farming and lastly flood-tolerant crops. On farming dates, all the farmers (100%) ranked it as the most important as well. With various recommended choices made by a farmer for future crop production, some of the recommendations we looked against results from the implementation of such practices.

5.6.1 Cost-benefit Analysis (CBA) as a decision support tool

This method as a decision-making tool assisted in the identification of solutions which were related to either policy options or options for an efficient allocation of scarce financial resources. This was carried out on assumptions which anticipated the expected outcomes of climate change adaptation interventions and policies. The application of Cost benefit analysis (CBA) was supplemented by specific analytical elements with the intention of properly considering impacts of climatic changes on the cultivation of sunflower, soybean, and groundnut by smallholder farmers in relation to related risks; uncertainty of climate scenarios; climate change adaptation policies; and long-term adaptation interventions and investments (UNDP, 2018; World Bank, 2014). A myriad of technological, institutional, and policy options for climate-smart interventions have varying environmental and economic impacts and costs. Therefore, identifying appropriate interventions requires trade-offs across all levels from farmers to sub-national and national policymakers and consideration by decision-makers on what is appropriate for each context (CGAIR, 2015b).

Targeting and prioritizing approaches included Climate Smart Agriculture (CSA) investments, with the objective to assist farmers and decision-makers to identify best-bet CSA investment portfolios that achieve gains in food security, farmers' resilience to climate change, and low-emissions development of the agriculture sector. CSA as an emerging mechanism for coherent and coordinated action has as objectives of climate change adaptation and mitigation to add to an already existing multi-objective decision-making process from agriculture and development sectors (GCIAR, 2015). Activities across CSA ultimately aim to help smallholder farmers, governments, manufacturer and other stakeholders sustainably increase productivity, build resilience to climate variability and change and mitigate climate change when possible (WRI, 2014). Establishing a successful CSA program will require the formulation of good means of measuring production, emissions and sustainability. Methods that can inform decision-makers about practices, technologies, and policies that can effectively enable adaptation of CSA initiation (GCIAR, 2015) are discussed below.

5.6.1.1 Crop rotation

The benefit of crop rotation in reducing production risk involves three distinct influences that were described by Helmers et al. (2001). Firstly, rotations, as opposed to monoculture cropping, may result in overall higher crop yields as well as reduced production costs. Secondly, rotation cropping is generally thought to reduce yield variability compared with monoculture practices. Thirdly, crop rotation involves diversification, with the theoretical advantage that low returns in a specific year for one crop are combined with a relatively high return for a different crop. Drought, however, is usually detrimental to all crops, often preventing this advantage from occurring. An obvious benefit of diversification is the reduction of risk through the inclusion of alternative crops with relatively low risk (Nel and Loubser, 2004). Higher yields associated with rotated crops will increase the per hectare cost of activities such as harvesting. On the other hand, weed and often pest control costs are less on rotated than monoculture crops, which will increase the net return. It is also known that nitrogen fertilization of grain crops can be reduced when grown in rotation with oil and protein-rich crops without affecting the yield. The savings on inputs most probably outweigh the extra costs of harvesting higher yields, which suggests that the net returns and risk for the rotation systems are conservative estimates (Nel and Loubser, 2004).

Other alternative cropping systems which can be adapted for the region which can be included in the model are: sunflower, soybean or groundnut -maize -sunflower, soybean or groundnut crop rotation, intercropping; agroforestry with recommended species such as Moringa, citrus and pigeon pea. The proposed methods have been shown to increase productivity and are sustainable. Hence the null hypothesis which states that the development of a decision support system for production regimes under the changing climate will enhance production is accepted.

5.7 Summary

This chapter explored various aspects of place vulnerability and addressed the research aims to guide this study, in reference to agronomic, socioeconomic and physical characteristics of farming communities and households that make them vulnerable to climate change. Synthesizing indicative variables on a local scale provides a detailed overview of place vulnerability as well as providing an in-depth analysis of place vulnerability on a small scale. Furthermore, this chapter presented the dynamics of place vulnerability in the summer rainfall areas, where such work has not previously been undertaken. Place vulnerability was examined for the study region as a whole and at the farm level. The research conclusions, contributions, and recommendations for future research are presented in the next chapter.

Chapter Six

Conclusion and Recommendations

6.1 Introduction

The conference of the Parties (COP7) in its seventh session looked at special circumstances of least developed and landlocked countries in relation to adopting measures to which addresses specific needs and concerns of these countries and to prepare and submit national adaptation action programmes (NAPAs). The objectives of the NAPAs involve the identification of communities and livelihoods most vulnerable to climate change. The issue of specific need for these countries and communities as covered in Article 4 clause 8 of the UNFCCC (UNFCCC, 2011) provides for parties to: …give full consideration to meet specific needs and concerns of developing country parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures, especially on [countries that are highly vulnerable to climate change including those] with fragile and mountainous eco-systems” as well as “land-locked and transit countries.”

South Africa’s commitment to the Paris Agreement on climate change will require collaboration between government and business to achieve its stated carbon reduction goals. There has been tremendous progress in South Africa in responding to the Paris Agreement on climate change that was the key output of the Conference of Parties (COP21) held in Paris in 2015. The commitment to the agreement by South Africa has resulted in the country now needing to achieve a 42% reduction of its carbon emissions over ‘business as usual’ by 2025.

South Africa submitted their Intended Nationally Determined Contributions (INDCs) on 25 September 2015. The commitment made is that South Africa’s emissions by 2025 and 2030 will be in a range of between 398 and 614 MT CO2e. Achieving this will require collaboration between the national government, local government, and business. South Africa’s response is guided by the objectives outlined in the National Climate Change Response White Paper (NCCRP) issued in 2011. The objectives that will guide the country include:

- To effectively manage inevitable climate change impacts through interventions that build and sustain South Africa’s social, economic and environmental resilience and emergency response capacity.
- To make a fair contribution to the global effort to stabilize greenhouse gas (GHG) concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system within a timeframe that enables economic, social and environmental development to proceed in a sustainable manner.

The strategy to deliver on these two objectives is contained in the INDCs. They also recognized the need to ensure that any strategy has to respond to the priorities in South Africa of eliminating poverty and inequality; creating decent employment which leads to sustainable economic development; improve basic education, health, and social welfare; and enable access to food, shelter and modern energy services.

The NCCRP is quite clear that any mitigation and/or adaptation activities need to consider the above four priorities in the implementation of various programmes and projects.

The adaptation goals include:

- Develop a National Adaptation Plan and begin operationalization as part of the NCCRP for the period through to 2030.
- Take into account climate considerations in national development, sub-national and sector policy frameworks through to 2030.
- Build the necessary institutional capacity for climate change response planning and implementation through to 2030.
- Develop an early warning, vulnerability, and adaptation monitoring system for key climate-vulnerable sectors and geographic areas through to 2030 and reporting of the National Adaptation Plan with rolling five-year implementation periods.
- Develop a vulnerability assessment and adaptation needs framework by 2020 to support a continuous presentation of adaptation needs.
- Communicate past investments in adaptation for education and awareness as well as for international recognition.

The mitigation goals include:

- The principle that the country will shift from a ‘deviation from business-as-normal’ commitment to a ‘peak, plateau and decline GHG emissions trajectory’.
- Time frames for the implementation of policy instruments under development that include a carbon tax, desired emission reduction outcomes (DEROs), company-level carbon budgets, as well as regulatory standards and controls for specifically identified GHG pollutants and emitters.
- The scope and coverage that will be economy-wide for all sectors and with a material focus on three GHGs: carbon dioxide, methane, and nitrous oxide. The major categories identified include energy; industrial processes and production (IPPU); waste; and AFOLU (agriculture, forestry, and other land use).
- Planning processes, assumptions and methodologies based on the national climate policy (NCCRP) and the National Development Plan (NDP) and will be given effect to through energy, industrial and other plans and legislation.
- Determining that the South African contribution is an ambitious and fair effort to carbon reduction with a focus on ensuring that it considers the national context.

Various South African agriculture policies since 1994 have been found to have three main focus areas in common: improving the competitiveness of commercial agriculture in a free market dispensation, improving participation by disadvantaged communities, and protecting the natural resource base (Drimie,2016).In lieu of this, the National Development Plan (NDP) of 2012 identifies agriculture as primarily an important economic activity and thus promotes greater investment in the agricultural and agro-processing sectors; areas of small, medium and micro-enterprise growth to create jobs and redress skewed ownership patterns; and fruit and vegetable production in order to better align the sector to nutritional intake guidelines. The NDP also pays attention to advances in ecological approaches to sustainable agriculture. This includes greater attention to soil quality, minimum tillage and other forms of conservation farming. Also, the National Food and Nutrition Strategic Plan (NFNSP) 2017-2022 has as its vision to provide optimal food security and enhanced nutritional status for all South Africans. Objective two of this plan focuses particularly on ‘Establishing inclusive local food value chains to support access to nutritious and affordable food'. The NFNSP places greater focus on raising the productivity of Smallholder Holder Producers as a way of increasing local access to nutritious foods.

Furthermore, policies such as the Agricultural Research Act (1990) made provision for the establishment of the Agricultural Research Act with the object of promoting agriculture and industry in order to contribute to the improvement of the quality of life of the people of the Republic through research.

The Agroforestry Strategy Framework for South Africa, March 2017 on its part has as its vision to achieve the integration and mainstreaming of agroforestry as an accepted land use that contributes to food security, improved livelihoods, and income generation while building resilient, climate-smart systems that sustain South Africa's natural resources. The principles include that of:

- Inclusiveness- agroforestry should consider not only farm-scale systems but also include agroforestry as part of the broader landscape to contribute to natural resource, forestry, and agricultural policy objectives.
- There is the recognition that agroforestry systems are area and climate specific – it is necessary to develop agroforestry systems that are locally relevant and must consider the biophysical and socio-economic context (including land tenure) on a case by case basis. Both urban and rural agroforestry systems must be supported .
- Agroforestry should contribute to food, energy and fibre sovereignty.
- Indigenous species that can be applied in agroforestry systems should be identified and developed.
- The strategy should focus on systems and supporting people, rather than buying inputs and should have a programmatic rather than project-based approach with on-going learning.

To achieve the vision of the strategy, three key strategic themes for agroforestry development hinge on (i) Policy: creating the enabling environment for agroforestry (ii) knowledge development: developing the science of agroforestry, demonstrating the benefits and developing the skills of agroforestry and (iii) implementation: adopting and integrating agroforestry into the landscape for social and economic benefit.

Recommendations:

- The role of the government besides the frameworks of laws and regulations is to make available the necessary financial support to research and development of adaptation measures. It is important that the government realizes the role that continious research plays in the realization the goals set out in the White Paper Act on Renewable Energy, which states that by 2013, South Africa should be generating 10 000 GWh of energy from renewable sources (Wilson et al., 2005). Realizing this and other benefits, biodiesel and biofuels should benefit from higher priority, of currently available renewable energy technologies, regarding policies and financing from the South African government. Furthermore, research into new cultivars and smart agricultural tools need to be enhanced.
- The South African government needs to realize the role it has to play to create a thriving and lasting agricultural industry in the country because agriculture as a major contributor to greenhouse gases can also be a major contributor to mitigation.
- Many agricultural practices and technologies already show proven benefits to farmers' productivity, resilience and food security. Indigenous knowledge provides the backbone of successful climate change adaptation in farming given the differences in agro-ecological zones and farming systems. Therefore, interventions need to be targeted in specific contexts.
- Decision support to match practices and technologies with agroecological zones should be a priority. Matching these aspects together is more likely to realize goals of food security, resilience and increased productivity in the face of climate change.
- Strong mechanisms for finance, capacity enhancement, and technology transfer are prerequisites for success. This can be done by engaging the farmers, especially the women in the design and management of new technologies and practices.
- The government needs to take a more solid stance in its designs and implementation of policies and commits to agriculture and agricultural research and extension. This is on the premise that both socio-economic policies put in place and as well as the institutional environment must be supportive of various agricultural research and extension services.

- The research institutions, Department of Agriculture, Rural Development and Land Reform as well as extension officers should form closer working relations so as to combine resources and be able to reach every needy farmer.
- Given the current poor reach of extension services in South Africa, better public-private partnerships should be developed and improve better coordination in such partnerships. Available public funding should be extended to include the expansion of pluralistic extension arrangements through contracting and developing joint programmes.
- The government needs to implement a coherent extension policy to advance a varied system of extension providers. Given the fact that climate change impacts are diverse, vulnerability is place specific and adaptation requirements are diverse, there are various benefits from having various providers. This will mean the delivery of advice, technology, and innovations as well as facilitating services will be available from varied sources. Such a strategy will require that new and appropriate mechanisms for financing and/or co-financing the needs of farmers are in existence. Also, most importantly, it will require putting in place adequate mechanisms which will enhance the quality of services provided by diverse institutions. To effectively pursue such a strategy, the government needs to better understand the nature of the existing support services in order to design policies which will be supportive of a pluralistic system. It is also necessary that the government conducts a survey which will help in creating an inventory of key players and stakeholders, what they provide, whom they provide to, assess the quality of the services they render before making a decision on the type of reform necessary.
- Various institutions as stated in the Department of Agriculture, Forestry and Fisheries Strategic Plan for Smallholder Support 2011-2014/15 should participate in the development and support of smallholder producers by the providing a series of linkages and technical support to them.
- The South African government needs to encourage the private sector to increase their participation in agricultural extension and agricultural research for development. This can be done through an increase in various awareness programmes in both the public and private sectors, of the significant benefits that can be derived from such collaborations.

- Moreover, the success in fulfiling the public-private sector partnerships potential in South Africa is dependent on the creation of new ways to break down barriers to support systems through which the farmers can benefit.

Conclusion

The initial objectives of this study were to assess the risk and vulnerability of smallholder farmers producing soybean, sunflower, and groundnut and to develop a decision support framework to enable them to adapt to future climatic conditions. There are many methods to calculate the relative competitiveness of an industry. This study followed a pragmatic approach by unpacking the basic interactions in the crop production not only from an empirical perspective but also from an institutional perspective where the general sentiments and interaction of role-players in the sector are taken into consideration. Through this approach, the real issues on the ground were captured and used to identify the critical drivers that have to be taken into consideration for the development of a turnaround strategy of the smallholder farmers. The focus of the adaptation strategy is to improve the sustainability of smallholder farmers production.

6.2 Contributions to knowledge by the study and areas of further research

The study has provided important information on vulnerability and adaptive capacity of dryland agriculture in Limpopo, Free State and the summer rainfall areas of South Africa, with yield evaluation and suitability mapping for soybean, sunflower and groundnut. The study has demonstrated the effectiveness of using the “hazard of place model” in which integrated assessment techniques were employed in assessing crop management and production, assessing climate variability, assessing risk and adaptation as well as mapping suitable areas for selected crop cultivation. These techniques are an improvement to the conventional methods of vulnerability assessments which look at either socioeconomic or biophysical aspects seperately. The use of crop simulation models allowed for the inclusion of other attributes of crop production and management specific to the study area which enhanced the accuracy and presentation of crop yield data, farm management techniques and crop suitability maps. The suitability maps for the cultivation of soybean, sunflower, and groundnut, under different farm input management, highlight very clearly, areas most suitable for the cultivation of these crops.

The study used various vulnerability assessment methods to assess the vulnerability of dryland crop production in terms of both social and biophysical aspects and in relation to specific crops. Results obtained helped in guiding recommended mitigation strategies which will aid the adaptation and sustainable production of crop in the summer rainfall areas of South Africa. In order to further assess the agricultural suitability status of the study area with regards to soybean, sunflower and groundnut, a crop suitability map was produced using inputs from GAEZ model. The study developed a Crop Sensitivity Index (CSI) to evaluate crop production across the years and to assess if production was productive or not. The results from this analysis provided further analyses which produced results that compared favorably with the calculations showing climate variability in the area. The adaptive capacity of farmers in the study area was calculated by adapting established scholarly methodology - indicator approach. Farmer adaptive capacity was investigated in terms of the support they were receiving from each agroecological region of Limpopo. This revealed critical gaps which should be bridged if farmers in the study area are to sufficiently adapt to the impacts of climate change. Similar studies in the literature such as that of Maponya and Mpandeli (2012), Maponya and Mpandeli (2013) were based on physical data for assessing agricultural vulnerability while Eluma, Modisea and Marr (2017), investigated the influence of extension officers to farmers adaptive capacity and production and Gbetibouo, Ringler and Hassan (2010) looked at the vulnerability of farmers.

This study, however, extensively assessed socioeconomic factors that largely serves as impediments for adaptive capacity for agricultural productivity and sustainability in the area and looked at what institutional policies exist as well as institutional support available to farmers in the area. The assessment of institutional support factors available to farmers in the areas provided evidence of poor support to farmers which if optimized can be used to enhance the agricultural potential and quality of adaptation conditions in the study area. Several issues which had to do with cultivation methods, farm practices, resources management, yield optimization and farm inputs application were brought to the fore and contributed immensely in arriving at the findings presented in this study that poor agronomic practices are contributing to declining yields apart from climate change. In addition, the analysis of climate extremes such as floods and droughts, climate variability, population growth and dynamics, and literacy rates provided a balanced and holistic view of the immediate and futuristic interrelationship between biophysical factors, socioeconomic factors and sustainable agricultural production in the study area. Above all, the utilization of GIS-enabled modelling with multiple biophysical and socioeconomic data are justified in the

FAO framework usually preferred in countries where scarcity of data is an issue with vulnerability assessments.

Drawing from the methodological approach of this study, the current and future agricultural potentials of the study area has been examined from the physical, economic and social dimensions of the environment. It is, therefore, clear that in assessing vulnerability of agriculture, the consideration of socioeconomic data adds value to the process of sensitivity, exposure and adaptive capacity of agricultural production, and the completeness of agricultural suitability and sustainability. In general, the methodological steps and the collective findings of this study presents important information on the Limpopo and the summer rainfall areas which would be beneficial to the scientific community and future research in the study area and beyond. It was highlighted in the study that support measures were presented as a “one size fits all’ which will not be of any use to areas where such supports are not solving any pressing vulnerability issue.

Areas of further research should focus on :

- The use of remote sensing and GIS as sources of input data for crop simulation models, trends of climatic variation and crop yield;
- The performance of various crop varieties under current and future scenarios of physical and socioeconomic conditions using crop simulation model and
- The long term effects of institutional supports in enhancing adaptation in the study area.

The findings of this study, which would be widely disseminated, would be useful to relevant policy makers, active players in government and local communities as a quality reference material in designing, planning, coordinating and implementing sustainable agricultural development activities and practices that would be owned by all stakeholders. Furthermore, results from this study has shown that the future production of oilseed crops which have attracted much attention as potential renewable sources of raw material for liquid fuel compatible are a possibility or alternative as other sources of income for small scale farmers. This study has, therefore, achieved its objectives.

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APPENDICES

Appendix 3.1: Field Experiment Layout and land preparation

Appendix 3.2 Questionnaire

As part of the study: **RISK AND VULNERABILITY ANALYSIS OF DRYLAND AGRICULTURE UNDER PROJECTED CLIMATE CHANGE: ADAPTIVE RESPONSE IN SOUTH AFRICAN SUMMER RAINFALL AREAS we** would like to invite you to complete the attached survey to inform our understanding of the vulnerability of farmers in Limpopo to climate change and variability. By participating, you will have the opportunity to provide important information about your experience as a farmer faced with the challenges of climate change and variability and will help us to give suggestions on adaptation measures. All the information you provide will be kept completely confidential. No reference will be made in written or oral materials that could link you to the study. In reports, the information you give us will be combined with what we get from everyone who participates in these interviews. Your participation in the interviews is completely voluntary.

Thank you for your participation!

SECTION A: BACKGROUND INFORMATION

A1. Age………………………………………………………

A2. Sex...

A3. Locality……………………………………………………

A4. Name of farm………………………………………………

A5. Size of Farm………………………………………………

SECTION B: AGRONOMIC PRACTICES AND CROP PRODUCTION

B1. How long have you been farming?...(in years)

B2. Which of the following crops do you grow?

Groundnuts	1	
Soybeans	2	
Sunflower	3	
Others	4	

B3. What tillage system do you use?

No-tillage	1	
Mulch tillage:	2	
Strip or zonal tillage:	3	
Ridge till:	4	
Reduced or minimum tillage:	5	
Hand digging of entire field	6	
Planting basins	7	
If other specify	8	

B4. What varieties of the following crops do you grow?

B4.1 Groundnuts	1	Akwa (254)	2	Anel (254)	3	Billy (254)	4	Mwenje (1137)	21	Unknown
	5	Nyanda (1173)	6	Phb 95Y40 R (411	7	Inkanyezi (959)	8	Phb 95Y41 R (411)		
	9	Phb 96B01 R (411	10	PAN 9212	11	Phb 95B53 R (411)	12	Kangwane Red(254)		
	13	Harts (254	14	Phb 95Y20 R (411)	15	JL 24 (959	16	Rambo (254)		
	17	Kwarts (254)	18	Sellie……Tufa (254)	19	SA Juweel (254)	20	OtherSpecify		
B4.2 Soybean:	1	SNK 500 (24)	2	Dundee (254)	3	Jimmy (254)	4	Kiaat (489)	21	Unknown
	5	Egret (254)	6	Mukwa (489	7	Sonop (150)	8	Stork (254		
	9	Maruti (305)	10	Dumela (305)	11	Mopanie (489)	12	Knap (150)		
	13	Tambotie (489	14	LS 678 (484) ……	15	LS 677 (484)	16	PAN 626 (1412)		
	17	PAN 809 (1412)	18	PAN 660 (1412)	19	PAN 1669 (1412	20	Other Specify		
B4.3 Sunflower	1		2	HV 3037 (254)	3	Sirena (1421)	4	AFG 271 (1)	21	Unknown
	5	Hysun 3.33 (1421)	6	AGSUN 4672 (254)	7	AFG 272 (1)	8	Hysun 346 (1421)		
	9	AGSUN 4683 (254)	10	AGSUN 5261 (1)	11	Hysun 3.34 (1421)	12	PAN 7034 (1412		
	13	AGSUN 5282 (1)	14	PAN 7001 (1412)	15	DK 4040 (80)	16	NK FERTI (809		
	17	ADAGIO CL (809	18	PAN 7031 (1412)	19	DKF 68-22 (80	20	Other Specify		

B5. During planting, are the row spacing random or non-random, if non-random what spacing?

B5.1 Row spacing for Groundnuts	**(1)** Random
B5.2 row spacing for soybeans	**(1) Random**
B5.3. Sunflower	**(1) Random**

B5.1.1 Spacing	(1) Length (cm)	**(2)** Breadth (cm)
b.5.2.1 Spacing	(1) Length (cm)	**(2)** Breadth (cm)
B5.3.1 Spacing	(1) Length (cm)	**(2)** Breadth (cm)

B6. When do/did you plant?

B6.1 Planting date for groundnut	**[1]** September	**[2]** October	**[3]** November	**[4] December**
B6.2 Planting date for soybeans	**[1]** September	**[2]** October	**[3]** November	**[4] December**
B6.3 Planting date for sunflower	**[1]** September	**[2]** October	**[3]** November	**[4] December**

B7. When do you apply fertilizer?

Fertiliser application	**[1]** Before planting	**[2]** Days after planting	**[4]** Flowering
B7.1 Groundnut			
B7.2 Soybean			
B7.3 Sunflower			

[5] Do not apply

B8. What types of fertilizer do you use, if any?

B8.1 Groundnut	**[1]** Nitrogen (N)	**[2]** Phosphate (P2O5)	**[3]** Potash (K2O)	**[4]** Ammonium Nitrate or Urea	**[5]** Compound D	**none**
B8.2 Soybeans	**[1] Nitrogen** (N)	**[2]** Phosphate (P2O5)	**[3]** Potash (K2O)	**[4]** Ammonium Nitrate or Urea		
B8.3 Sunflower	**[1]**	**[2]** Phosphate (P2O5)	**[3]** Potash (K2O)	**[4]** Ammonium Nitrate or Urea		

9. What is the rate of fertilizer application?

B9.1 Groundnut	**[1]** Nitrogen (N)	**[2]** Phosphate (P2O5)	**[3]** Potash (K2O)	**[4]** Ammonium Nitrate or Urea	**[5]** Compound D
B9.2 Soybeans	**[1] Nitrogen** (N)	**[2]** Phosphate (P2O5)	**[3]** Potash (K2O)	**[4]** Ammonium Nitrate or Urea	
B9.3 Sunflower	**[1]**	**[2]** Phosphate (P2O5)	**[3]** Potash (K2O)	**[4]** Ammonium Nitrate or Urea	

B10. What other means of fertilization do you employ?

B10.1 Groundnut	**[1]** Kraal manure		**[2]** compost	**[3]** Leaf litter	**[4]** Ash	**[5] Crop**	**[6] others**
B10.2 Soybeans	**[1]**		**[2]**	**[3]**			
B10.3 Sunflower	**[1]**		**[2]**	**[3]**			

11. What is the rate of fertilizer application?

B11.1 Groundnut	**[1]** Kraal manure	**[2]** compost	**[3]** Leaf litter	**[4]** Ash	**[5] Unknown**
B11.2 Soybeans	**[1]**	**[2]**	**[3]**		
B11.3 Sunflower	**[1]**	**[2]**	**[3]**		

B12. Do you apply herbicides, pesticides, fungicide?

	Yes [1]	**NO [2]**
12.1 Herbicide		
12.2 Pesticide		
12.3 fungicide		

B. 13 Do you control weeds on your farm? Yes [1]☐ No [2]☐

B. 13**.1. How effective is your weed control?**

Degree of effectiveness	[1] very effective	[2] somewhat effective	[3] not effective at all

B13. 2 How often do you weed the field from planting to harvesting?

crop	**[1]** Once	**[2]** twice	**[3] Thrice**
B13.2.1 Groundnut			
B13.2.2 Soybean			
B13.2.3 Sunflower			

14. What methods of weeding do you use?

Pesticide application	**[1]** chemical	**[2]** manual Hoe	**[3]** mechanical (tractor)
B14.1 Groundnut			
B14.2 Soybean			
B14.3 Sunflower			

B15. Do you use any water management techniques? Yes [1]☐ No [2]☐
B. 15.1 If Yes, which water management techniques do you use?

	[1] cover crops	**[2]** Contour ploughing	**[3]** Ridging	**[4]** Deep weeding	**[5]** Pot holding	**A [6]** mulching	**[7]** furrow Drainage	**[8] if** other Specify
B15.1.1 Groundnut								
B15.1.2 Soybean								
B15.1.3 Sunflower								

B16. Which crop production factors influence your investment decisions?

crops	**Factors**	**Constrain(A)**	**Non constrain(B)**
B16.1 Groundnut	**[1] Input availability**		
	[2] Labour		
	[3] Food security		
	[4] Draft power		
	[5] rainfall		
	[6] floods		
	[7] [Temperature		
	[8] water(irrigation)		
	[9] irrigation equipment		
	[10] Implements		
	[11] Cash		
B16.2 Soybean	**[1] Input availability**		
	[2] Labour		
	[3] Food security		
	[4] Draft power		
	[5] Rainfall		
	[6] Flood		
	[7] Temperature		
	[8] Water(irrigation)		

	[9] Irrigation equipment		
	[10] Implements		
	[11] Cash		
B16.3 Sunflower	**[1] Input availability**		
	[2] Labour		
	[3] Food security		
	[4] Draft power		
	[5] Rainfall		
	[6] flood		
	[7] Temperature		
	[8] Water (irrigation)		
	[9] Irrigation equipment		
	[10] Implements		
	[11] Cash		

B17. Which cropping decisions are influenced by climate?

	[1] Planting date	**[2]** Fertilizer application	**[3]** Choice of crop	**[4]** Deep weeding	**[5]** Variety to grow	**[6]** water	**[7] others**
B17.1 Groundnut							
B17.2 Soybean							
B17.3 Sunflower							

B18. Are there any deviations from usual agronomic practices, this year? Yes [1]☐ No [2]☐

B18.1 if yes, what were the deviations?

	[1] Increased range of crops	**[2]** Reduced range of crops	**[3]** More area planted	**[4]** Less area planted	**[5]** Different varieties	**[6]** Conservation tillage	**[7]** Fertilizer applied at planting	**[8] if** other Specify
B18.1.1 Ground nut								
B18.1.2 Soybean								
B18.1.3 Sunflower								
B 18.1.4								

B19. What are the reasons for deviations in B16 above apart from climatic factors?

	[1] Seed availability	**[2]** Fertilizer	**[3]** water	**[4] temperature**	**[5] if others specify**
B19.1 Groundnut					
B19.2 Soybean					
B19.3 Sunflower					

SECTION C: CONSTRAINTS ON AGRONOMIC PRACTICES AND CROP PRODUCTION CAUSED BY CLIMATE CHANGE AND VARIABILITY

C1. Have you noticed any changes in the general weather from the time you started farming? Yes [1]☐ No [2]☐

C**2**. If yes, how?

Short season length	1	
Low rainfall	2	
Mid-season dry spells	3	
Abrupt end of season	4	
Late rains	5	
High rainfall (Higher than normal)	6	

C3. Are these changes in the weather apparent from year to year? Yes [1]☐ No [2]☐

C4.If "yes", how has it affected you in the past farming season 2016/2017?

	[1] Increased range of crops	**[2]** Reduced range of crops	**[3]** More area planted	**[4]** Less area planted	**[5]** Different varieties	**[6]** Conservation tillage	**[7]** Fertilizer not applied at planting	**[8] if** other Specify
C4.1 Groundnut								
C4.2 Soybean								
C4.3 Sunflower								

C5. Do these changes in the weather impact your farming activities? Yes [1]☐ No [2]☐

C5.1. If yes, how so?

	[1] Planting date	**[2]** Fertilizer application	**[3]** Choice of crop	**[4]** Varieties to grow	**[5]** If other specify
C5.1.1 Groundnut					
C5.1.2 Soybean					
C5.1.3 Sunflower					

C6. Have these changes in activities change drastically since you started farming? Yes [1]☐ No [2]☐

C7. Changes in activities from year to year? Yes [1] ☐ No [2]☐

C8. Which climatic thresholds have affected you the most?

Floods	1	
Droughts	2	
Hail	3	
Water logging	4	
Snow	5	
Others (Name)	6	

SECTION D: COPING /ADAPTATION STRATEGIES TO CLIMATE VARIABILITY/ CHANGE

D1. Have you any ways to deal with the extreme event mentioned in C8 above? Yes [1]☐ No [2]☐

D2. If yes, have your method(s) of dealing with the above mentioned event involve changes in practices/strategies on the farm since you started farming? Yes [1]☐ No [2]☐

D3. If "yes", how and what are the methods

D4. Did you notice any changes due to the response method employed in (D3)? Yes [1]☐ No [2]☐

D5. If yes what were these changes?

D6. How do you manage changes in:

Short season length:

Low rainfall:

Mid-season dry spells:

Abrupt end of season:

Late rains:

High rainfall (Higher than normal):

Waterlogging:

D7. What other sources of income do you have?

Other commercial activities	1	
Employment	2	
Animal	3	
Pension	4	
Child grant	5	

D8. What is the size of your household?

D8.1. Gender	**M[1]**	**F[2]**
Total		

D8.2. Age (Years)	**0-15 [1]**	**16-26 [2]**	**27-37 [3]**	**38 -48 [4]**	**49-59 [5]**	**Above 60 [6]**

D.8.3. Marital Status	**Single [1]**	**Married [2]**	**Divorced [3]**	**Widowed.[4]**

D9. Are there any other members of your extended family dependent on you? Yes [1]☐ No [2]☐

D9.1 if yes how many__________

D10. What is the predominant livelihood of your community?

D11. What infrastructure and institutional arrangements are in place to support farmers?

institution	Monetary [1]	Seeds [2]	Machinery [3]	Educational support [4]	Others (Irrigation, fertilizers, animals) [5]
11.1 Agro finance					
11.2 Banks					
11.3 DAFF					
11.4 others					

D12. Are these institutions easily accessible? Yes [1]☐ No [2]☐

D13. How easy is it for you to get loans from financial institutions?

	[1] **Very easy**	**[2]** **Somewhat easy**	**[3]** **easy**	**[4]** **Not very easy**	**[5]** **Not easy at all**
Agro finance					
Banks					
Cooperatives					

D 14. According to you what are the most important changes best situated to maintain production of your crops in the face of climate change: Rank them in order of importance with 1 being the most important

Practices categories	**Description**	**code**	**Rank (1-5)**
D14.1 On-farm	Apply fertilizers according to fertilizer recommendations	[1]	

Management			
	Apply fertilizer that breaks down and releases nutrients slowly	[2]	
	Changing crop produced to another	[3]	
	Feed crop residues to livestock	[4]	
	Changing plant density	[5]	
D 14.2 **New technologies**	Adopt drought tolerant and fast maturing cultivars	[1]	
	Changing in tools used for faring	[2]	
D14.3 Conservation agriculture	Adopt no-till production	[1]	
	Adopt Ripper tillage production	[2]	
	Apply crop residue as a mulch to bare soil	[3]	
D14.4 **Diversification on and beyond the Farm**	Intercrop with legumes	[1]	
	Intercrop crop with trees	[2]	
	Changing from crop production to livestock and dairy production	[3]	
	Shift from farming to non-farming activities	[4]	
Different dating of farm practices	Changing planting date	[1]	

SECTION E. REVENUE

E.1 Due to changes experienced in section B and C above, have you experienced any changes to

crop	**factor**	**Yes [1]**	**No [2]**	**Increase [1]**	**decrease [2]**
1.1 Groundnut	**Yield output**				
	Cost of production				
	Revenue				
E1.2 Soybean	**Yield output**				
	Cost of production				
	Revenue				
E1.3 Sunflower	**Yield output**				
	Cost of production				
	Revenue [				
E1.4 others	**Yield output**				
	Cost of production				
	Revenue [				

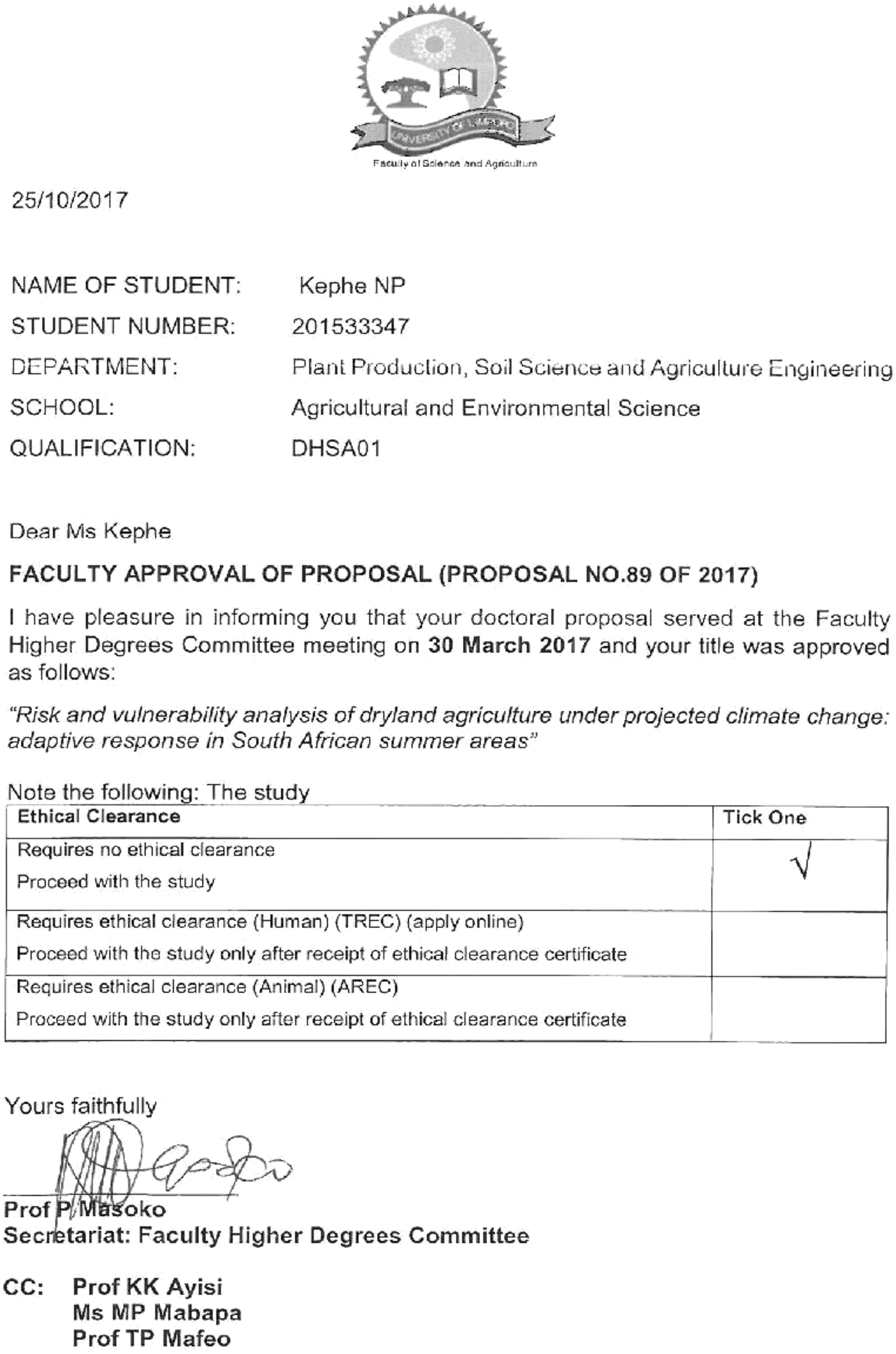
E2 what are the measured changes of these factors in the past three cropping season

crop	factor	2014/2015	2015/2016	2016/2017
E2.1 Groundnut	Yield output (t/ha)			
	Cost of production(R)			
	Revenue (R)			
E2.2 Soybean	Yield output (t/ha)			
	Cost of production (R)			
	Revenue (R)			
E2.3 Sunflower	Yield output (T/Ha)			
	Cost of production (R)			
	Revenue (R)			
others				

Farm management

Item		2015	2016	2017
Planting Date	Groundnut			
	Soybean			
	Sunflower			
Flowering Date	Groundnut			
	Soybean			
	Sunflower			
Harvesting date	Groundnut			
	Soybean			
	Sunflower			

Appendix 3.3: Ethical Clearance



Faculty of Science and Agriculture

25/10/2017

NAME OF STUDENT: Kephe NP
STUDENT NUMBER: 201533347
DEPARTMENT: Plant Production, Soil Science and Agriculture Engineering
SCHOOL: Agricultural and Environmental Science
QUALIFICATION: DHSA01

Dear Ms Kephe

FACULTY APPROVAL OF PROPOSAL (PROPOSAL NO.89 OF 2017)

I have pleasure in informing you that your doctoral proposal served at the Faculty Higher Degrees Committee meeting on **30 March 2017** and your title was approved as follows:

"Risk and vulnerability analysis of dryland agriculture under projected climate change: adaptive response in South African summer areas"

Note the following: The study

Ethical Clearance	**Tick One**
Requires no ethical clearance Proceed with the study	√
Requires ethical clearance (Human) (TREC) (apply online) Proceed with the study only after receipt of ethical clearance certificate	
Requires ethical clearance (Animal) (AREC) Proceed with the study only after receipt of ethical clearance certificate	

Yours faithfully

Prof P Masoko
Secretariat: Faculty Higher Degrees Committee

CC: Prof KK Ayisi
Ms MP Mabapa
Prof TP Mafeo

Appendix 4.1: Table Test of Significance

Chi-square (Observed value)	2.215
Chi-square (Critical value)	24.996
DF	15
p-value	1.000
alpha	0.05
Wilks' G^2 (Observed value)	3.151
Wilks' G^2 (Critical value)	24.996
DF	15
p-value	0.999
alpha	0.05

Appendix 4.2: Measure of sampling adequacy

Monetary	0.538
Seeds	0.532
Machinery	0.496
Educational support	0.692
Others (irrigation schemes, animals, fertilizers)	0.432
KMO	0.539
Cronbach's alpha: 0.585	

Appendix 4.3: Yield from field experiments in Syferkuil for Soybean, sunflower and groundnut for the 2016-2018 farming season

SOYBEAN 2017 SYFERKUIL

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Statistix 10.0                    11/11/2018, 3:05:02 PM
Randomized Complete Block AOV Table for biomass
Source     DF      SS         MS          F         P
Reps        2     76212     38105.8
ferti       2     14755      7377.4      1.20      0.3908
Error       4     24608      6152.1
Total       8    115575

Grand Mean      555.01
CV               14.13

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                DF      SS           MS          F        P
Nonadditivity          1    8710.0      8710.03      1.64    0.2899
Remainder              3   15898.5      5299.49

Relative Efficiency, RCB               2.11

Means of biomass for ferti
ferti       Mean
  0        512.53
 30        609.50
 60        543.00
Observations per Mean                      3
Standard Error of a Mean              45.285
Std Error (Diff of 2 Means)           64.042

Randomized Complete Block AOV Table for Yield

Source     DF      SS          MS          F         P
Reps        2    10870.6     5435.29
ferti       2     3721.9     1860.94     1.00      0.4453
Error       4     7466.1     1866.54
Total       8    22058.6

Grand Mean      1018.1
CV               4.24

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                DF      SS          MS          F        P
Nonadditivity          1    451.68      451.68      0.19    0.6900
Remainder              3   7014.47     2338.16

Relative Efficiency, RCB               1.36

Means of Yield for ferti
ferti       Mean
  0        1003.1
 30        1046.9
 60        1004.4
Observations per Mean                      3
Standard Error of a Mean              24.944
Std Error (Diff of 2 Means)           35.275
```

SOYBEAN 2018 SYFERKUIL

```
Statistix 10.0                        11/11/2018, 3:11:49 PM
Randomized Complete Block AOV Table for biomass

Source      DF       SS         MS          F        P
Reps         1     23553     23552.6
ferti        2     52350     26174.8      0.63     0.6140
Error        2     83286     41642.9
Total        5    159188

Grand Mean     636.41
CV              32.07

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                 DF      SS          MS          F         P
Nonadditivity           1    54453.6     54453.6     1.89     0.4005
Remainder               1    28832.3     28832.3

Relative Efficiency, RCB              0.82

Means of biomass for ferti
ferti       Mean
  0        562.09
 30        579.00
 60        768.15
Observations per Mean                       2
Standard Error of a Mean               144.30
Std Error (Diff of 2 Means)            204.07

Randomized Complete Block AOV Table for Yield
Source      DF       SS         MS          F        P
Reps         1     60823      60823
ferti        2    376195     188097      2.23     0.3099
Error        2    168969      84484
Total        5    605986

Grand Mean     961.37
CV              30.23

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                 DF      SS          MS          F         P
Nonadditivity           1     10257       10257      0.06     0.8415
Remainder               1    158712      158712

Relative Efficiency, RCB              0.85
Means of Yield for ferti
ferti       Mean
  0        1003.7
 30        1179.9
 60        1601.1
Observations per Mean                       2
Standard Error of a Mean               205.53
Std Error (Diff of 2 Means)            290.6
```

GROUNDNUT 2017 SYFERKUIL

```
Statistix 10.0                          11/11/2018, 3:16:04 PM
Randomized Complete Block AOV Table for biomass
Source      DF      SS          MS          F         P
Reps         2   2001.34     1000.67
ferti        2    668.79      334.40      0.81     0.5082
Error        4   1660.42      415.11
Total        8   4330.55

Grand Mean       1982.6
CV                1.03

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                 DF       SS          MS          F         P
Nonadditivity           1     389.17      389.174     0.92     0.4086
Remainder               3    1271.25      423.749

Relative Efficiency, RCB              1.24

Means of biomass for ferti
ferti       Mean
   0       1977.8
  30       1975.3
  60       1994.7
Observations per Mean                       3
Standard Error of a Mean               11.763
Std Error (Diff of 2 Means)            16.635

Randomized Complete Block AOV Table for Yield
Source      DF      SS          MS          F         P
Reps         2     4133        2066
ferti        2   781178      390589       89.05     0.0005
Error        4    17545        4386
Total        8   802855

Grand Mean       4141.8
CV                1.60

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                 DF       SS          MS          F         P
Nonadditivity           1    16492.5     16492.5      47.02     0.0063
Remainder               3     1052.2       350.7

Relative Efficiency, RCB              0.80

Means of Yield for ferti
ferti       Mean
   0       1461.7
  30       1248.2
  60       1329
Observations per Mean                       3
Standard Error of a Mean               38.237
Std Error (Diff of 2 Means)            54.075
```

GROUNDNUT 2018 SYFERKUIL

```
Statistix 10.0                               11/11/2018, 3:19:54 PM
Randomized Complete Block AOV Table for biomass
Source       DF       SS          MS          F          P
Reps          1    1501.00     1501.00
ferti         2     824.73      412.36      0.66      0.6016
Error         2    1245.32      622.66
Total         5    3571.05
Grand Mean      2177.3
CV               1.15

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source               DF       SS          MS          F          P
Nonadditivity         1    729.873     729.873      1.42     0.4449
Remainder             1    515.444     515.444

Relative Efficiency, RCB             1.15

Means of biomass for ferti
ferti       Mean
  0        2176.7
 30        2163.3
 60        2192.0
Observations per Mean                      2
Standard Error of a Mean                 17.645
Std Error (Diff of 2 Means)              24.953

Randomized Complete Block AOV Table for Yield

Source       DF       SS          MS          F          P
Reps          1     215225      215225
ferti         2    1325565      662783      5.61      0.1512
Error         2     236134      118067
Total         5    1776923

Grand Mean      3167.6
CV               10.85

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source               DF       SS          MS          F          P
Nonadditivity         1     162436      162436      2.20     0.3774
Remainder             1      73697       73697

Relative Efficiency, RCB             1.05

Means of Yield for ferti
ferti       Mean
  0        1172.5
 30        1208.3
 60        1021.7
Observations per Mean                      2
Standard Error of a Mean                 242.97
Std Error (Diff of 2 Means)              343.61
```

Appendix 4.4: Yield from field experiments in Ofcolaco for Soybean, sunflower and groundnut for the 2016-2018 farming season

OFCOLACO 2017 SOYBEAN

```
Statistix 10.0                          11/11/2018, 3:22:35 PM
Randomized Complete Block AOV Table for biomass
Source        DF      SS          MS          F          P
Reps           2     76212      38105.8
ferti          2     14755       7377.4      1.20      0.3908
Error          4     24608       6152.1
Total          8    115575

Grand Mean       675.01
CV                11.62
Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                  DF       SS            MS           F          P
Nonadditivity            1      8710.0        8710.03      1.64      0.2899
Remainder                3     15898.5        5299.49

Relative Efficiency, RCB                2.11

Means of biomass for ferti
ferti        Mean
  0         632.53
  30        729.50
  60        663.00
Observations per Mean                       3
Standard Error of a Mean                45.285
Std Error (Diff of 2 Means)             64.042

Randomized Complete Block AOV Table for Yield

Source        DF        SS            MS           F           P
Reps           2     10870.6       5435.29
ferti          2      3721.9       1860.94       1.00       0.4453
Error          4      7466.1       1866.54
Total          8     22058.6

Grand Mean       1138.1
CV                3.80

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                  DF       SS            MS           F          P
Nonadditivity            1      451.68        451.68       0.19      0.6900
Remainder                3     7014.47       2338.16

Relative Efficiency, RCB                1.36

Means of Yield for ferti
ferti        Mean
  0         1123.1
  30        1166.6
  60        1124.4
Observations per Mean                       3
Standard Error of a Mean                24.944
Std Error (Diff of 2 Means)             35.275
```

OFCOLACO 2017 GROUNDNUTS

```
Statistix 10.0                                 11/11/2018, 3:24:46 PM
Randomized Complete Block AOV Table for biomass
Source           DF       SS          MS           F          P
Rep               2     2001.34     1000.67
ferti             2      668.79      334.40       0.81       0.5082
Error             4     1660.42      415.11
Total             8     4330.55

Grand Mean       2102.6
CV                 0.97
Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                  DF       SS          MS          F          P
Nonadditivity            1     389.17      389.174      0.92       0.4086
Remainder                3    1271.25      423.749

Relative Efficiency, RCB              1.24

Means of biomass for fertiSOY
fert            Mean
   0            2097.8
  30            2095.3
  60            2114.7
Observations per Mean                       3
Standard Error of a Mean                11.763
Std Error (Diff of 2 Means)             16.635

Randomized Complete Block AOV Table for Yield
Source           DF       SS          MS           F          P
Rep               2      4133        2066
fert              2     781178      390589       89.05       0.0005
Error             4      17545        4386
Total             8     802855

Grand Mean       4261.8
CV                 1.55

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                  DF       SS          MS          F          P
Nonadditivity            1    16492.5     16492.5      47.02       0.0063
Remainder                3     1052.2       350.7

Relative Efficiency, RCB              0.80
Means of Yield for fert
fert            Mean
   0            2034.7
  30            2195.9
  60            2195.8
Observations per Mean                       3
Standard Error of a Mean                38.237
Std Error (Diff of 2 Means)             54.075
```

```
OFCOLACO 2018 SOYBEAN
Statistix 10.0                          11/11/2018, 3:32:35 PM
Randomized Complete Block AOV Table for biomass
Source          DF      SS          MS          F          P
Rep              1    1501.00     1501.00
fert             2     824.73      412.36     0.66      0.6016
Error            2    1245.32      622.66
Total            5    3571.05

Grand Mean       3177.3
CV                 0.79

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                DF      SS          MS          F          P
Nonadditivity          1    729.873     729.873     1.42      0.4449
Remainder              1    515.444     515.444

Relative Efficiency, RCB              1.15

Means of biomass for fert
fert            Mean
   0           3176.7
  30           3163.3
  60           3192.0
Observations per Mean                       2
Standard Error of a Mean               17.645
Std Error (Diff of 2 Means)            24.953

Randomized Complete Block AOV Table for Yield

Source          DF      SS          MS          F          P
Rep              1     215225      215225
fert             2    1325565      662783     5.61      0.1512
Error            2     236134      118067
Total            5    1776923

Grand Mean       4167.6
CV                 8.24

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                DF      SS          MS          F          P
Nonadditivity          1    162436      162436      2.20      0.3774
Remainder              1     73697       73697

Relative Efficiency, RCB              1.05

Means of Yield for fert
fert            Mean
   0           993.7
  30           1000.9
  60           1000.6
Observations per Mean                       3
Standard Error of a Mean               242.97
Std Error (Diff of 2 Means)            343.61
```

OFCOLACO 2018 GROUNDNUTS

fert **Mean**

Statistix 10.0 11/11/2018, 4:03:49 PM

Randomized Complete Block AOV Table for biomass

Source	**DF**	**SS**	**MS**	**F**	**P**
RepOF18	2	2001.34	1000.67		
fertiSOY	2	668.79	334.40	0.81	0.5082
Error	4	1660.42	415.11		
Total	8	4330.55			
Grand Mean	2102.6				
CV	0.97				

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	**DF**	**SS**	**MS**	**F**	**P**
Nonadditivity	1	389.17	389.174	0.92	0.4086
Remainder	3	1271.25	423.749		

Relative Efficiency, RCB 1.24

Means of biomass for ferti

fertiSOY	**Mean**
0	2097.8
30	2095.3
60	2114.7

Observations per Mean	3
Standard Error of a Mean	11.763
Std Error (Diff of 2 Means)	16.635

Randomized Complete Block AOV Table for Yield

Source	**DF**	**SS**	**MS**	**F**	**P**
RepOF18	2	4133	2066		
fertiSOY	2	781178	390589	89.05	0.0005
Error	4	17545	4386		
Total	8	802855			

Grand Mean	4261.8
CV	1.55

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	**DF**	**SS**	**MS**	**F**	**P**
Nonadditivity	1	16492.5	16492.5	47.02	0.0063
Remainder	3	1052.2	350.7		

Relative Efficiency, RCB 0.80

Means of Yield for ferti

fertiSOY	**Mean**
0	1560.5
30	1678.6
60	1625.7

Observations per Mean	3
Standard Error of a Mean	38.237
Std Error (Diff of 2 Means)	54.075

Appendix 4.5: Yield from field experiments in Punda Maria for Soybean, sunflower and groundnut for the 2016-2017 farming season

```
Statistix 10.0                          11/8/2018, 11:58:13 AM
PUNDA MARIA SUNFLOWER 2018
Randomized Complete Block AOV Table for Biomass
Source      DF        SS          MS          F          P
Rep          1      26894       26894
Fert         2     770260      385130       8.32      0.1073
Error        2      92609       46304
Total        5     889762

Grand Mean      1391.3
CV               15.47

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source               DF       SS          MS           F          P
Nonadditivity         1     32911.2     32911.2       0.55      0.5934
Remainder             1     59697.6     59697.6

Relative Efficiency, RCB               0.82

Means of Biomass for Fert
Fert       Mean
  0       1047.8
 75       1885.7
150       1240.5
Observations per Mean                        2
Standard Error of a Mean                   152.16
Std Error (Diff of 2 Means)                215.18

Randomized Complete Block AOV Table for GrainYld

Source      DF        SS          MS          F          P
Rep          1      803059      803059
Fert         2     1145140      572570      0.91      0.5227
Error        2     1253946      626973
Total        5     3202145

Grand Mean      1959.8
CV               40.40

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source               DF       SS          MS           F          P
Nonadditivity         1      67709       67709        0.06      0.8507
Remainder             1     1186237     1186237

Relative Efficiency, RCB               0.95

Means of GrainYld for Fert
Fert       Mean
  0       1355.8
 75       2149.1
150       2374.4
Observations per Mean                        2
Standard Error of a Mean                   559.90
Std Error (Diff of 2 Means)                791.82
```

```
Statistix 10.0                       11/8/2018, 12:00:36 PM
PUNDA MARIA SOYBEAN 2018
Randomized Complete Block AOV Table for Biomass
Source       DF        SS            MS            F          P
Rep           1     2655.2       2655.25
Fert          2     6572.6       3286.30        3.47      0.2235
Error         2     1891.9        945.93
Total         5    11119.7

Grand Mean      1003.9
CV               3.06

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                 DF       SS           MS            F          P
Nonadditivity           1     608.62       608.62        0.47      0.6161
Remainder               1    1283.23      1283.23

Relative Efficiency, RCB              1.23

Means of Biomass for Fert
Fert      Mean
  0       966.5
 30      1046.9
 60       998.3
Observations per Mean                        2
Standard Error of a Mean                  21.748
Std Error (Diff of 2 Means)               30.756

Randomized Complete Block AOV Table for GrainYld

Source       DF        SS           MS            F          P
Rep           1      29857       29856.8
Fert          2     149144       74572.2        7.08      0.1237
Error         2      21059       10529.3
Total         5     200060

Grand Mean      1243.6
CV               8.25

Tukey's 1 Degree of Freedom Test for Nonadditivity
Source                 DF       SS           MS            F          P
Nonadditivity           1    12398.1      12398.1        1.43      0.4432
Remainder               1     8660.6       8660.6

Relative Efficiency, RCB              1.23

Means of GrainYld for Fert
Fert      Mean
  0      1086.6
 30      1459.2
 60      1185.0
Observations per Mean                        2
Standard Error of a Mean                  72.558
Std Error (Diff of 2 Means)               102.61

Statistix 10.0                       11/8/2018, 12:20:01 PM
```

PUNDA MARIA GROUNDNUTS 2018

Randomized Complete Block AOV Table for Biomass

Source	DF	SS	MS	F	P
Rep	1	2655.2	2655.25		
Fert	2	6572.6	3286.30	3.47	0.2235
Error	2	1891.9	945.93		
Total	5	11119.7			

Grand Mean	1003.9
CV	3.06

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	608.62	608.62	0.47	0.6161
Remainder	1	1283.23	1283.23		

Relative Efficiency, RCB 1.23

Means of Biomass for Fert

Fert	Mean
0	966.5
30	1046.9
60	998.3

Observations per Mean	2
Standard Error of a Mean	21.748
Std Error (Diff of 2 Means)	30.756

Randomized Complete Block AOV Table for GrainYld

Source	DF	SS	MS	F	P
Rep	1	29857	29856.8		
Fert	2	149144	74572.2	7.08	0.1237
Error	2	21059	10529.3		
Total	5	200060			

Grand Mean	1243.6
CV	8.25

Tukey's 1 Degree of Freedom Test for Nonadditivity

Source	DF	SS	MS	F	P
Nonadditivity	1	12398.1	12398.1	1.43	0.4432
Remainder	1	8660.6	8660.6		

Relative Efficiency, RCB 1.23

Means of GrainYld for Fert

Fert	Mean
0	2372.5
30	1508.6
60	1521.7

Observations per Mean	2
Standard Error of a Mean	72.558
Std Error (Diff of 2 Means)	102.61

Appendix 7: Yield from field experiments in Phalaborwa for Soybean, sunflower and groundnut for the 2015-2017 farming season

Appendix 4.6: Summary Statistics for soybean Ofcolaco 2017 season

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed yield 2017	3	0	3	1154.400	1223.100	1181.367	36.653
Fertilizer treatment	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer treatment	observed yield 2017
Fertilizer treatment	**1**	-0.937
observed yield 2017	-0.937	**1**

Regression of variable observed yield 2017:

Goodness of fit statistics (observed yield 2017):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.878
Adjusted R²	0.757
MSE	327.082
RMSE	18.085
MAPE	0.836
DW	3.000
Cp	2.000
AIC	18.075
SBC	16.272
PC	0.609
Press	4415.603
Q²	-0.643

Analysis of variance (observed yield 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	2359.845	2359.845	7.215	0.227
Error	1	327.082	327.082		
Corrected Total	2	2686.927			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (observed yield 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer treatment	1	2359.845	2359.845	7.215	0.227

Type III Sum of Squares analysis (observed yield 2017):

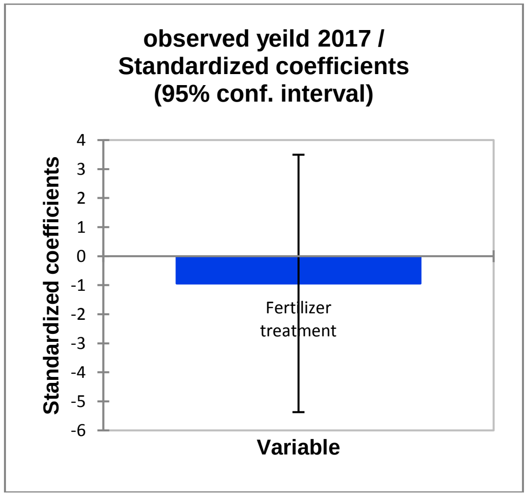
Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer treatment	1	2359.845	2359.845	7.215	0.227

Model parameters (observed yield 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1215.717	16.510	73.637	**0.009**	1005.942	1425.491
Fertilizer treatment	-1.145	0.426	-2.686	0.227	-6.561	4.271

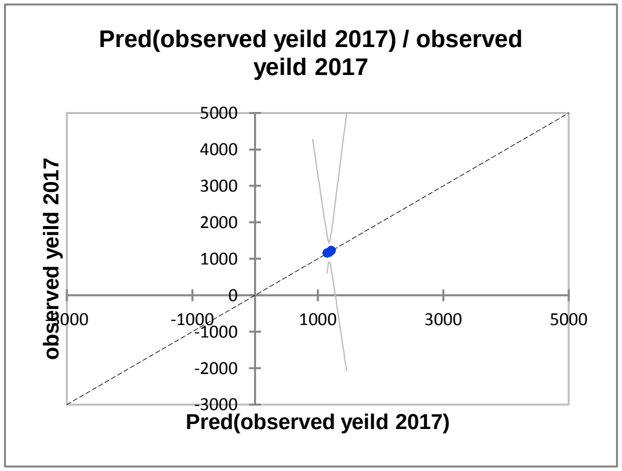
Equation of the model (observed yield 2017):
observed yield 2017 = 1215.71666666667-1.145*Fertilizer treatment
Standardized coefficients (observed yield 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer treatment	-0.937	0.349	-2.686	0.227	-5.370	3.496

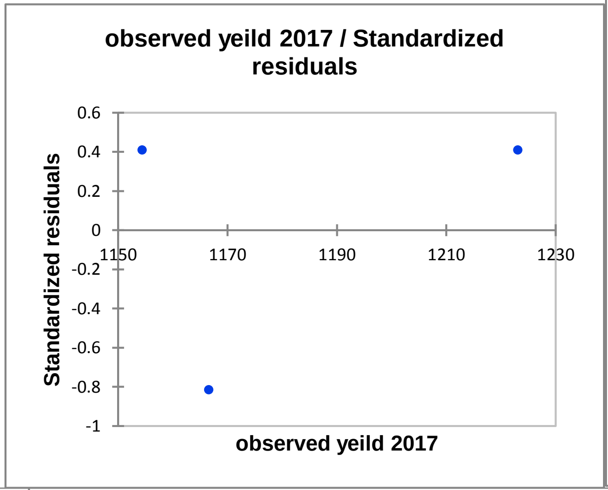


Predictions and residuals (observed yield 2017):

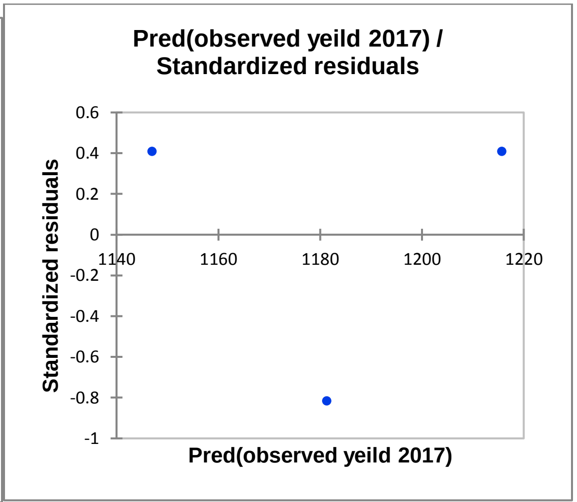
Observation	Weight	Fertilizer treatment	observed yield 2017	Pred(observed yield 2017)	Residual	Std. residual	Studentized residuals	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1223.100	1215.717	7.383	0.408	1.000	16.510	1005.942	1425.491	24.488	904.570	1526.863
Obs2	1	30.000	1166.600	1181.367	-14.767	-0.816	-1.000	10.442	1048.693	1314.040	20.883	916.020	1446.713
Obs3	1	60.000	1154.400	1147.017	7.383	0.408	1.000	16.510	937.242	1356.791	24.488	835.870	1458.163



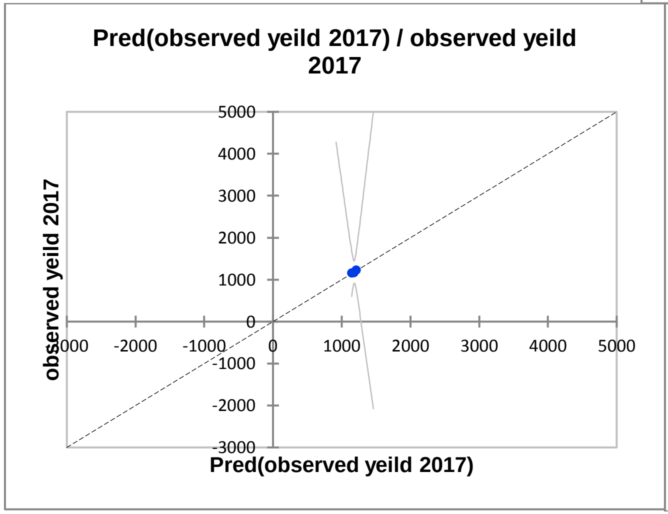
Pred(observed yeild 2017) / observed yeild 2017



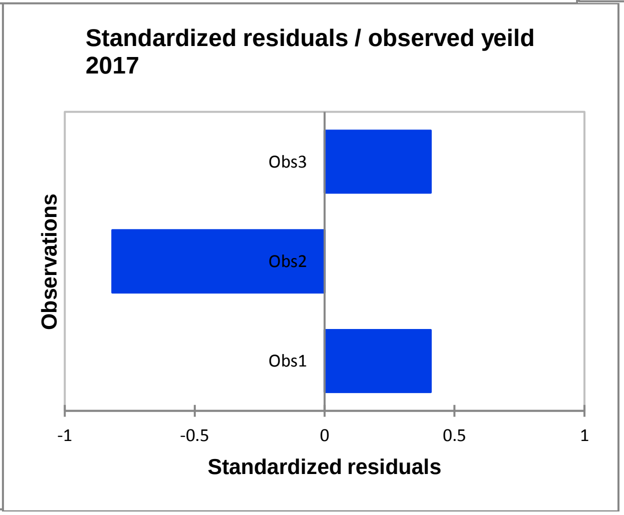
observed yeild 2017 / Standardized residuals



Pred(observed yeild 2017) / Standardized residuals



Pred(observed yeild 2017) / observed yeild 2017



Standardized residuals / observed yeild 2017

Appendix 4.7: Summary Statistics for soybean Syferkuil

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed soybean yield Syferkuil 2017	3	0	3	1103.100	2004.400	1584.800	453.848
Fertilizer	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer	observed soybean yield Syferkuil 2017
Fertilizer	**1**	0.993
observed soybean yield Syferkuil 2017	0.993	**1**

Regression of variable observed soybean yield Syferkuil 2017:

Summary of the variables selection observed soybean yield Syferkuil 2017:

Nbr. of variables	Variables	MSE	R²	Adjusted R²	Mallows' Cp	Akaike's AIC	Schwarz's SBC	Amemiya's PC
1	Fertilizer	5784.615	0.986	**0.972**	2.000	26.693	24.890	0.023

The best model for the selected selection criterion is displayed in blue

Goodness of fit statistics (observed soybean yield Syferkuil 2017):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.986
Adjusted R²	0.972
MSE	5784.615
RMSE	76.057
MAPE	2.712
DW	3.000
Cp	2.000
AIC	26.693
SBC	24.890
PC	0.070

Analysis of variance (observed soybean yield Syferkuil 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	406170.845	406170.845	70.216	0.076
Error	1	5784.615	5784.615		
Corrected Total	2	411955.460			

Computed against model Y=Mean(Y)

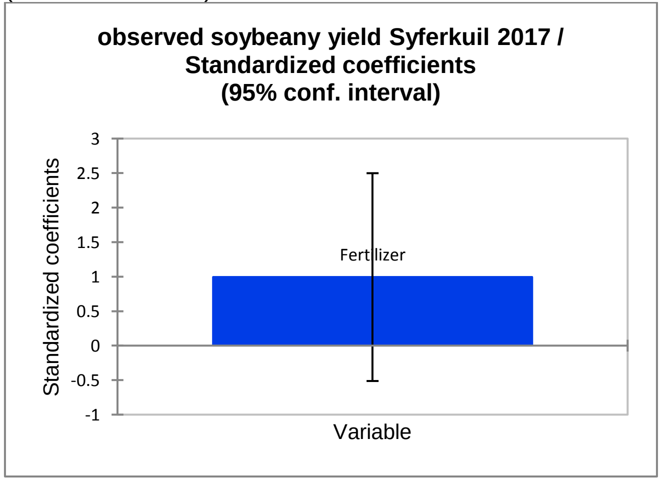
Model parameters (observed soybean yield Syferkuil 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1134.150	69.430	16.335	**0.039**	251.959	2016.341
Fertilizer	15.022	1.793	8.379	0.076	-7.756	37.800

Equation of the model (observed soybean yield Syferkuil 2017):
observed soybean yield Syferkuil 2017 = 1134.15+15.0216666666667*Fertilizer
Standardized coefficients (observed soybean yield Syferkuil 2017):

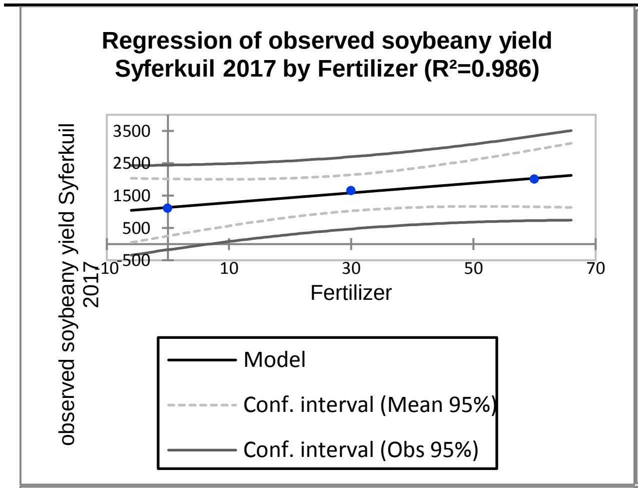
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.993	0.118	8.379	0.076	-0.513	2.499

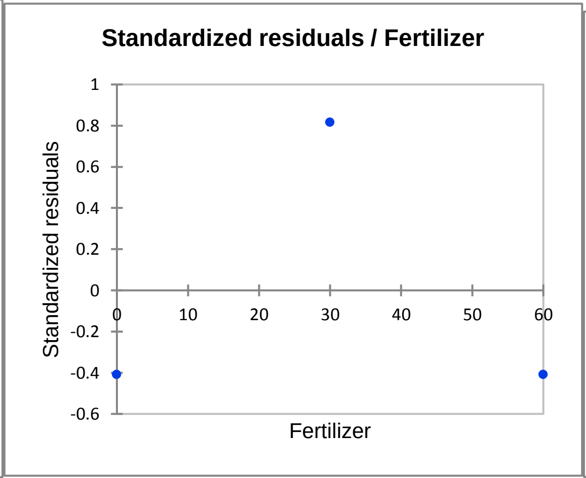
Figure: observed soybean yield Syferkuil 2017 / Standardized coefficients
(95% conf. interval)

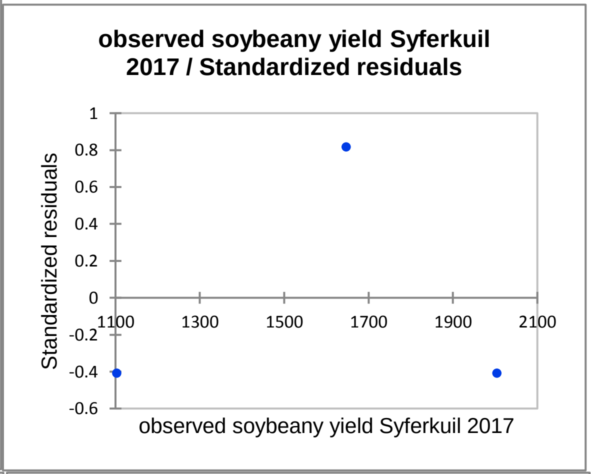


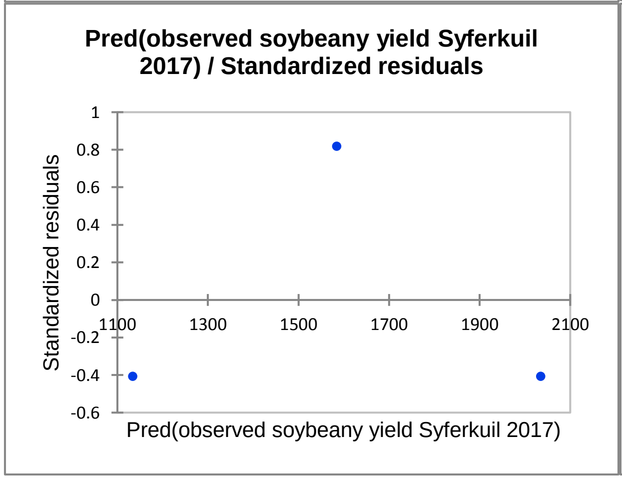
Predictions and residuals (observed soybean yield Syferkuil 2017):

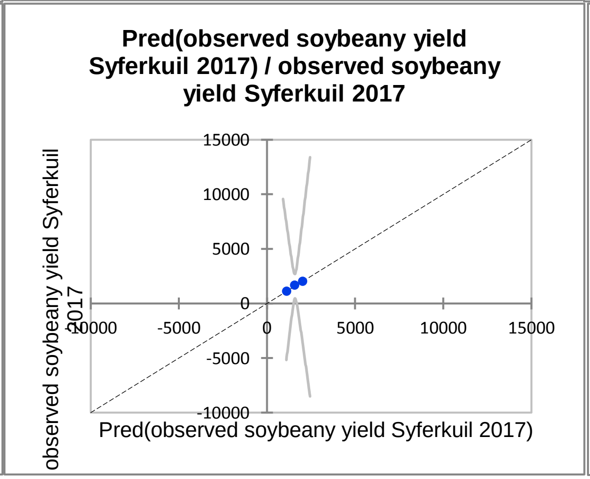
Observation	Weight	Fertilizer	observed soybean yield Syferkuil 2017	Pred(observed soybean yield Syferkuil 2017)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1103.100	1134.150	-31.050	-0.408	69.430	251.959	2016.341	102.981	-174.350	2442.650
Obs2	1	30.000	1646.900	1584.800	62.100	0.816	43.911	1026.854	2142.746	87.823	468.907	2700.693
Obs3	1	60.000	2004.400	2035.450	-31.050	-0.408	69.430	1153.259	2917.641	102.981	726.950	3343.950

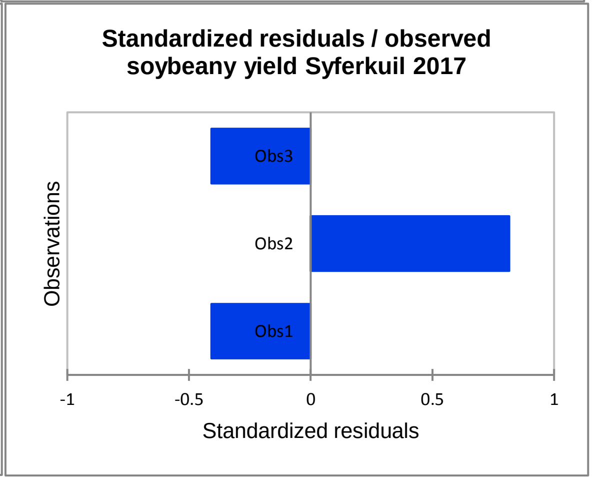

Regression of observed soybeany yield Syferkuil 2017 by Fertilizer (R²=0.986)


Standardized residuals / Fertilizer


observed soybeany yield Syferkuil 2017 / Standardized residuals


Pred(observed soybeany yield Syferkuil 2017) / Standardized residuals


Pred(observed soybeany yield Syferkuil 2017) / observed soybeany yield Syferkuil 2017


Standardized residuals / observed soybeany yield Syferkuil 2017

Test assumptions:

Test on the normality of the residuals (Shapiro-Wilk) (observed soybean yield Syferkuil 2017):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:

H0: The residuals follow a Normal distribution.

Ha: The residuals do not follow a Normal distribution.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

Interpretation (observed soybean yield Syferkuil 2017):

Using the Best model variable selection method, one variable has been retained in the model.

Given the R2, 99% of the variability of the dependent variable observed soybean yield Syferkuil 2017 is explained by the explanatory variable.

Appendix 4.8: Summary Statistics for Sunflower ofcolaco 2017

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed yield 2017	3	0	3	1192.100	1560.700	1383.467	184.706
Fertilizer treatment	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer treatment	observed yield 2017
Fertilizer treatment	**1**	-0.442
observed yield 2017	-0.442	**1**

Regression of variable observed yield 2017:

Goodness of fit statistics (observed yield 2017):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.195
Adjusted R²	-0.610
MSE	54931.802

RMSE	234.375
MAPE	9.677
DW	3.000
Cp	2.000
AIC	33.446
SBC	31.643
PC	4.025
Press	741579.322
Q²	-9.868

Analysis of variance (observed yield 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	13300.805	13300.805	0.242	0.709
Error	1	54931.802	54931.802		
Corrected Total	2	68232.607			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (observed yield 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer treatment	1	13300.805	13300.805	0.242	0.709

Type III Sum of Squares analysis (observed yield 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer treatment	1	13300.805	13300.805	0.242	0.709

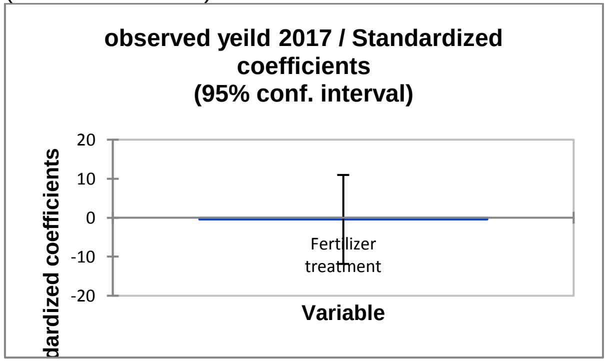
Model parameters (observed yield 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1465.017	213.954	6.847	0.092	-1253.532	4183.566
Fertilizer treatment	-2.718	5.524	-0.492	0.709	-72.911	67.474

Equation of the model (observed yield 2017):
Observed yield 2017 = 1465.01666666667-2.71833333333334*Fertilizer treatment
Standardized coefficients (observed yield 2017):

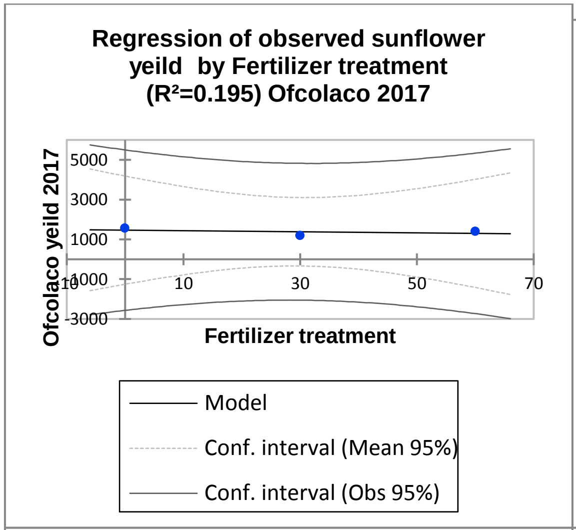
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer treatment	-0.442	0.897	-0.492	0.709	-11.842	10.959

Figure: observed yield 2017 / Standardized coefficients (95% conf. interval)

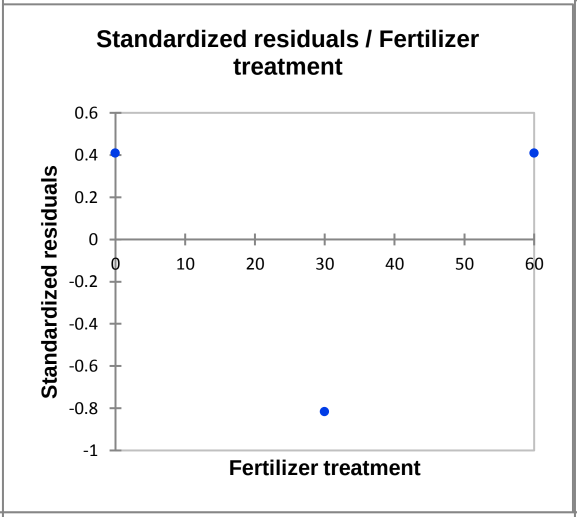


Predictions and residuals (observed yield 2017):

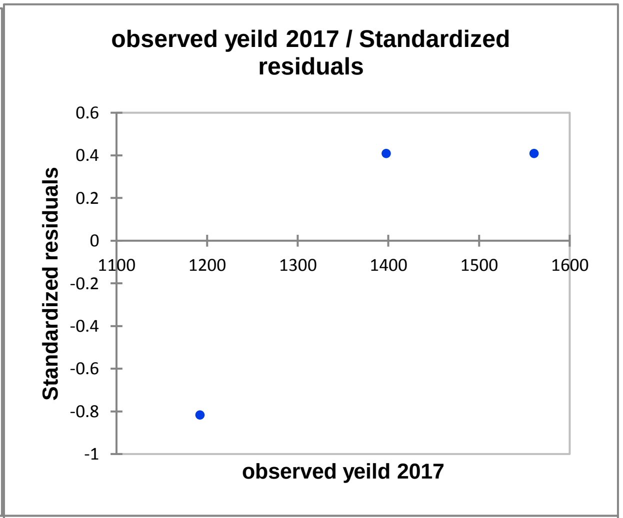
Observation	Weight	Fertilizer treatment	observed yield 2017	Pred(observed yield 2017)	Residual	Std. residual	Studentized residuals	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1560.700	1465.017	95.683	0.408	1.000	213.954	-1253.532	4183.566	317.346	-2567.243	5497.276
Obs2	1	30.000	1192.100	1383.467	-191.367	-0.816	-1.000	135.317	-335.895	3102.828	270.633	-2055.256	4822.189
Obs3	1	60.000	1397.600	1301.917	95.683	0.408	1.000	213.954	-1416.632	4020.466	317.346	-2730.343	5334.176



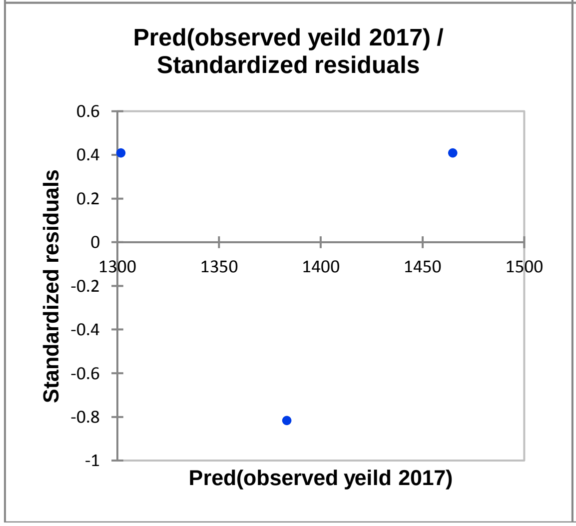
Regression of observed sunflower yeild by Fertilizer treatment (R²=0.195) Ofcolaco 2017



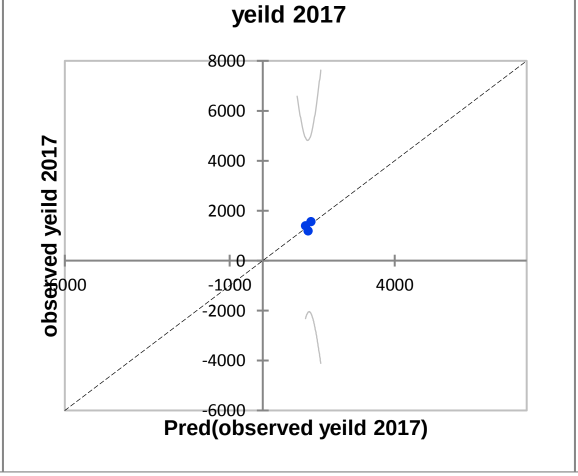
Standardized residuals / Fertilizer treatment



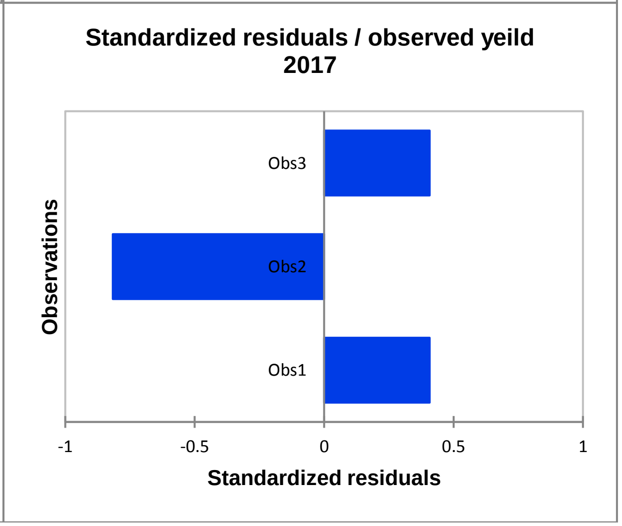
observed yeild 2017 / Standardized residuals



Pred(observed yeild 2017) / Standardized residuals



Pred(observed yeild 2017) / observed yeild 2017



Standardized residuals / observed yeild 2017

Interpretation (observed yield 2017):
Given the R2, 19% of the variability of the dependent variable observed yield 2017 is explained by the explanatory variable.

Appendix 4.9: Summary Statistics for Sunflower Syferkuil 2017

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed sunflower yield Syferkuil 2017	3	0	3	1245.800	2036.500	1558.600	420.411
Fertilizer	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer	observed sunflower yield Syferkuil 2017
Fertilizer	**1**	0.940
observed sunflower yield Syferkuil 2017	0.940	**1**

Regression of variable observed sunflower yield Syferkuil 2017:

Summary of the variables selection observed sunflower yield Syferkuil 2017:

Nbr. of variables	Variables	MSE	R²	Adjusted R²	Mallows' Cp	Akaike's AIC	Schwarz's SBC	Amemiya's PC
1	Fertilizer	40887.015	0.884	**0.769**	2.000	32.560	30.757	0.193

The best model for the selected selection criterion is displayed in blue

Goodness of fit statistics (observed sunflower yield Syferkuil 2017):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.884
Adjusted R²	0.769
MSE	40887.015
RMSE	202.205
MAPE	7.509
DW	3.000
Cp	2.000
AIC	32.560
SBC	30.757
PC	0.578

Analysis of variance (observed sunflower yield Syferkuil 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	312603.245	312603.245	7.646	0.221
Error	1	40887.015	40887.015		
Corrected Total	2	353490.260			

Computed against model Y=Mean(Y)

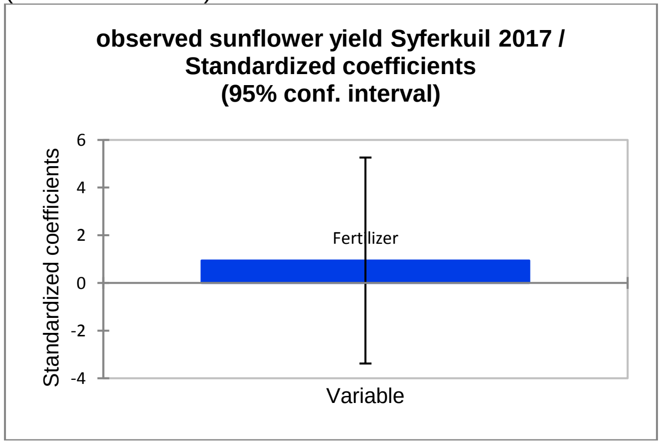
Model parameters (observed sunflower yield Syferkuil 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1163.250	184.587	6.302	0.100	-1182.155	3508.655
Fertilizer	13.178	4.766	2.765	0.221	-47.380	73.736

Equation of the model (observed sunflower yield Syferkuil 2017):
observed sunflower yield Syferkuil 2017 = 1163.25+13.1783333333333*Fertilizer
Standardized coefficients (observed sunflower yield Syferkuil 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.940	0.340	2.765	0.221	-3.381	5.262

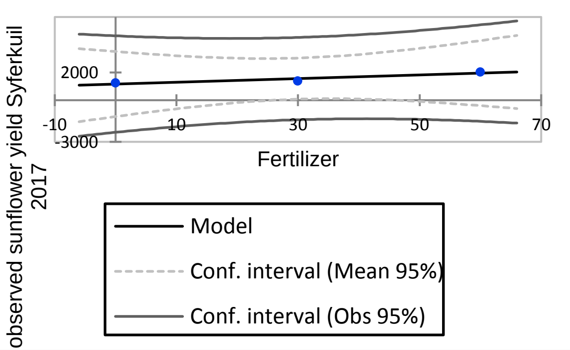
Figure: observed sunflower yield Syferkuil 2017 / Standardized coefficients
(95% conf. interval)



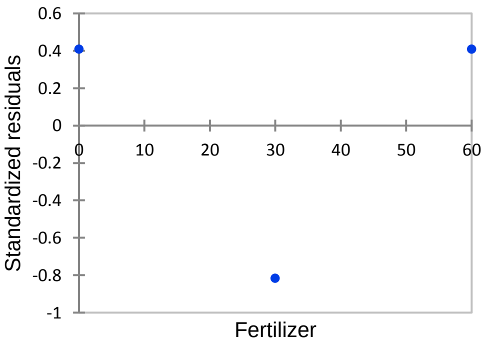
Observati	Weig	Fertiliz	observed sunflower yield	Pred(observed sunflower yield	Residu	Std. resid	Std. dev. on pred.	Lower bound 95%	Upper bound 95%	Std. dev. on pred.	Lower bound 95%	Upper bound 95%

on	ht	er	Syferkuil 2017	Syferkuil 2017)	al	ual	(Mean)	(Mean)	(Mean)	(Observation)	(Observation)	(Observation)
Obs1	1	0.000	1245.800	1163.250	82.550	0.408	184.587	-1182.155	3508.655	273.787	-2315.548	4642.048
Obs2	1	30.000	1393.500	1558.600	-165.100	-0.816	116.743	75.235	3041.965	233.487	-1408.129	4525.329
Obs3	1	60.000	2036.500	1953.950	82.550	0.408	184.587	-391.455	4299.355	273.787	-1524.848	5432.748

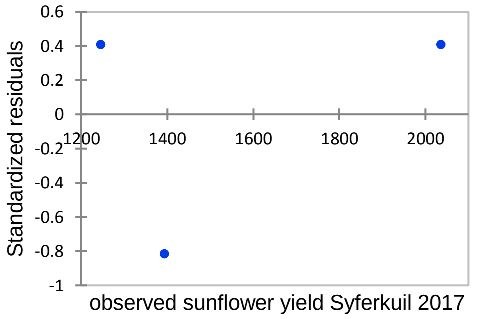
Regression of observed sunflower yield Syferkuil 2017 by Fertilizer (R²=0.884)



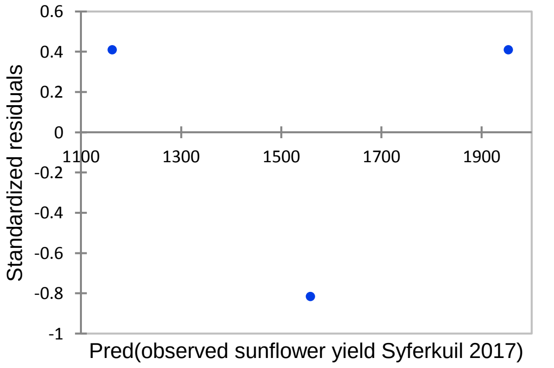
Standardized residuals / Fertilizer



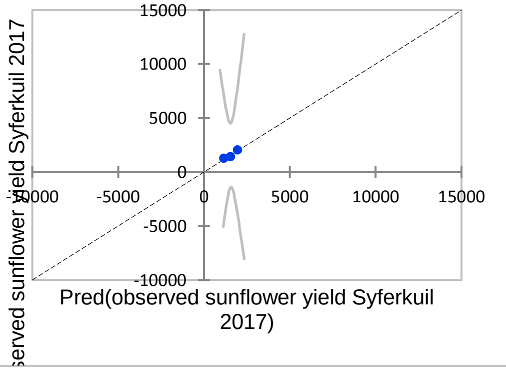
observed sunflower yield Syferkuil 2017 / Standardized residuals



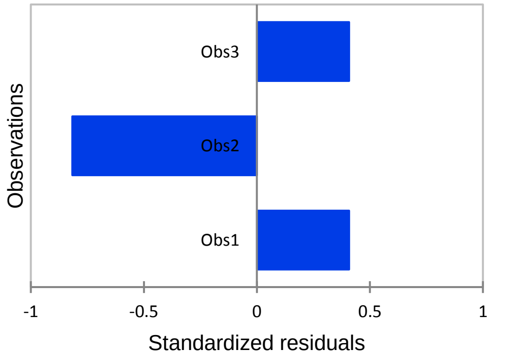
Pred(observed sunflower yield Syferkuil 2017) / Standardized residuals



Pred(observed sunflower yield Syferkuil 2017) / observed sunflower yield Syferkuil 2017



Standardized residuals / observed sunflower yield Syferkuil 2017



Test assumptions:

Test on the normality of the residuals (Shapiro-Wilk) (observed sunflower yield Syferkuil 2017):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:
H0: The residuals follow a Normal distribution.
Ha: The residuals do not follow a Normal distribution.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Interpretation (observed sunflower yield Syferkuil 2017):
Using the Best model variable selection method, one variable has been retained in the model.
Given the R2, 88% of the variability of the dependent variable observed sunflower yield Syferkuil 2017 is explained by the explanatory variable.

Appendix 4.10: Summary Statistics for groundnut Ofcolaco 2017

Summary statistics

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed groundnut yield Ofcolaco 2017	3	0	3	2034.700	2195.900	2142.117	93.026
Fertilizer treatment	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer treatment	**observed groundnut yield Ofcolaco 2017**
Fertilizer treatment	**1**	0.866
observed groundnut yield Ofcolaco 2017	0.866	**1**

Goodness of fit statistics (observed groundnut yield Ofcolaco 2017):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.749

Adjusted R²	0.499
MSE	4338.970
RMSE	65.871
MAPE	1.665
DW	3.000
Cp	2.000
AIC	25.830
SBC	24.028
PC	1.253
Press	58576.101
Q²	-2.384

Analysis of variance (observed groundnut yield Ofcolaco 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	12968.551	12968.551	2.989	0.334
Error	1	4338.970	4338.970		
Corrected Total	2	17307.522			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (observed groundnut yield Ofcolaco 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer treatment	1	12968.551	12968.551	2.989	0.334

Type III Sum of Squares analysis (observed groundnut yield Ofcolaco 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer treatment	1	12968.551	12968.551	2.989	0.334

Model parameters (observed groundnut yield Ofcolaco 2017):

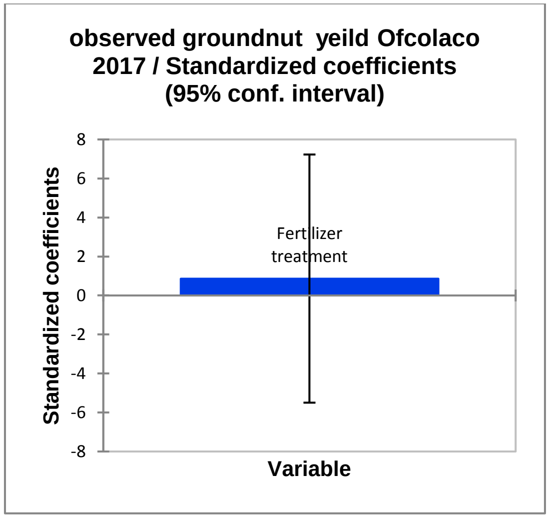
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	2061.592	60.132	34.285	**0.019**	1297.547	2825.636
Fertilizer treatment	2.684	1.553	1.729	0.334	-17.043	22.412

Equation of the model (observed groundnut yield Ofcolaco 2017):

observed groundnut yield Ofcolaco 2017 = 2061.59166666667+2.68416666666666*Fertilizer treatment

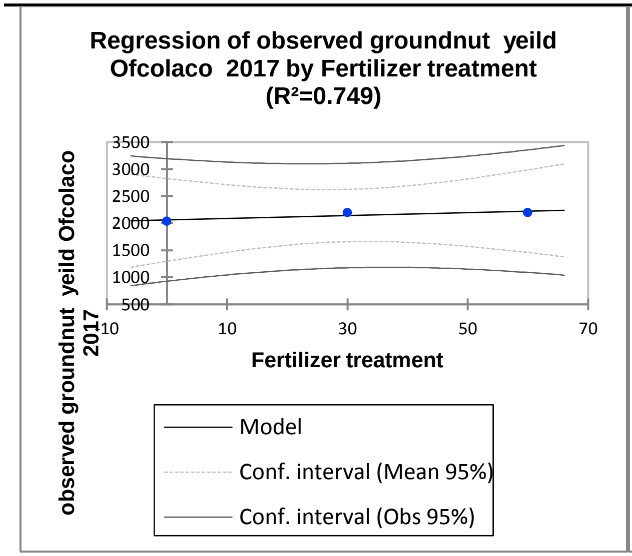
Standardized coefficients (observed groundnut yield Ofcolaco 2017):

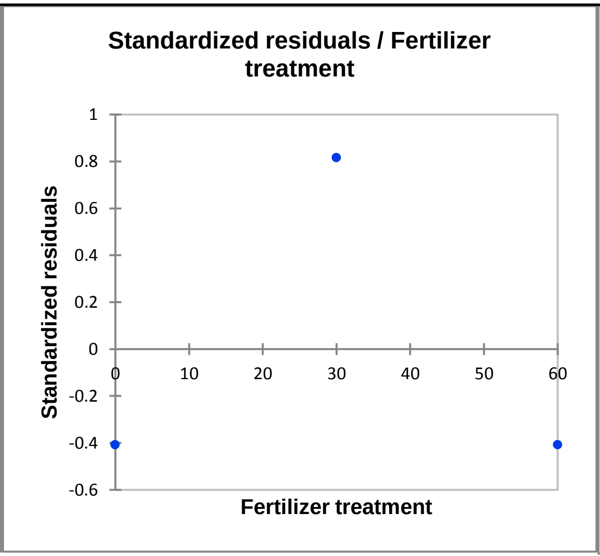
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer treatment	0.866	0.501	1.729	0.334	-5.496	7.228

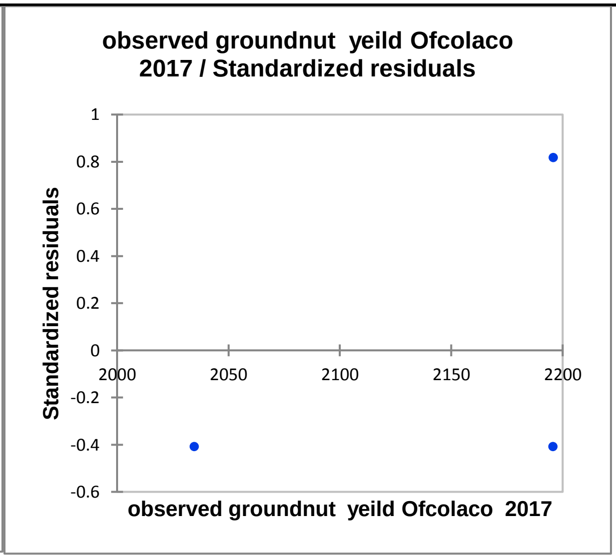


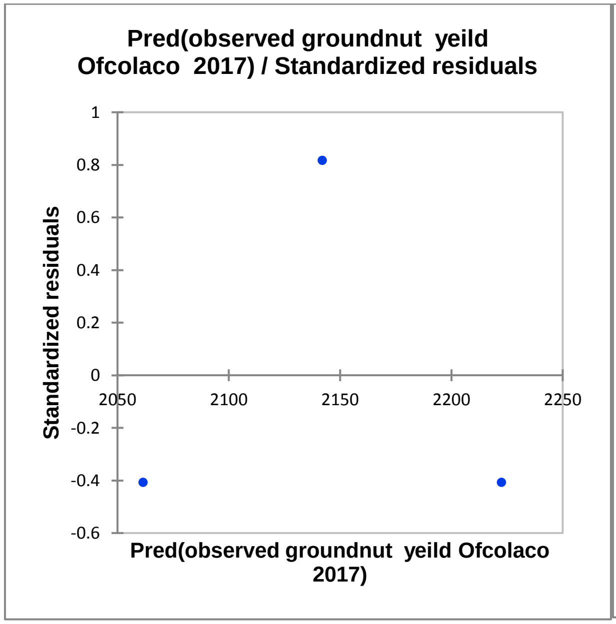
Obs	Weight	Fertilizer treatme	observed groundnu	Pred (observed	Residu al	Std. residual	Studentized residuals	Std. dev. on pred.	Lower bound	Upper bound	Std. dev. on pred.	Lower bound 95%	Upper bound 95%

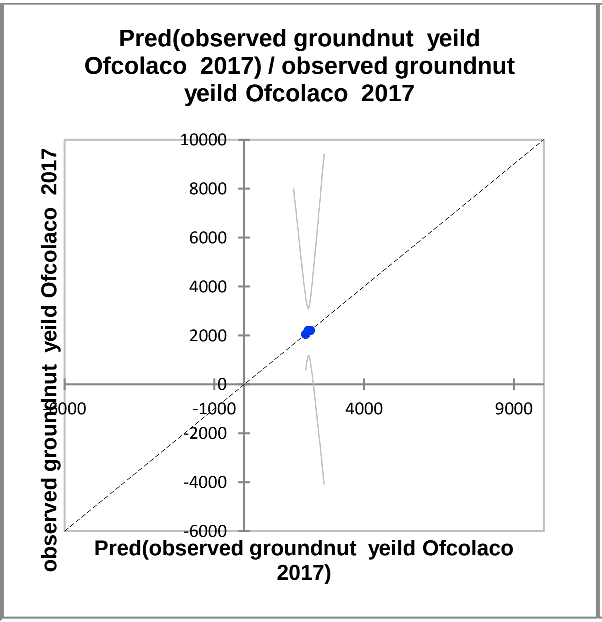
		nt	t yield Ofcolaco 2017	groundnut yield Ofcolaco 2017)				(Mean)	95% (Mean)	95% (Mean)	(Observation)	(Observation)	(Observation)
Obs 1	1	0.000	2034.700	2061.59	-26.892	-0.408	-1.000	60.132	1297.547	2825.636	89.190	928.331	3194.853
Obs 2	1	30.000	2195.900	2142.12	53.783	0.816	1.000	38.031	1658.893	2625.341	76.061	1175.669	3108.565
Obs 3	1	.000	2195.750	2222.6	-26.892	-0.408	-1.000	60.132	1458.597	2986.686	89.190	1089.381	3355.903

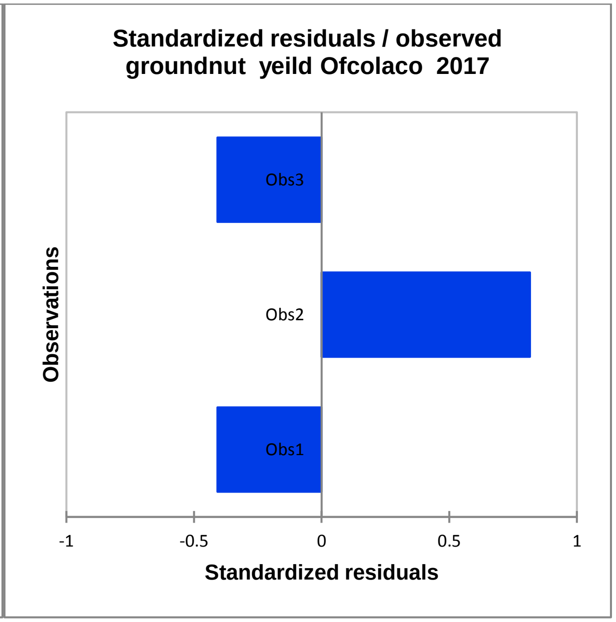

Regression of observed groundnut yeild Ofcolaco 2017 by Fertilizer treatment (R²=0.749)


Standardized residuals / Fertilizer treatment


observed groundnut yeild Ofcolaco 2017 / Standardized residuals







Appendix 4.11: Summary Statistics for groundnut Syferkuil 2017

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed groundnut yield Syferkuil 2017	3	0	3	1248.200	1461.700	1346.300	107.796
Fertilizer	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer	observed groundnut yield Syferkuil 2017
Fertilizer	**1**	-0.616
observed groundnut yield Syferkuil 2017	-0.616	**1**

Regression of variable observed groundnut yield Syferkuil 2017:

Summary of the variables selection observed groundnut yield Syferkuil 2017:

Nbr. of variables	Variables	MSE	R²	Adjusted R²	Mallows' Cp	Akaike's AIC	Schwarz's SBC	Amemiya's PC
1	Fertilizer	14435.415	0.379	**-0.242**	2.000	29.436	27.634	1.035

The best model for the selected selection criterion is displayed in blue

Goodness of fit statistics (observed groundnut yield Syferkuil 2017):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.379
Adjusted R²	-0.242
MSE	14435.415
RMSE	120.147
MAPE	4.969
DW	3.000
Cp	2.000
AIC	29.436
SBC	27.634
PC	3.106

Analysis of variance (observed groundnut yield Syferkuil 2017):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	8804.645	8804.645	0.610	0.578
Error	1	14435.415	14435.415		
Corrected Total	2	23240.060			

Computed against model Y=Mean(Y)

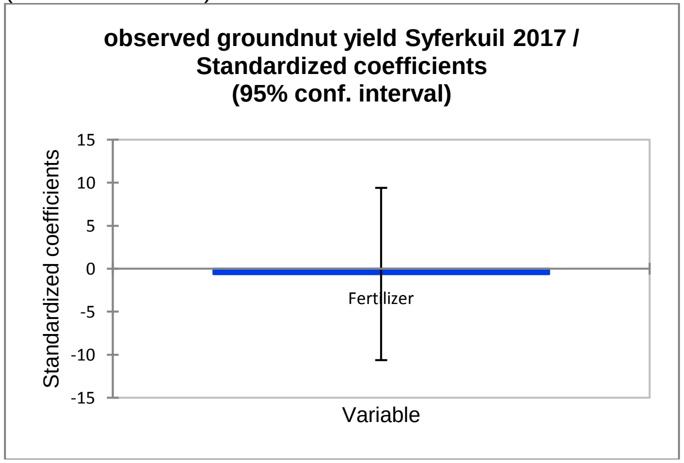
Model parameters (observed groundnut yield Syferkuil 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1412.650	109.679	12.880	**0.049**	19.044	2806.256
Fertilizer	-2.212	2.832	-0.781	0.578	-38.194	33.771

Equation of the model (observed groundnut yield Syferkuil 2017):
observed groundnut yield Syferkuil 2017 = 1412.65-2.21166666666667*Fertilizer
Standardized coefficients (observed groundnut yield Syferkuil 2017):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	-0.616	0.788	-0.781	0.578	-10.630	9.399

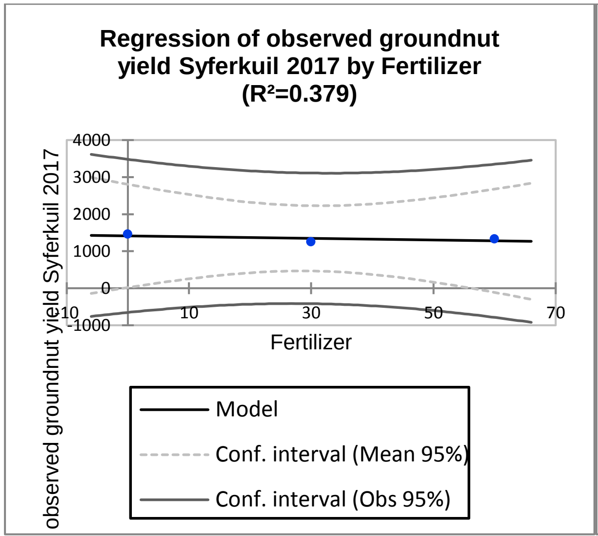
Figure: observed groundnut yield Syferkuil 2017 / Standardized coefficients (95% conf. interval)

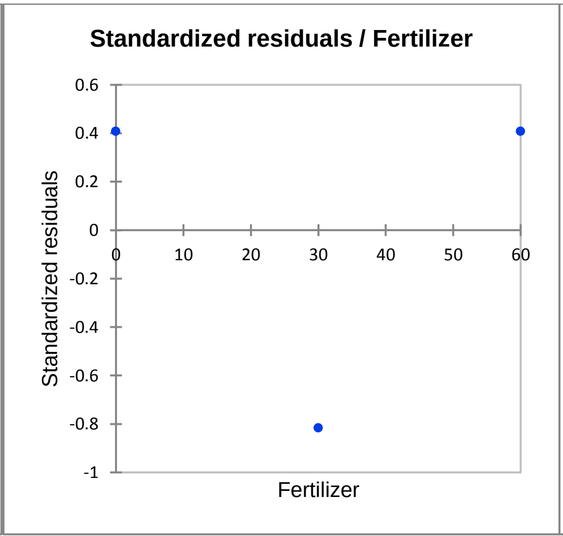


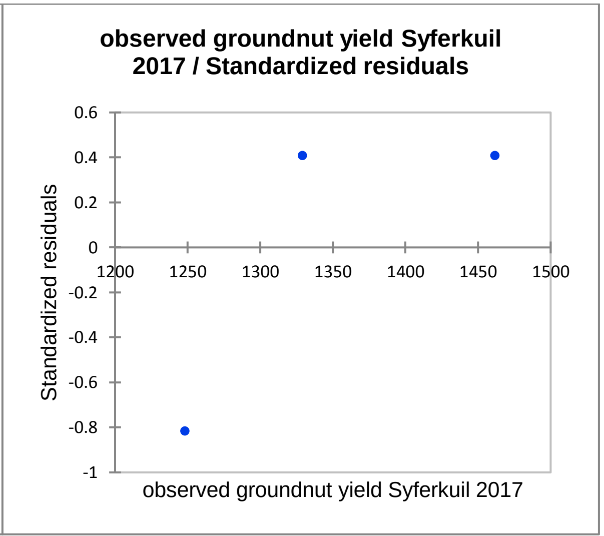
Predictions and residuals (observed groundnut yield Syferkuil 2017):

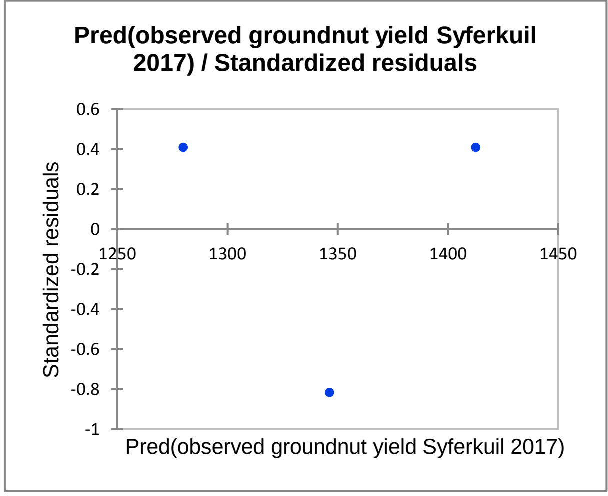
Observation	Weight	Fertilizer	observed groundnut yield Syferkuil 2017	Pred(observed groundnut yield Syferkuil 2017)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1461.700	1412.650	49.050	0.408	109.679	19.044	2806.256	162.680	-654.401	3479.701
Obs2	1	30.000	1248.200	1346.300	-98.100	-0.816	69.367	464.906	2227.694	138.734	-416.487	3109.087
Obs3	1	60.000	1329.000	1279.950	49.050	0.408	109.679	-113.656	2673.556	162.680	-787.101	3347.001

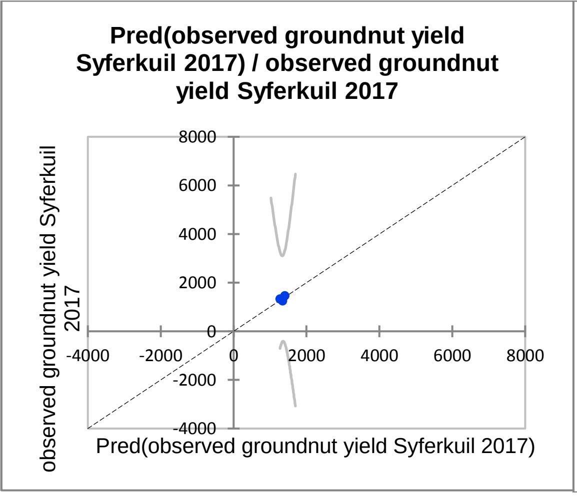
Figure: Regression of observed groundnut yield Syferkuil 2017 by Fertilizer (R^2=0.379)

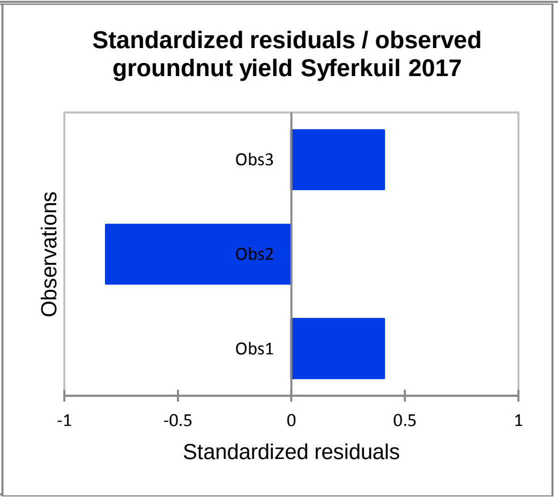

Regression of observed groundnut yield Syferkuil 2017 by Fertilizer (R^2=0.379)


Standardized residuals / Fertilizer


observed groundnut yield Syferkuil 2017 / Standardized residuals


Pred(observed groundnut yield Syferkuil 2017) / Standardized residuals


Pred(observed groundnut yield Syferkuil 2017) / observed groundnut yield Syferkuil 2017


Standardized residuals / observed groundnut yield Syferkuil 2017

Test assumptions:

Test on the normality of the residuals (Shapiro-Wilk) (observed groundnut yield Syferkuil 2017):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:
H0: The residuals follow a Normal distribution.
Ha: The residuals do not follow a Normal distribution.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Interpretation (observed groundnut yield Syferkuil 2017):
Using the Best model variable selection method, one variable has been retained in the model.
Given the R2, 38% of the variability of the dependent variable observed groundnut yield Syferkuil 2017 is explained by the explanatory variable.

Appendix 4.12: Summary Statistics for soybean Ofcolaco 2018

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
OFCOLACO-SOYBEAN YIELD	3	0	3	933.700	1000.900	978.400	38.712
SYFERKUIL SOYBEAN YIELD	3	0	3	1003.700	1601.100	1261.567	306.959
PUNDA MARIA- SOYBEAN YIELD	3	0	3	1908.600	2459.200	2184.267	275.301
Fertilizer	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer	OFCOLACO-SOYBEAN YIELD	SYFERKUIL SOYBEAN YIELD	PUNDA MARIA- SOYBEAN YIELD
Fertilizer	**1**	0.864	0.973	0.502
OFCOLACO-SOYBEAN YIELD	0.864	**1**	0.725	0.869
SYFERKUIL SOYBEAN YIELD	0.973	0.725	**1**	0.289
PUNDA MARIA- SOYBEAN YIELD	0.502	0.869	0.289	**1**

Goodness of fit statistics (OFCOLACO-SOYBEAN YIELD):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.747
Adjusted R²	0.493
MSE	759.375
RMSE	27.557

MAPE	1.526
DW	3.000
Cp	2.000
AIC	20.602
SBC	18.799
PC	1.267

Analysis of variance (OFCOLACO-SOYBEAN YIELD):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	2237.805	2237.805	2.947	0.336
Error	1	759.375	759.375		
Corrected Total	2	2997.180			

Computed against model Y=Mean(Y)

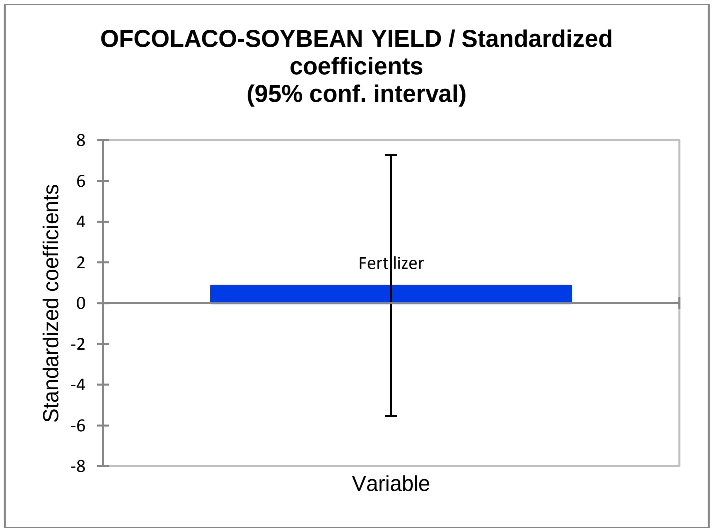
Model parameters (OFCOLACO-SOYBEAN YIELD):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	944.950	25.156	37.564	**0.017**	625.316	1264.584
Fertilizer	1.115	0.650	1.717	0.336	-7.138	9.368

Equation of the model (OFCOLACO-SOYBEAN YIELD):
OFCOLACO-SOYBEAN YIELD = 944.95+1.115*Fertilizer
Standardized coefficients (OFCOLACO-SOYBEAN YIELD):

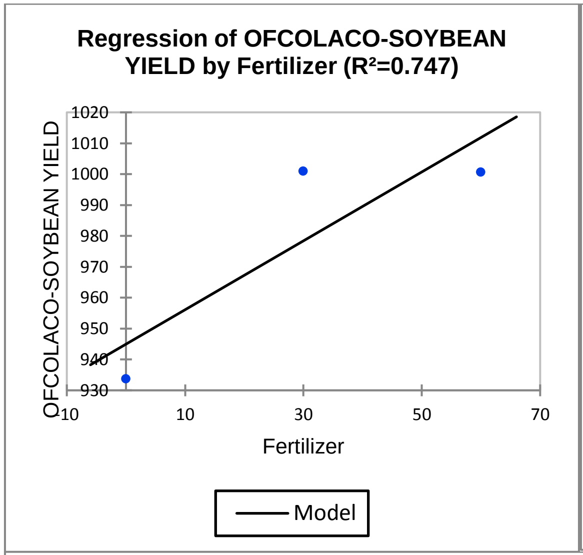
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.864	0.503	1.717	0.336	-5.532	7.260

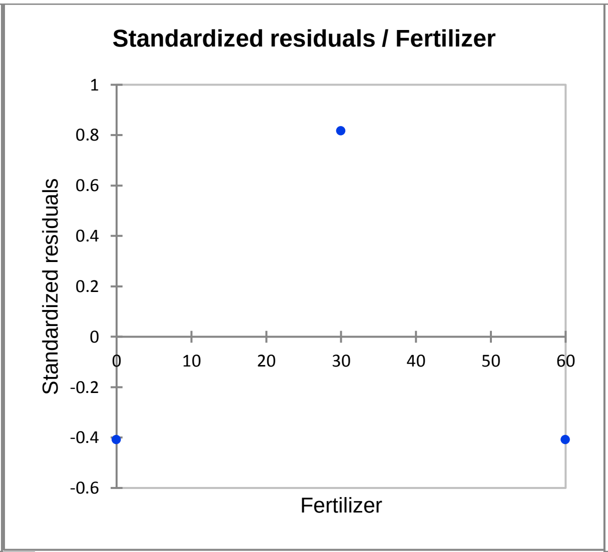
Figure: OFCOLACO-SOYBEAN YIELD / Standardized coefficients
(95% conf. interval)

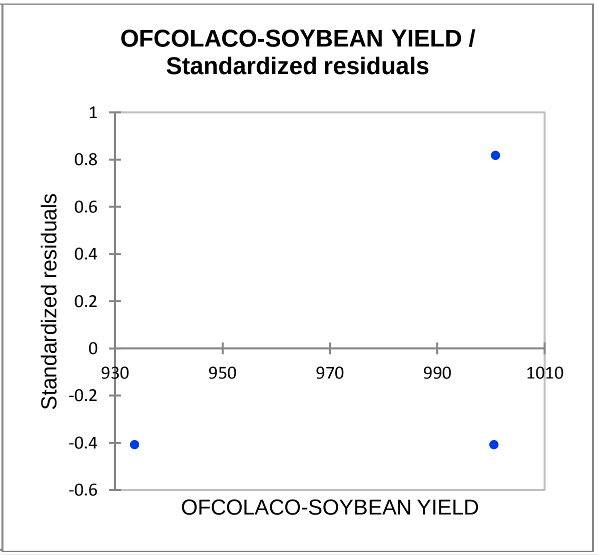

OFCOLACO-SOYBEAN YIELD / Standardized coefficients (95% conf. interval)

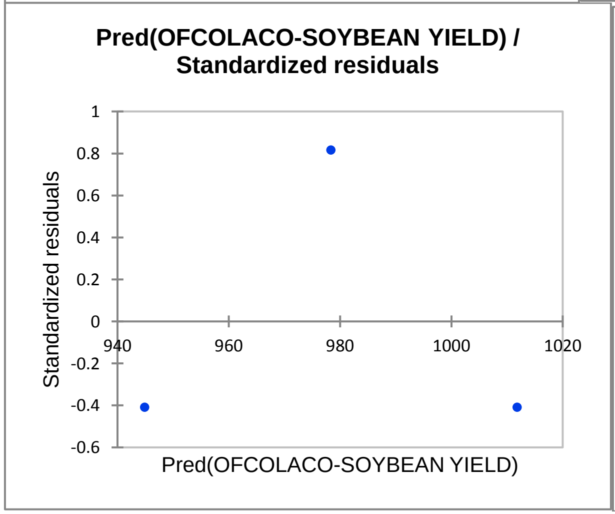
Predictions and residuals (OFCOLACO-SOYBEAN YIELD):

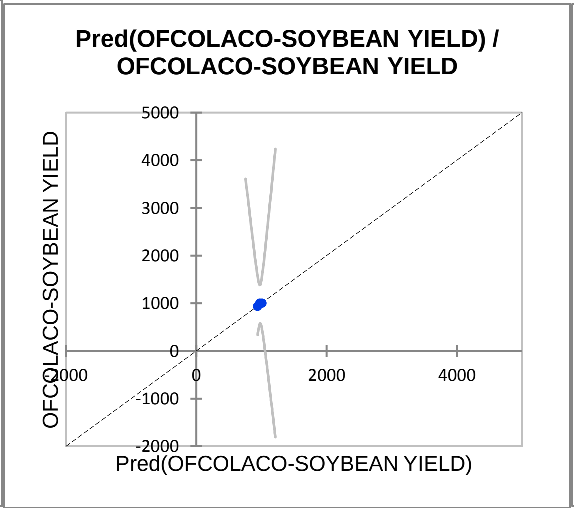
Observation	Weight	Fertilizer	OFCOLACO-SOYBEAN YIELD	Pred(OFCOLACO-SOYBEAN YIELD)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	933.700	944.950	-11.250	-0.408	25.156	625.316	1264.584	37.312	470.856	1419.044
Obs2	1	30.000	1000.900	978.400	22.500	0.816	15.910	776.246	1180.554	31.820	574.091	1382.709
Obs3	1	60.000	1000.600	1011.850	-11.250	-0.408	25.156	692.216	1331.484	37.312	537.756	1485.944

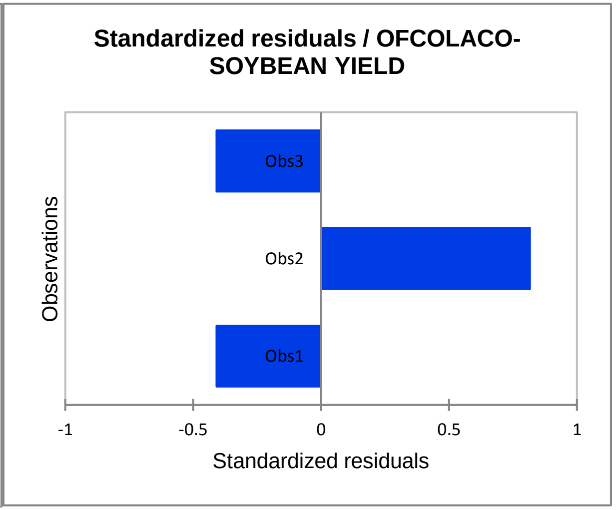

Regression of OFCOLACO-SOYBEAN YIELD by Fertilizer (R²=0.747)


Standardized residuals / Fertilizer


OFCOLACO-SOYBEAN YIELD / Standardized residuals


Pred(OFCOLACO-SOYBEAN YIELD) / Standardized residuals


Pred(OFCOLACO-SOYBEAN YIELD) / OFCOLACO-SOYBEAN YIELD


Standardized residuals / OFCOLACO-SOYBEAN YIELD

Test assumptions:

Test on the normality of the residuals (Shapiro-Wilk) (OFCOLACO-SOYBEAN YIELD):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:
H0: The residuals follow a Normal distribution.
Ha: The residuals do not follow a Normal distribution.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Interpretation (OFCOLACO-SOYBEAN YIELD):
Given the R2, 75% of the variability of the dependent variable OFCOLACO-SOYBEAN YIELD is explained by the explanatory variable.
Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Appendix 4.13: Summary Statistics for soybean Syferkuil 2018

Regression of variable SYFERKUIL SOYBEAN YIELD:
Goodness of fit statistics (SYFERKUIL SOYBEAN YIELD):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.947
Adjusted R²	0.894
MSE	10004.167
RMSE	100.021
MAPE	4.513
DW	3.000
Cp	2.000
AIC	28.336
SBC	26.534
PC	0.265

Analysis of variance (SYFERKUIL SOYBEAN YIELD):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	178443.380	178443.380	17.837	0.148
Error	1	10004.167	10004.167		
Corrected Total	2	188447.547			

Computed against model Y=Mean(Y)

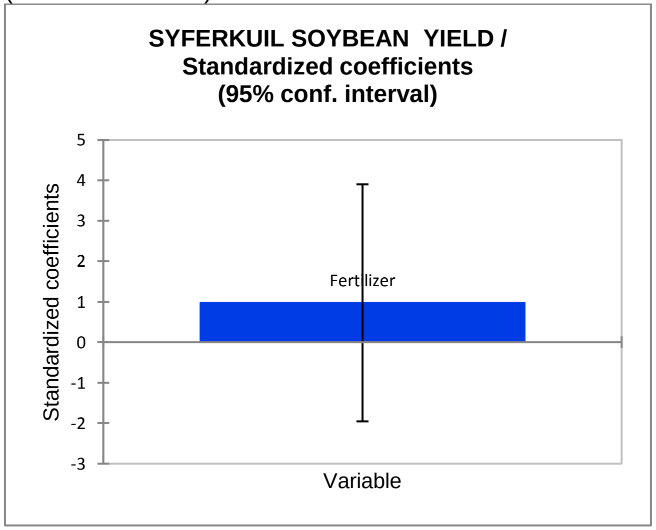
Model parameters (SYFERKUIL SOYBEAN YIELD):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	962.867	91.306	10.545	0.060	-197.287	2123.021
Fertilizer	9.957	2.358	4.223	0.148	-19.998	39.912

Equation of the model (SYFERKUIL SOYBEAN YIELD):
SYFERKUIL SOYBEAN YIELD = 962.866666666667+9.95666666666666*Fertilizer
Standardized coefficients (SYFERKUIL SOYBEAN YIELD):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.973	0.230	4.223	0.148	-1.955	3.901

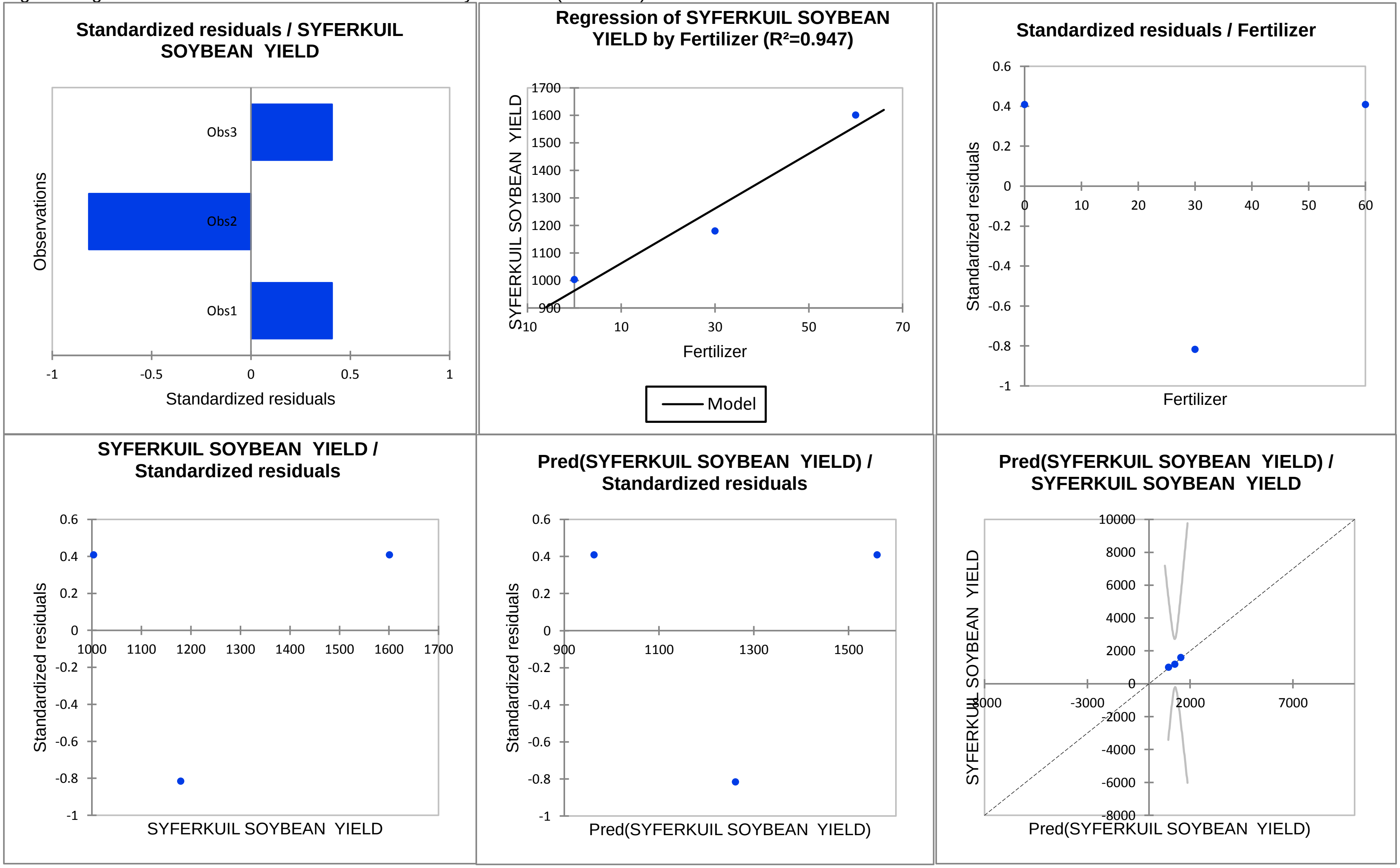
Figure: SYFERKUIL SOYBEAN YIELD / Standardized coefficients (95% conf. interval)



Predictions and residuals (SYFERKUIL SOYBEAN YIELD):

Observation	Weight	Fertilizer	SYFERKUIL SOYBEAN YIELD	Pred(SYFERKUIL SOYBEAN YIELD)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1003.700	962.867	40.833	0.408	91.306	-197.287	2123.021	135.429	-757.920	2683.653
Obs2	1	30.000	1179.900	1261.567	-81.667	-0.816	57.747	527.821	1995.313	115.494	-205.925	2729.058
Obs3	1	60.000	1601.100	1560.267	40.833	0.408	91.306	400.113	2720.421	135.429	-160.520	3281.053

Figure: Regression of SYFERKUIL SOYBEAN YIELD by Fertilizer (R²=0.947)



Test on the normality of the residuals (Shapiro-Wilk) (SYFERKUIL SOYBEAN YIELD):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:
H0: The residuals follow a Normal distribution.
Ha: The residuals do not follow a Normal distribution.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Interpretation (SYFERKUIL SOYBEAN YIELD):
Given the R2, 95% of the variability of the dependent variable SYFERKUIL SOYBEAN YIELD is explained by the explanatory variable.
Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Appendix 4.14: Summary Statistics for soybean Punda Maria 2018

Regression of variable PUNDA MARIA- SOYBEAN YIELD:
Goodness of fit statistics (PUNDA MARIA- SOYBEAN YIELD):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.252
Adjusted R²	-0.496
MSE	113382.507
RMSE	336.723
MAPE	8.225
DW	3.000
Cp	2.000
AIC	35.620
SBC	33.817
PC	3.740

Analysis of variance (PUNDA MARIA- SOYBEAN YIELD):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	38198.480	38198.480	0.337	0.665
Error	1	113382.507	113382.507		
Corrected Total	2	151580.987			

Computed against model Y=Mean(Y)

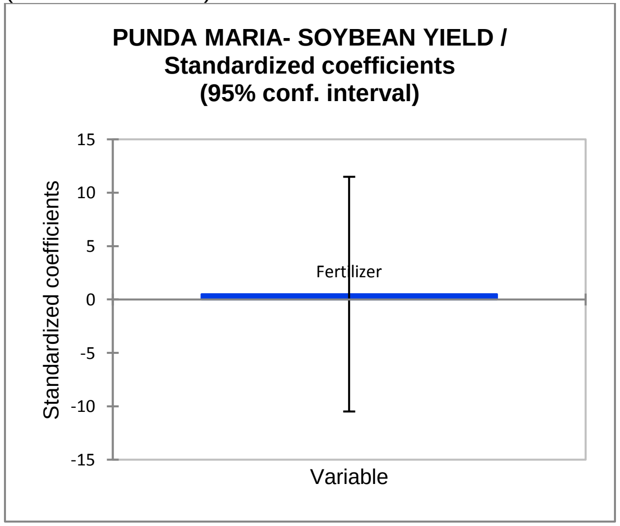
Model parameters (PUNDA MARIA- SOYBEAN YIELD):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	2046.067	307.385	6.656	0.095	-1859.628	5951.761
Fertilizer	4.607	7.937	0.580	0.665	-96.238	105.451

Equation of the model (PUNDA MARIA- SOYBEAN YIELD):
PUNDA MARIA- SOYBEAN YIELD = 2046.06666666667+4.60666666666667*Fertilizer
Standardized coefficients (PUNDA MARIA- SOYBEAN YIELD):

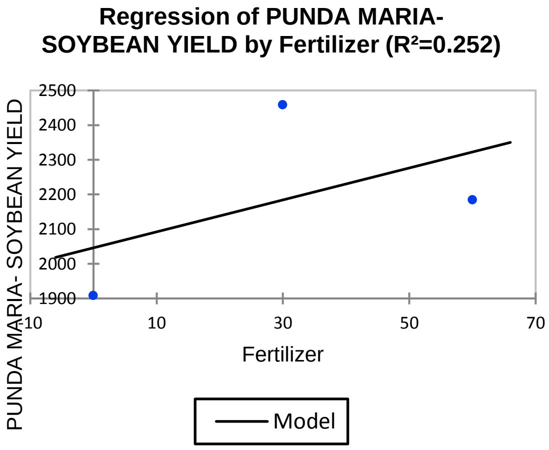
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.502	0.865	0.580	0.665	-10.487	11.491

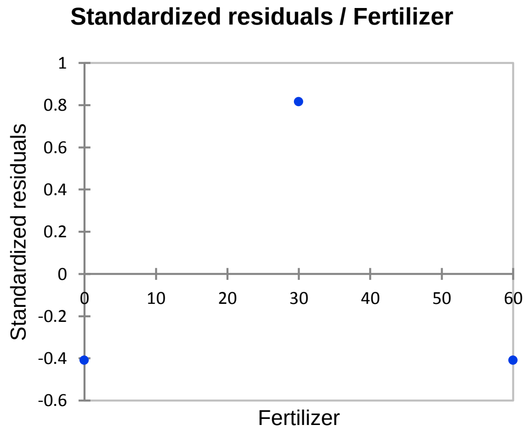
Figure: PUNDA MARIA- SOYBEAN YIELD / Standardized coefficients
(95% conf. interval)

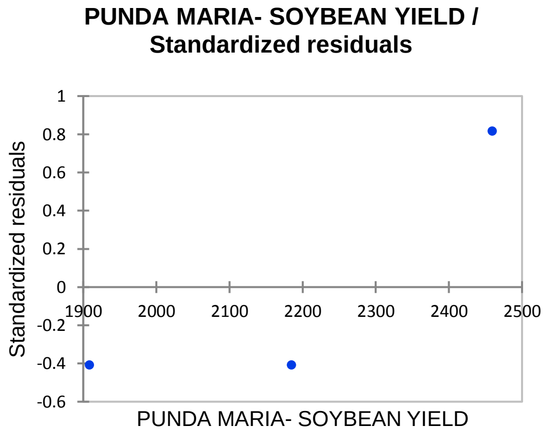


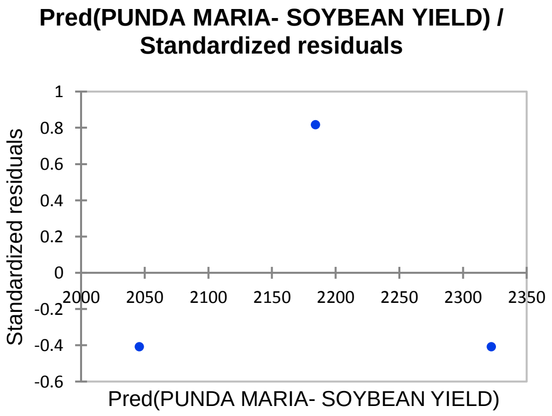
Predictions and residuals (PUNDA MARIA- SOYBEAN YIELD):

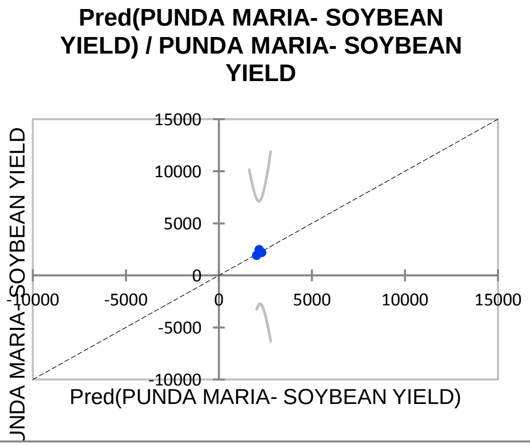
Observation	Weight	Fertilizer	PUNDA MARIA- SOYBEAN YIELD	Pred(PUNDA MARIA- SOYBEAN YIELD)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1908.600	2046.067	-137.467	-0.408	307.385	-1859.628	5951.761	455.925	-3747.014	7839.148
Obs2	1	30.000	2459.200	2184.267	274.933	0.816	194.407	-285.911	4654.445	388.814	-2756.089	7124.623
Obs3	1	60.000	2185.000	2322.467	-137.467	-0.408	307.385	-1583.228	6228.161	455.925	-3470.614	8115.548

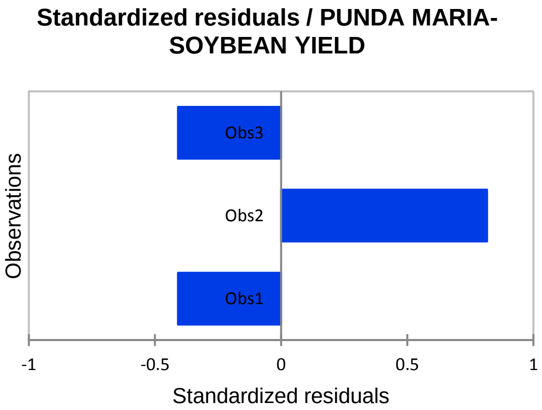












Test assumptions:

Test on the normality of the residuals (Shapiro-Wilk) (PUNDA MARIA- SOYBEAN YIELD):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

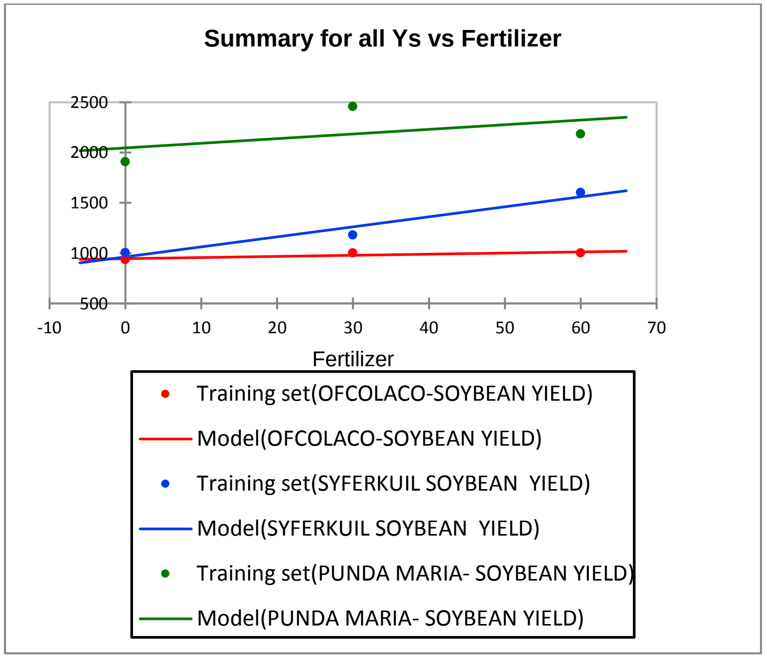
Test interpretation:
H0: The residuals follow a Normal distribution.
Ha: The residuals do not follow a Normal distribution.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Interpretation (PUNDA MARIA- SOYBEAN YIELD):
Given the R2, 25% of the variability of the dependent variable PUNDA MARIA- SOYBEAN YIELD is explained by the explanatory variable.
Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Summary of the normality tests for all the dependent variables:

	p-value
OFCOLACO-SOYBEAN YIELD	**< 0.0001**
SYFERKUIL SOYBEAN YIELD	**< 0.0001**
PUNDA MARIA- SOYBEAN YIELD	**< 0.0001**

Values in bold are correspond to tests where the null hypothesis is not accepted with a significance level alpha=0.05
Summary for all Ys:

	OFCOLACO-SOYBEAN YIELD	SYFERKUIL SOYBEAN YIELD	PUNDA MARIA-SOYBEAN YIELD
R²	0.747	0.947	0.252
F	2.947	17.837	0.337
Pr > F	0.336	0.148	0.665



Appendix 4.15: Summary Statistics for sunflower Ofcolaco 2018

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
OFCOLACO SUNFLOWER	3	0	3	1192.100	1397.600	1303.167	103.755
SYFERKUIL SUNFLOWER	3	0	3	1190.500	2119.800	1546.733	501.161
PUNDA MARIA SUNFLOWER	3	0	3	1055.800	1374.400	1226.433	160.505
Fertilizer	3	0	3	0.000	150.000	75.000	75.000

Correlation matrix:

	Fertilizer	OFCOLACO SUNFLOWER	SYFERKUIL SUNFLOWER	PUNDA MARIA SUNFLOWER
Fertilizer	**1**	0.375	-0.927	0.992
OFCOLACO SUNFLOWER	0.375	**1**	0.000	0.259
SYFERKUIL SUNFLOWER	-0.927	0.000	**1**	-0.966
PUNDA MARIA SUNFLOWER	0.992	0.259	-0.966	**1**

Regression of variable OFCOLACO SUNFLOWER:

Goodness of fit statistics (OFCOLACO SUNFLOWER):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.141
Adjusted R²	-0.719
MSE	18503.707
RMSE	136.028
MAPE	5.833
DW	3.000
Cp	2.000
AIC	30.181
SBC	28.379
PC	4.297

Analysis of variance (OFCOLACO SUNFLOWER):

Source	**DF**	**Sum of squares**	**Mean squares**	**F**	**Pr > F**
Model	1	3026.420	3026.420	0.164	0.755
Error	1	18503.707	18503.707		
Corrected Total	2	21530.127			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (OFCOLACO SUNFLOWER):

Source	**DF**	**Sum of squares**	**Mean squares**	**F**	**Pr > F**
Fertilizer	1	3026.420	3026.420	0.164	0.755

Type III Sum of Squares analysis (OFCOLACO SUNFLOWER):

Source	**DF**	**Sum of squares**	**Mean squares**	**F**	**Pr > F**
Fertilizer	1	3026.420	3026.420	0.164	0.755

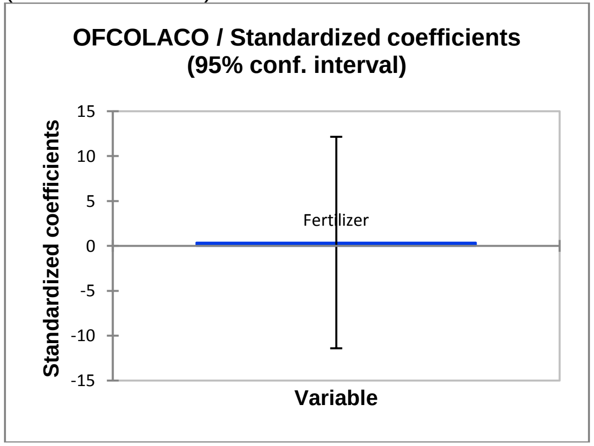
Model parameters (OFCOLACO SUNFLOWER):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1264.267	124.176	10.181	0.062	-313.543	2842.076
Fertilizer	0.519	1.282	0.404	0.755	-15.777	16.814

Equation of the model (OFCOLACO SUNFLOWER):
OFCOLACO SUNFLOWER = 1264.26666666667+0.518666666666667*Fertilizer
Standardized coefficients (OFCOLACO SUNFLOWER):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.375	0.927	0.404	0.755	-11.404	12.154

Figure: OFCOLACO SUNFLOWER / Standardized coefficients
(95% conf. interval)



Predictions and residuals (OFCOLACO SUNFLOWER):

Observation	Weight	Fertilizer	OFCOLACO SUNFLOWER	Pred(OFCOLACO SUNFLOWER)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1319.800	1264.267	55.533	0.408	124.176	-313.543	2842.076	184.183	-1076.003	3604.536
Obs2	1	75.000	1192.100	1303.167	-111.067	-0.816	78.536	305.272	2301.061	157.072	-692.622	3298.955
Obs3	1	150.000	1397.600	1342.067	55.533	0.408	124.176	-235.743	2919.876	184.183	-998.203	3682.336

Figure: Regression of OFCOLACO SUNFLOWER by Fertilizer (R²=0.141)

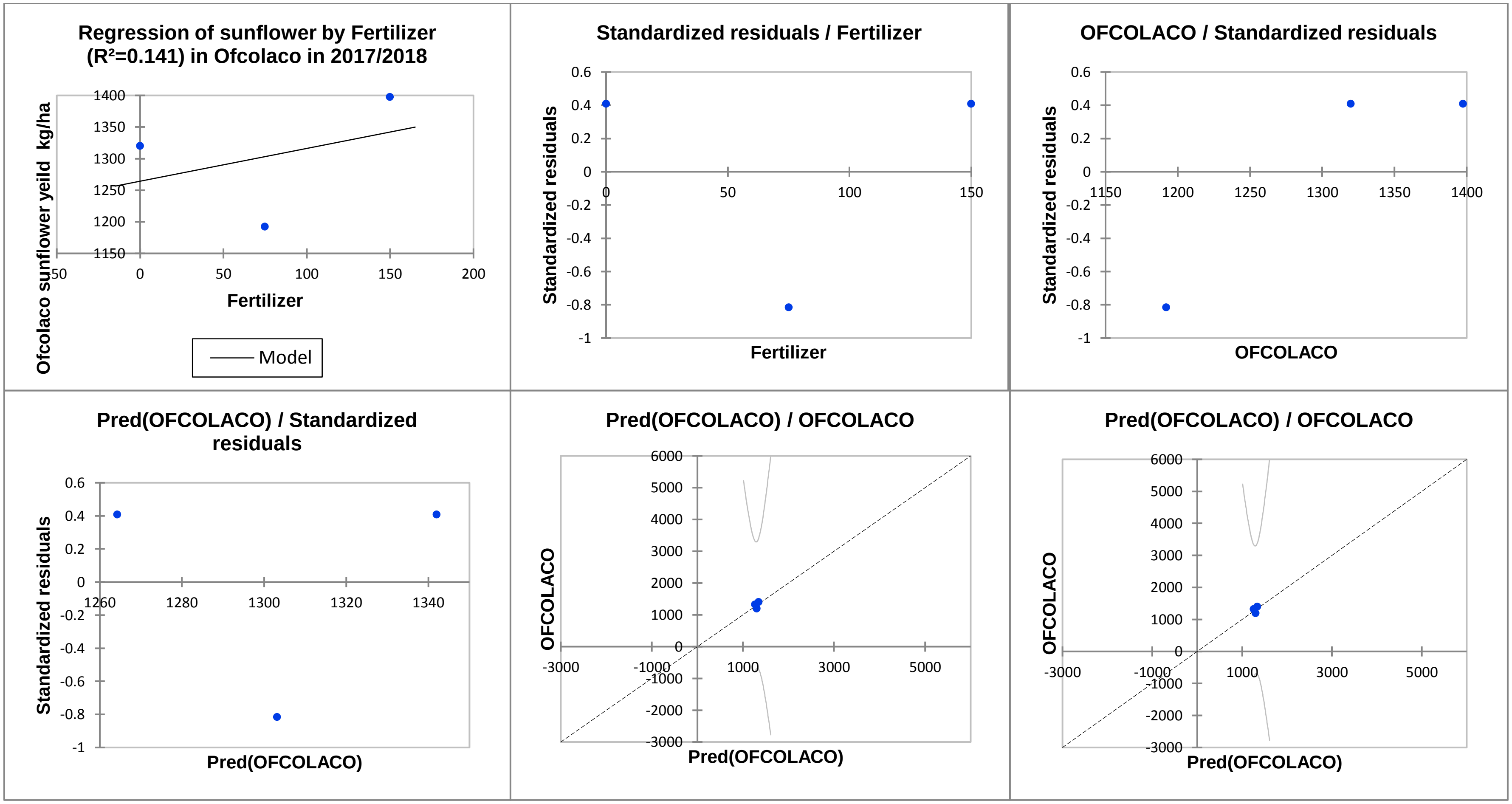
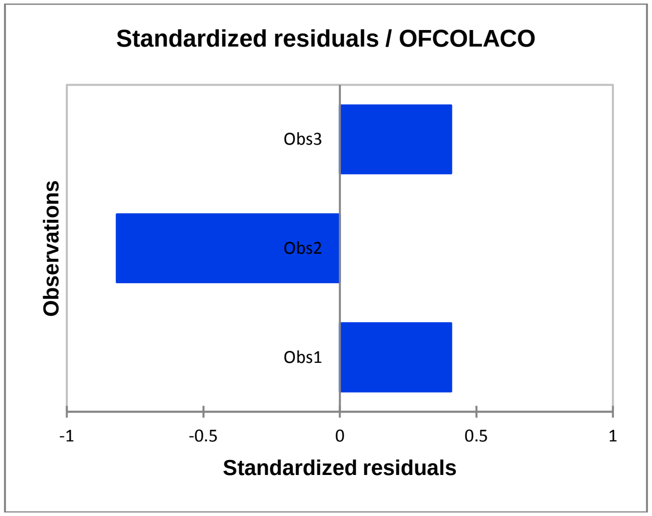


Figure: Standardized residuals / OFCOLACO SUNFLOWER



Interpretation (OFCOLACO SUNFLOWER):
Given the R2, 14% of the variability of the dependent variable OFCOLACO SUNFLOWER is explained by the explanatory variable.
Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Appendix 4.16: Summary Statistics for sunflower Syferkuil 2018

Regression of variable SYFERKUIL SUNFLOWER:
Goodness of fit statistics (SYFERKUIL SUNFLOWER):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.860
Adjusted R²	0.719
MSE	70525.042
RMSE	265.566
MAPE	10.175
DW	3.000

Cp	2.000
AIC	34.195
SBC	32.393
PC	0.702

Analysis of variance (SYFERKUIL SUNFLOWER):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	431799.245	431799.245	6.123	0.245
Error	1	70525.042	70525.042		
Corrected Total	2	502324.287			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (SYFERKUIL SUNFLOWER):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer	1	431799.245	431799.245	6.123	0.245

Type III Sum of Squares analysis (SYFERKUIL SUNFLOWER):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer	1	431799.245	431799.245	6.123	0.245

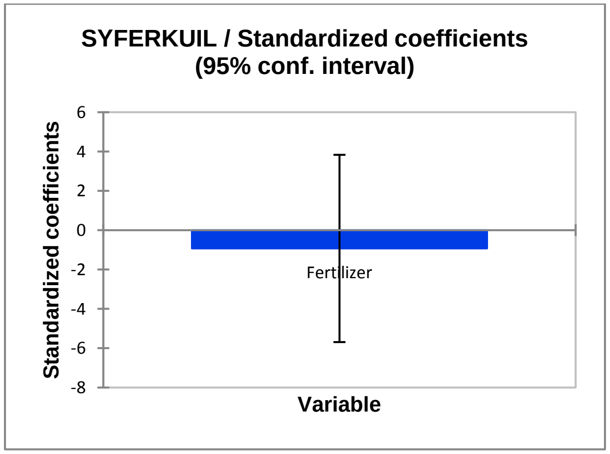
Model parameters (SYFERKUIL SUNFLOWER):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	2011.383	242.427	8.297	0.076	-1068.944	5091.711
Fertilizer	-6.195	2.504	-2.474	0.245	-38.009	25.618

Equation of the model (SYFERKUIL SUNFLOWER):
SYFERKUIL SUNFLOWER = 2011.38333333333-6.19533333333333*Fertilizer
Standardized coefficients (SYFERKUIL SUNFLOWER):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	-0.927	0.375	-2.474	0.245	-5.688	3.834

Figure: SYFERKUIL SUNFLOWER / Standardized coefficients
(95% conf. interval)



Predictions and residuals (SYFERKUIL SUNFLOWER):

Observation	Weight	Fertilizer	SYFERKUIL SUNFLOWER	Pred(SYFERKUIL SUNFLOWER)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	2119.800	2011.383	108.417	0.408	242.427	-1068.944	5091.711	359.577	-2557.481	6580.247
Obs2	1	75.000	1329.900	1546.733	-216.833	-0.816	153.324	-401.437	3494.904	306.649	-2349.607	5443.074
Obs3	1	150.000	1190.500	1082.083	108.417	0.408	242.427	-1998.244	4162.411	359.577	-3486.781	5650.947

Figure: Regression of SYFERKUIL SUNFLOWER by Fertilizer ($R^2=0.860$)

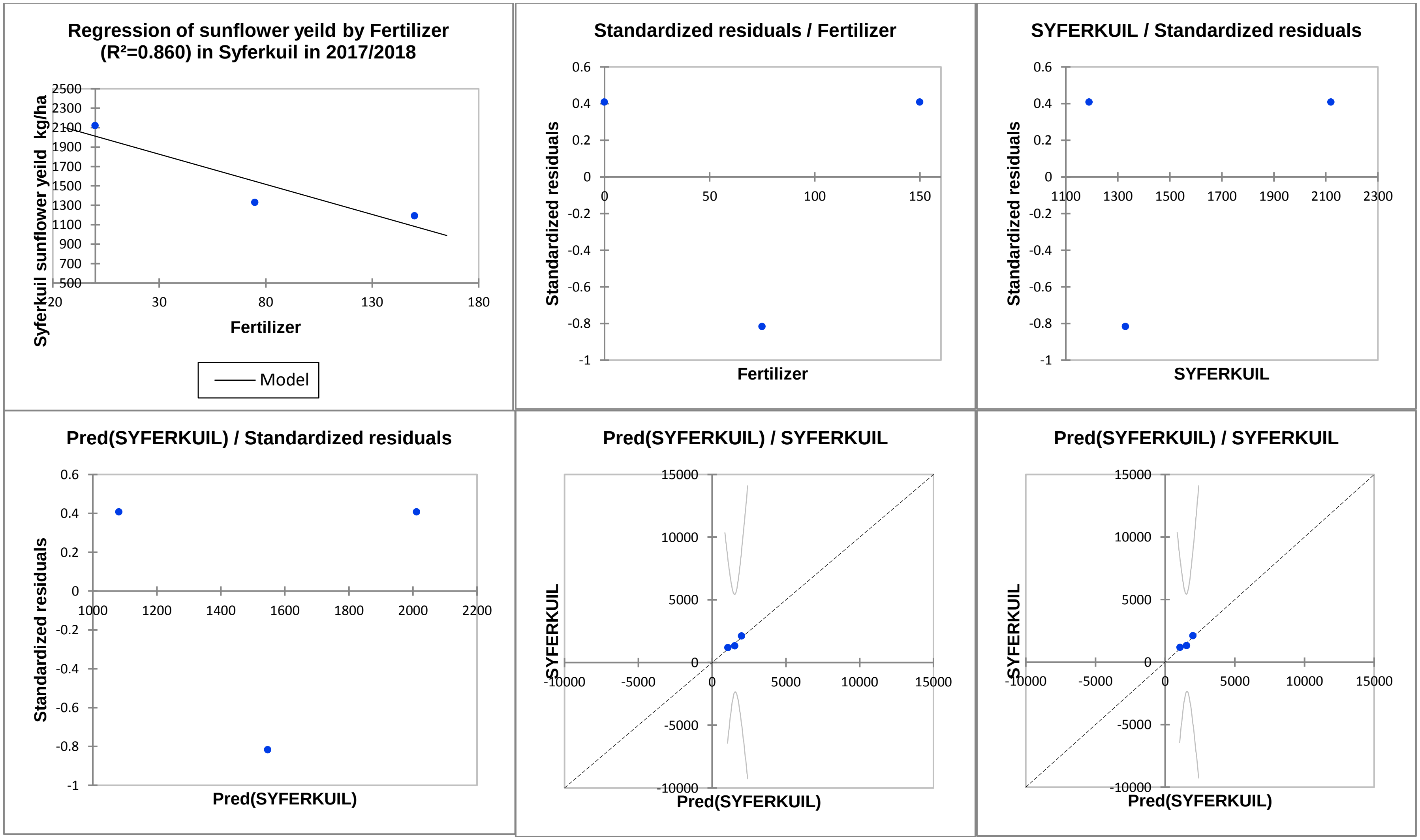
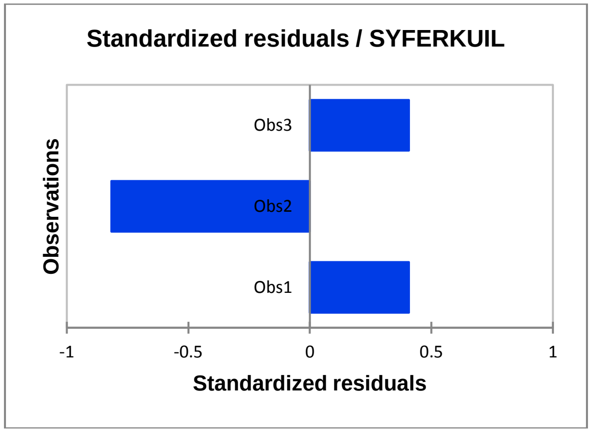


Figure: Standardized residuals / SYFERKUIL SUNFLOWER



Interpretation (SYFERKUIL SUNFLOWER):
Given the R2, 86% of the variability of the dependent variable SYFERKUIL SUNFLOWER is explained by the explanatory variable.
Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Appendix 4.17: Summary Statistics for sunflower for Punda Maria 2018

Regression of variable PUNDA MARIA SUNFLOWER:

Goodness of fit statistics (PUNDA MARIA SUNFLOWER):

Observations	3.000
Sum of weights	3.000
DF	1.000
R^2	0.985
Adjusted R^2	0.970
MSE	770.667
RMSE	27.761
MAPE	1.238
DW	3.000
Cp	2.000
AIC	20.646
SBC	18.843
PC	0.075

Analysis of variance (PUNDA MARIA SUNFLOWER):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	50752.980	50752.980	65.856	0.078
Error	1	770.667	770.667		
Corrected Total	2	51523.647			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (PUNDA MARIA SUNFLOWER):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer	1	50752.980	50752.980	65.856	0.078

Type III Sum of Squares analysis (PUNDA MARIA SUNFLOWER):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Fertilizer	1	50752.980	50752.980	65.856	0.078

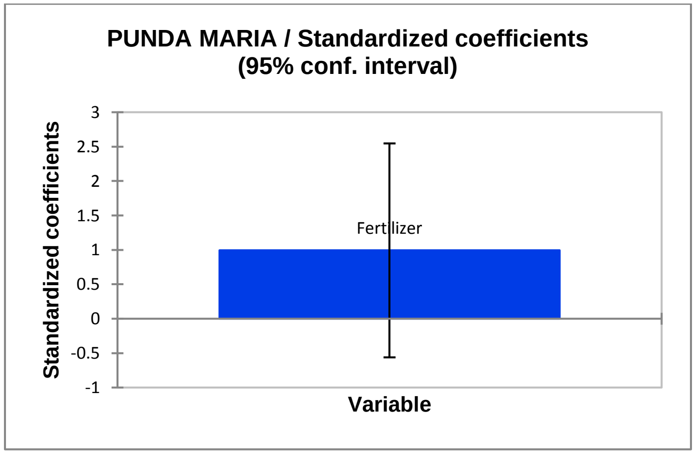
Model parameters (PUNDA MARIA SUNFLOWER):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1067.133	25.342	42.109	**0.015**	745.131	1389.135
Fertilizer	2.124	0.262	8.115	0.078	-1.202	5.450

Equation of the model (PUNDA MARIA SUNFLOWER):
PUNDA MARIA SUNFLOWER = 1067.13333333333+2.124*Fertilizer
Standardized coefficients (PUNDA MARIA SUNFLOWER):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.992	0.122	8.115	0.078	-0.561	2.546

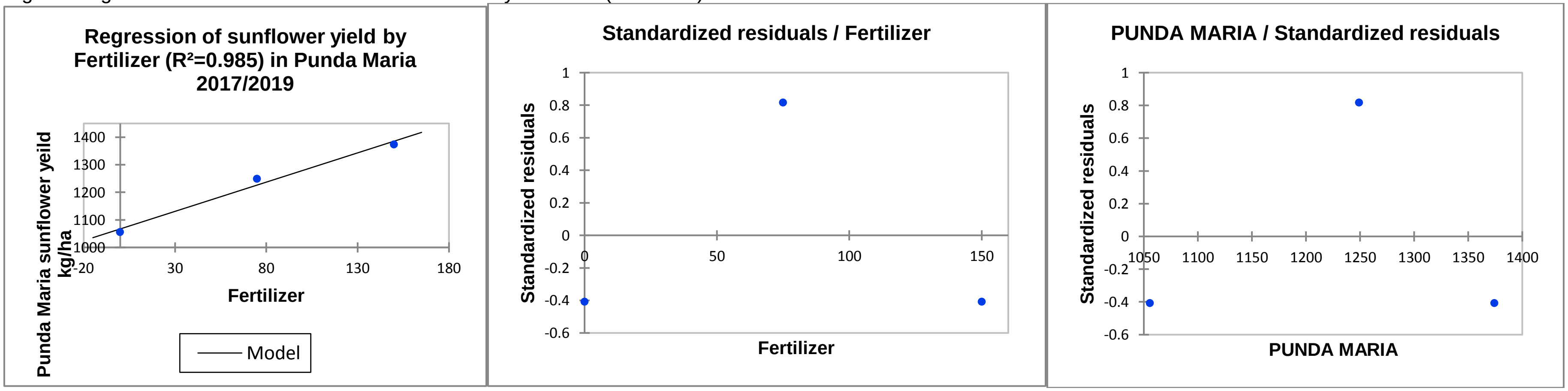
Figure: PUNDA MARIA SUNFLOWER / Standardized coefficients
(95% conf. interval)

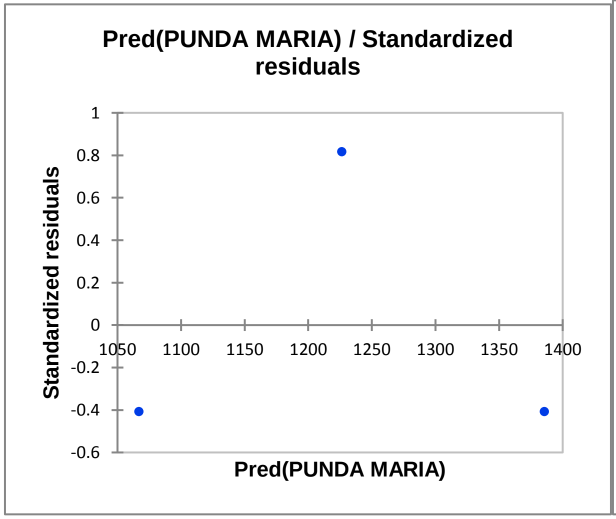


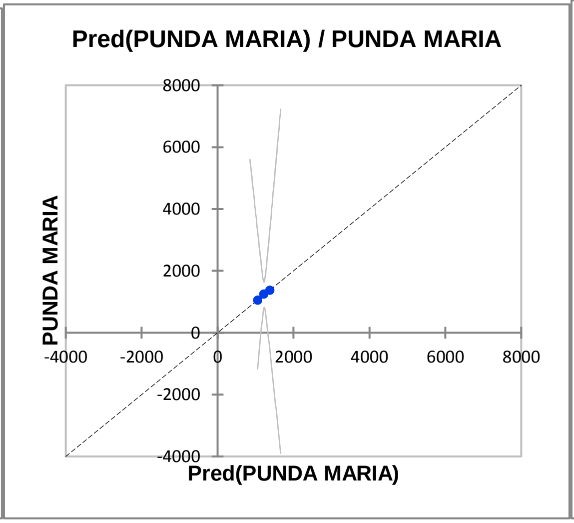
Predictions and residuals (PUNDA MARIA SUNFLOWER):

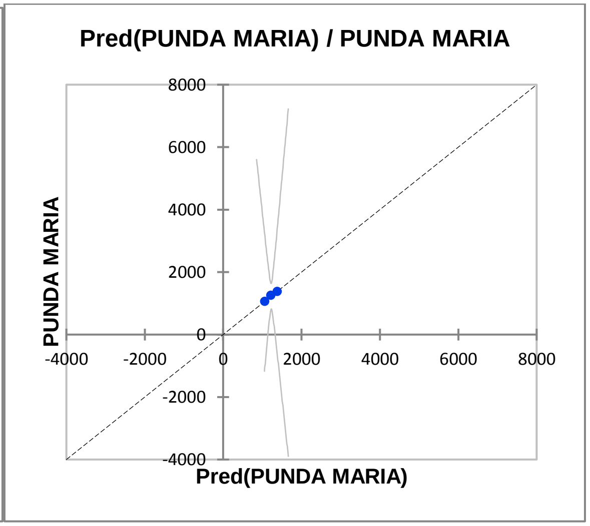
Observation	Weight	Fertilizer	PUNDA MARIA SUNFLOWER	Pred(PUNDA MARIA SUNFLOWER)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1055.800	1067.133	-11.333	-0.408	25.342	745.131	1389.135	37.588	589.527	1544.739
Obs2	1	75.000	1249.100	1226.433	22.667	0.816	16.028	1022.781	1430.085	32.056	819.129	1633.737
Obs3	1	150.000	1374.400	1385.733	-11.333	-0.408	25.342	1063.731	1707.735	37.588	908.127	1863.339

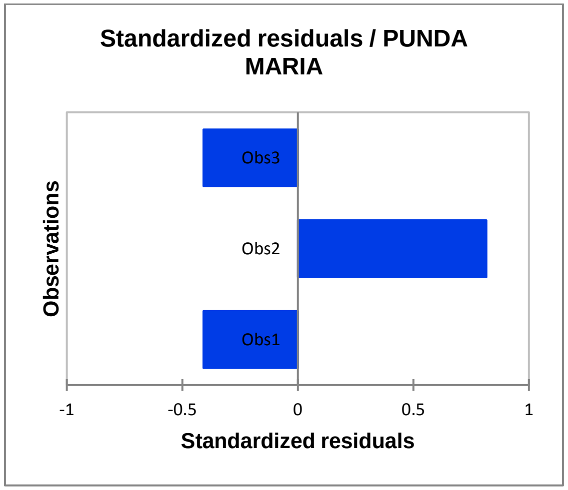
Figure: Regression of PUNDA MARIA SUNFLOWER by Fertilizer (R²=0.985)




Pred(PUNDA MARIA) / Standardized residuals
Standardized residuals
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1050
1100
1150
1200
1250
1300
1350
1400
Pred(PUNDA MARIA)


Pred(PUNDA MARIA) / PUNDA MARIA
PUNDA MARIA
8000
6000
4000
2000
0
-2000
-4000
-4000
-2000
0
2000
4000
6000
8000
Pred(PUNDA MARIA)


Pred(PUNDA MARIA) / PUNDA MARIA
PUNDA MARIA
8000
6000
4000
2000
0
-2000
-4000
-4000
-2000
0
2000
4000
6000
8000
Pred(PUNDA MARIA)


Standardized residuals / PUNDA MARIA
Observations
Obs3
Obs2
Obs1
-1
-0.5
0
0.5
1
Standardized residuals

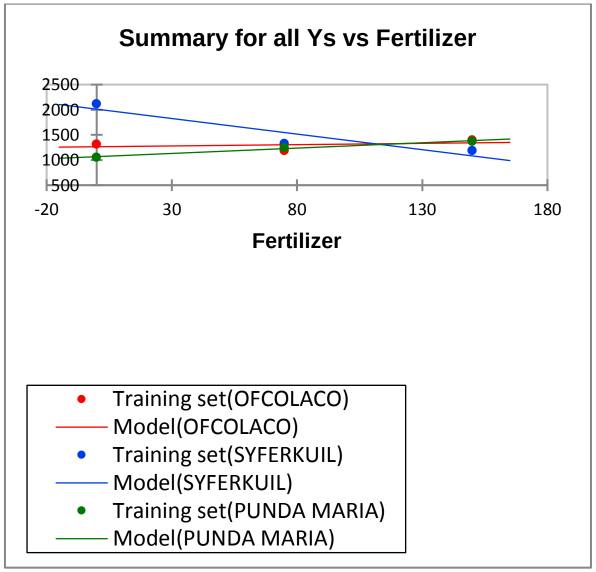
Interpretation (PUNDA MARIA SUNFLOWER):

Given the R2, 99% of the variability of the dependent variable PUNDA MARIA SUNFLOWER is explained by the explanatory variable.

Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Summary for all Ys:

	OFCOLACO SUNFLOWER	**SYFERKUIL SUNFLOWER**	**PUNDA MARIA SUNFLOWER**
R²	0.141	0.860	0.985
F	0.164	6.123	65.856
Pr > F	0.755	0.245	0.078
Fertilizer	0.164	6.123	65.856
	0.755	0.245	0.078



Appendix 4.18: Summary Statistics for groundnut Ofcolaco 2018

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
OFCOLACO-GROUNDNU YIELD	3	0	3	1560.500	1678.600	1621.600	59.157
SYFERKUIL GROUNDNUT YIELD	3	0	3	1021.700	1208.300	1134.167	99.030
PUNDA MARIA- GROUNDNUT YIELD	3	0	3	1172.500	1521.700	1400.933	197.937
Fertilizer	3	0	3	0.000	60.000	30.000	30.000

Correlation matrix:

	Fertilizer	OFCOLACO-GROUNDNU YIELD	SYFERKUIL GROUNDNUT YIELD	PUNDA MARIA- GROUNDNUT YIELD
Fertilizer	**1**	0.551	-0.761	0.882
OFCOLACO-GROUNDNU YIELD	0.551	**1**	0.121	0.879
SYFERKUIL GROUNDNUT YIELD	-0.761	0.121	**1**	-0.366
PUNDA MARIA- GROUNDNUT YIELD	0.882	0.879	-0.366	**1**

Goodness of fit statistics (OFCOLACO-GROUNDNU YIELD):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.304
Adjusted R²	-0.393
MSE	4873.500
RMSE	69.810
MAPE	2.325
DW	3.000
Cp	2.000
AIC	26.179
SBC	24.376
PC	3.482

Analysis of variance (OFCOLACO-GROUNDNU YIELD):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	2125.520	2125.520	0.436	0.628
Error	1	4873.500	4873.500		
Corrected Total	2	6999.020			

Computed against model Y=Mean(Y)

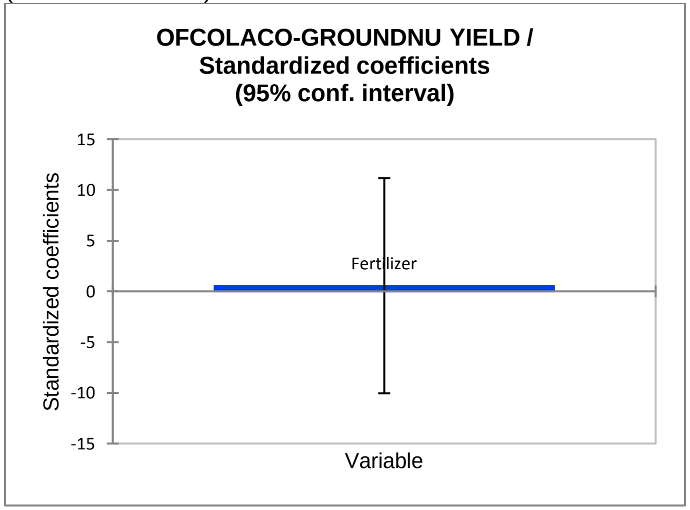
Model parameters (OFCOLACO-GROUNDNU YIELD):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1589.000	63.728	24.934	**0.026**	779.260	2398.740
Fertilizer	1.087	1.645	0.660	0.628	-19.821	21.994

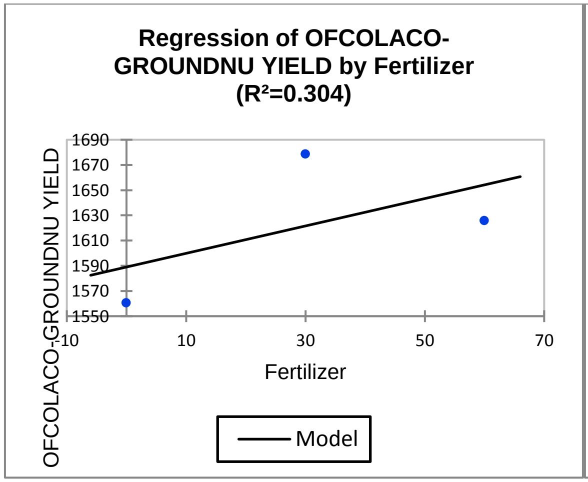
Equation of the model (OFCOLACO-GROUNDNU YIELD):
OFCOLACO-GROUNDNU YIELD = 1589+1.08666666666667*Fertilizer
Standardized coefficients (OFCOLACO-GROUNDNU YIELD):

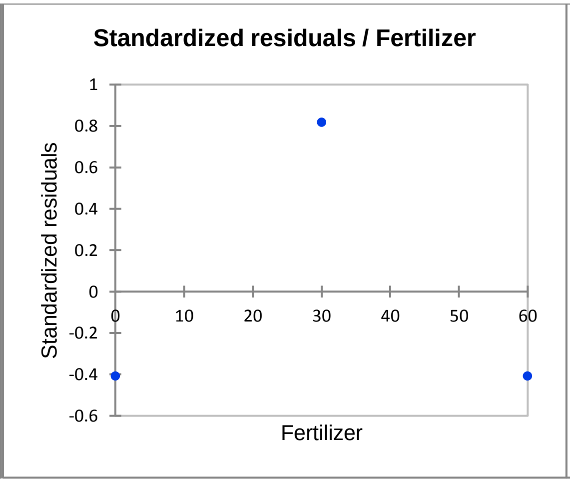
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.551	0.834	0.660	0.628	-10.052	11.154

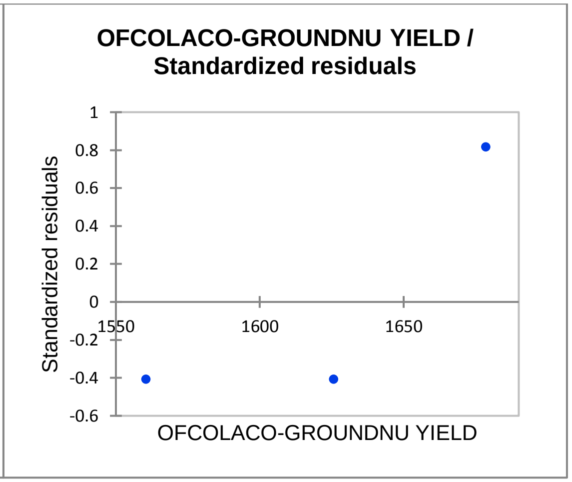
Figure: OFCOLACO-GROUNDNU YIELD / Standardized coefficients (95% conf. interval)

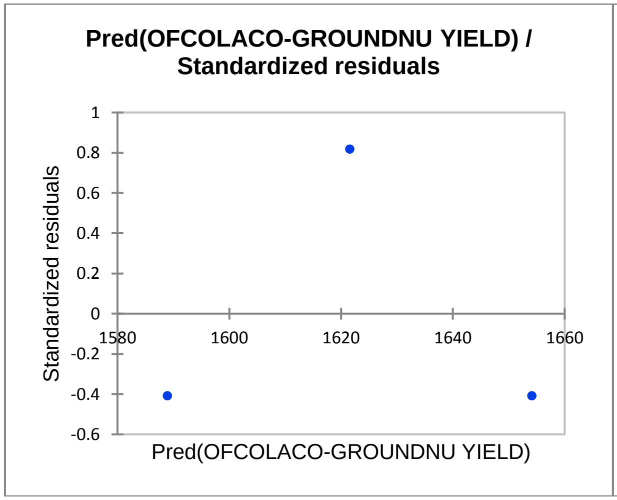


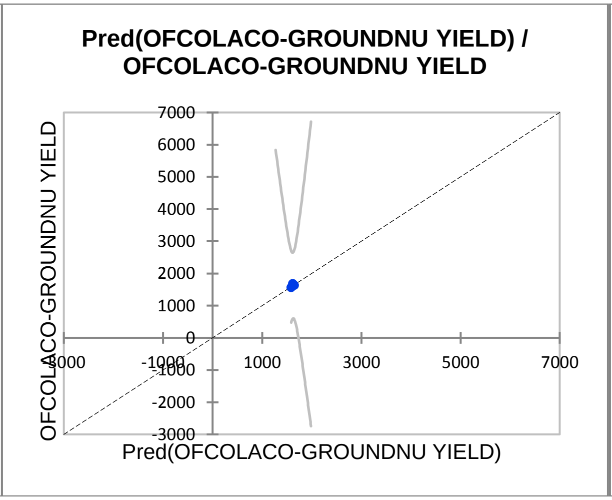
Observation	Weight	Fertilizer	OFCOLACO-GROUNDNU YIELD	Pred(OFCOLACO-GROUNDNU YIELD)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1560.500	1589.000	-28.500	-0.408	63.728	779.260	2398.740	94.524	387.961	2790.039
Obs2	1	30.000	1678.600	1621.600	57.000	0.816	40.305	1109.475	2133.725	80.610	597.351	2645.849
Obs3	1	60.000	1625.700	1654.200	-28.500	-0.408	63.728	844.460	2463.940	94.524	453.161	2855.239

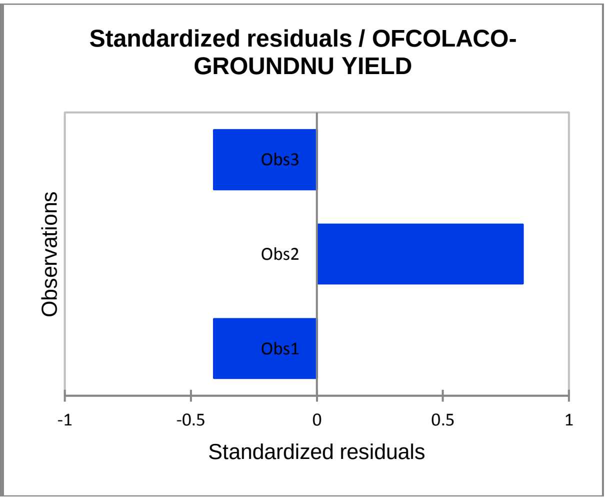

Regression of OFCOLACO-GROUNDNU YIELD by Fertilizer (R^2=0.304)


Standardized residuals / Fertilizer


OFCOLACO-GROUNDNU YIELD / Standardized residuals


Pred(OFCOLACO-GROUNDNU YIELD) / Standardized residuals


Pred(OFCOLACO-GROUNDNU YIELD) / OFCOLACO-GROUNDNU YIELD


Standardized residuals / OFCOLACO-GROUNDNU YIELD

Test assumptions:

Test on the normality of the residuals (Shapiro-Wilk) (OFCOLACO-GROUNDNU YIELD):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:
H0: The residuals follow a Normal distribution.
Ha: The residuals do not follow a Normal distribution.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Interpretation (OFCOLACO-GROUNDNU YIELD):
Given the R2, 30% of the variability of the dependent variable OFCOLACO-GROUNDNU YIELD is explained by the explanatory variable.
Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Appendix 4.19: Summary Statistics for groundnut Syferkuil 2018

Regression of variable SYFERKUIL GROUNDNUT YIELD:

Goodness of fit statistics (SYFERKUIL GROUNDNUT YIELD):

Observations	3.000
Sum of weights	3.000
DF	1.000
R²	0.580
Adjusted R²	0.159
MSE	8243.627
RMSE	90.794
MAPE	4.308
DW	3.000
Cp	2.000
AIC	27.756
SBC	25.953
PC	2.101

Analysis of variance (SYFERKUIL GROUNDNUT YIELD):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	11370.320	11370.320	1.379	0.449
Error	1	8243.627	8243.627		
Corrected Total	2	19613.947			

Computed against model Y=Mean(Y)

Model parameters (SYFERKUIL GROUNDNUT YIELD):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1209.567	82.884	14.594	**0.044**	156.431	2262.702
Fertilizer	-2.513	2.140	-1.174	0.449	-29.705	24.679

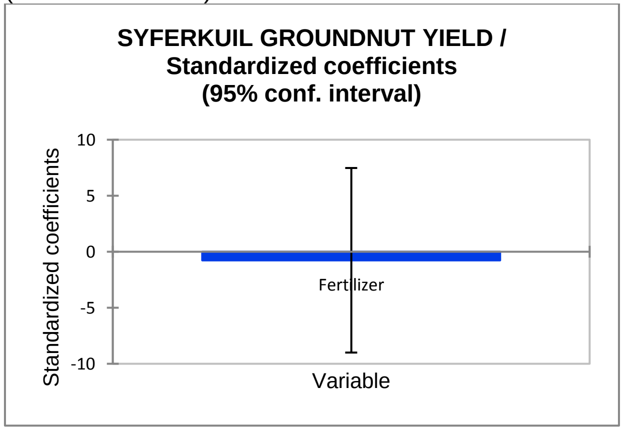
Equation of the model (SYFERKUIL GROUNDNUT YIELD):

SYFERKUIL GROUNDNUT YIELD = 1209.56666666667-2.51333333333333*Fertilizer

Standardized coefficients (SYFERKUIL GROUNDNUT YIELD):

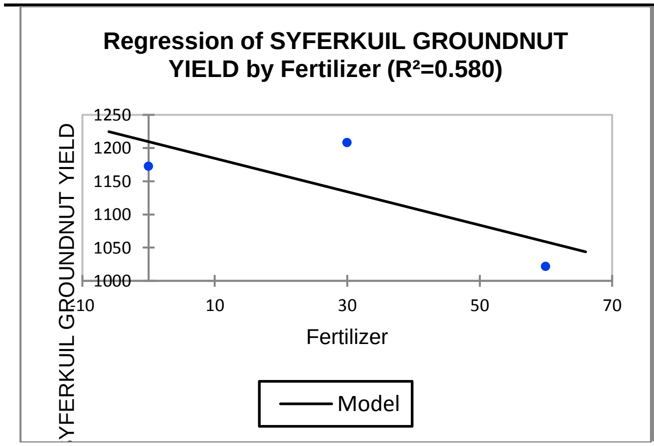
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	-0.761	0.648	-1.174	0.449	-8.999	7.476

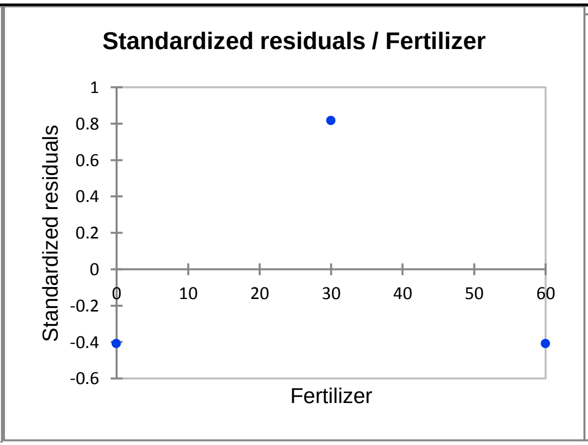
Figure: SYFERKUIL GROUNDNUT YIELD / Standardized coefficients (95% conf. interval)

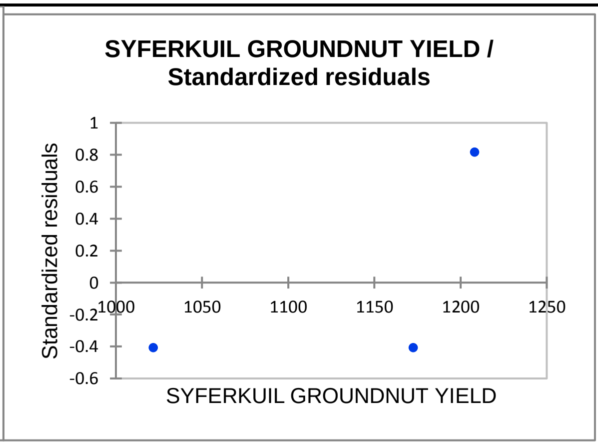

SYFERKUIL GROUNDNUT YIELD / Standardized coefficients (95% conf. interval)

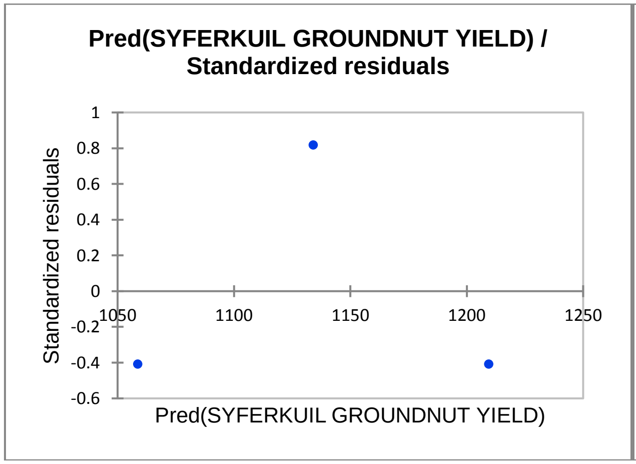
Predictions and residuals (SYFERKUIL GROUNDNUT YIELD):

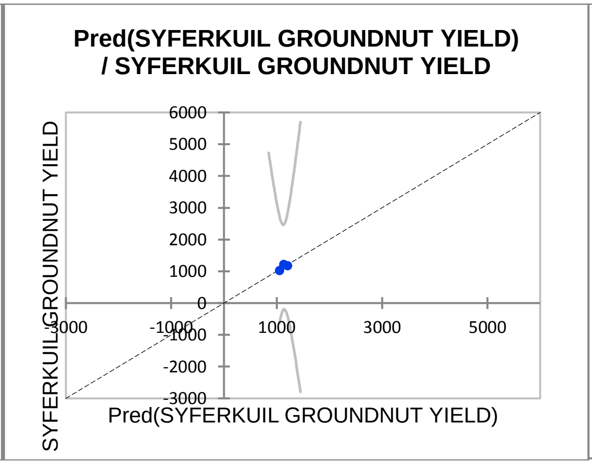
Observation	Weight	Fertilizer	SYFERKUIL GROUNDNUT YIELD	Pred(SYFERKUIL GROUNDNUT YIELD)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1172.500	1209.567	-37.067	-0.408	82.884	156.431	2262.702	122.936	-352.486	2771.620
Obs2	1	30.000	1208.300	1134.167	74.133	0.816	52.420	468.105	1800.228	104.840	-197.956	2466.290
Obs3	1	60.000	1021.700	1058.767	-37.067	-0.408	82.884	5.631	2111.902	122.936	-503.286	2620.820

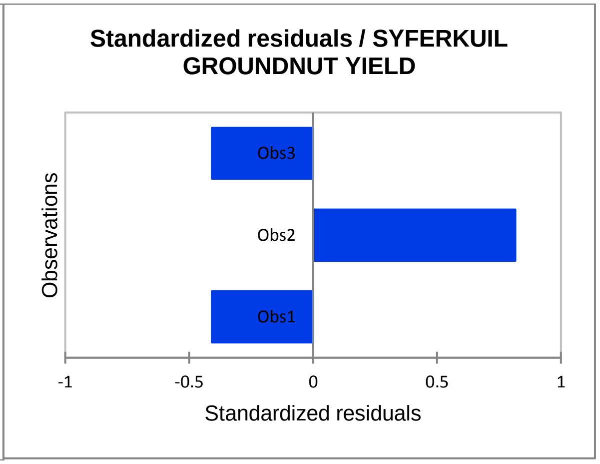

Regression of SYFERKUIL GROUNDNUT YIELD by Fertilizer (R²=0.580)


Standardized residuals / Fertilizer


SYFERKUIL GROUNDNUT YIELD / Standardized residuals







Test assumptions:

Test on the normality of the residuals (Shapiro-Wilk) (SYFERKUIL GROUNDNUT YIELD):

W	0.750
p-value (Two-tailed)	< 0.0001
alpha	0.05

Test interpretation:

H0: The residuals follow a Normal distribution.

Ha: The residuals do not follow a Normal distribution.

As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.

Interpretation (SYFERKUIL GROUNDNUT YIELD):

Given the R2, 58% of the variability of the dependent variable SYFERKUIL GROUNDNUT YIELD is explained by the explanatory variable.

Given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is not significantly better than what a basic mean would bring. The fact that variables do not bring significant information to the model may be interpreted in different ways: Either the variables do not contribute to the model, or some covariates that would help explaining the variability are missing, or the model is wrong, or the data contain errors.

Appendix 4.20: Summary Statistics for groundnut Punda Maria 2018

Regression of variable PUNDA MARIA- GROUNDNUT YIELD:

Goodness of fit statistics (PUNDA MARIA- GROUNDNUT YIELD):

Observations	3.000
Sum of weights	3.000
DF	1.000
R^2	0.778
Adjusted R^2	0.556
MSE	17388.167
RMSE	131.864
MAPE	5.089
DW	3.000
Cp	2.000
AIC	29.995
SBC	28.192
PC	1.110

Analysis of variance (PUNDA MARIA- GROUNDNUT YIELD):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	60970.320	60970.320	3.506	0.312
Error	1	17388.167	17388.167		
Corrected Total	2	78358.487			

Computed against model Y=Mean(Y)

Model parameters (PUNDA MARIA- GROUNDNUT YIELD):

Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Intercept	1226.333	120.375	10.188	0.062	-303.176	2755.843
Fertilizer	5.820	3.108	1.873	0.312	-33.672	45.312

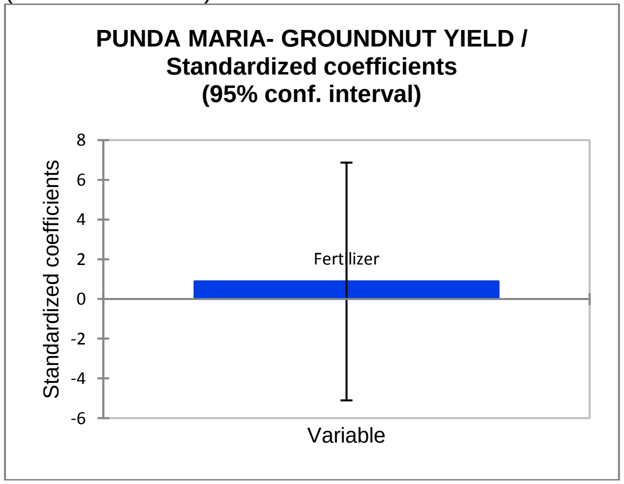
Equation of the model (PUNDA MARIA- GROUNDNUT YIELD):

PUNDA MARIA- GROUNDNUT YIELD = 1226.33333333333+5.82*Fertilizer

Standardized coefficients (PUNDA MARIA- GROUNDNUT YIELD):

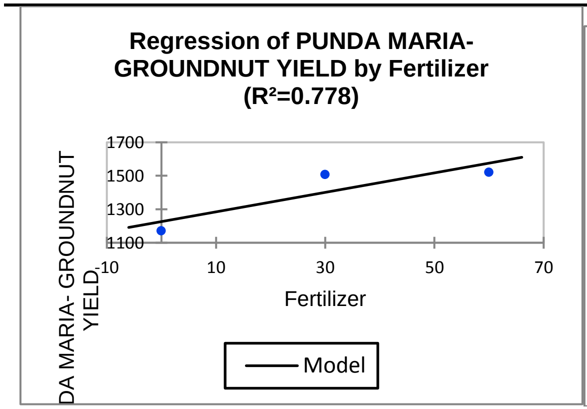
Source	Value	Standard error	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Fertilizer	0.882	0.471	1.873	0.312	-5.103	6.868

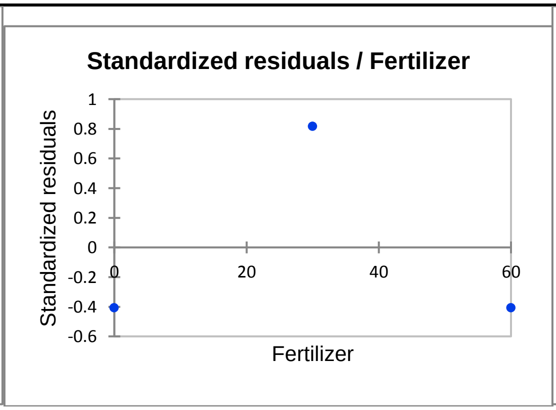
Figure: PUNDA MARIA- GROUNDNUT YIELD / Standardized coefficients (95% conf. interval)

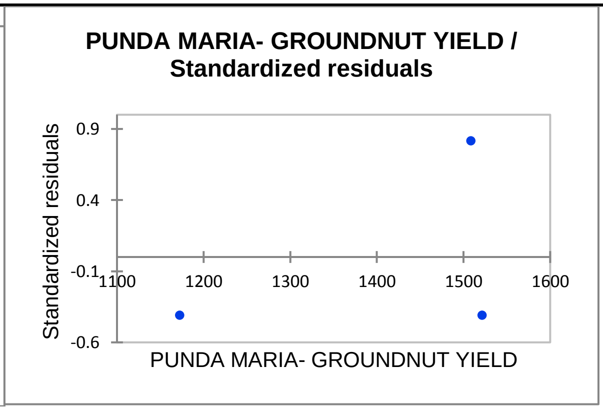


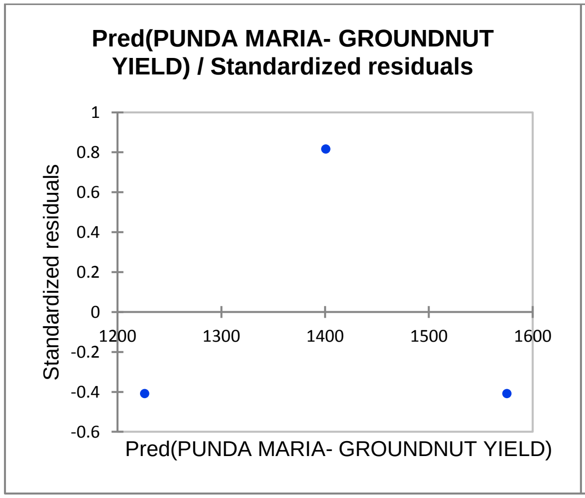
Predictions and residuals (PUNDA MARIA- GROUNDNUT YIELD):

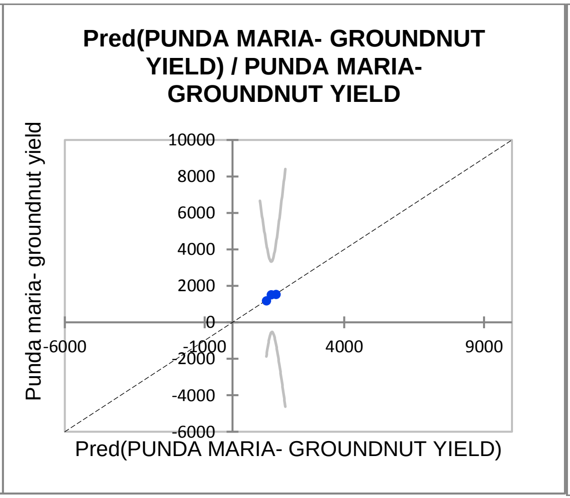
Observation	Weight	Fertilizer	PUNDA MARIA- GROUNDNUT YIELD	Pred(PUNDA MARIA- GROUNDNUT YIELD)	Residual	Std. residual	Std. dev. on pred. (Mean)	Lower bound 95% (Mean)	Upper bound 95% (Mean)	Std. dev. on pred. (Observation)	Lower bound 95% (Observation)	Upper bound 95% (Observation)
Obs1	1	0.000	1172.500	1226.333	-53.833	-0.408	120.375	-303.176	2755.843	178.545	-1042.296	3494.962
Obs2	1	30.000	1508.600	1400.933	107.667	0.816	76.132	433.587	2368.280	152.264	-533.760	3335.627
Obs3	1	60.000	1521.700	1575.533	-53.833	-0.408	120.375	46.024	3105.043	178.545	-693.096	3844.162

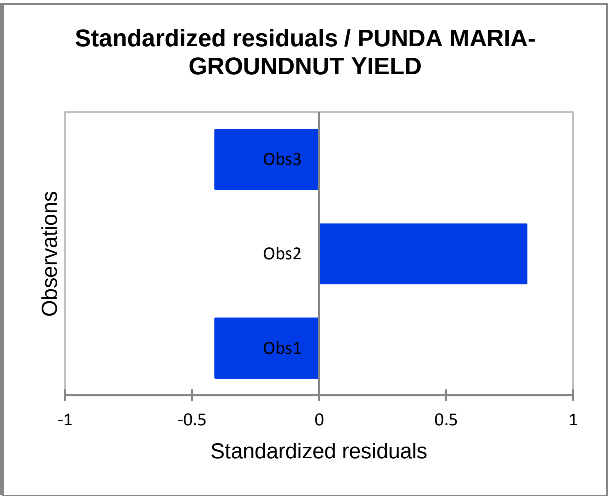







Pred(PUNDA MARIA- GROUNDNUT YIELD) / Standardized residuals


Pred(PUNDA MARIA- GROUNDNUT YIELD) / PUNDA MARIA- GROUNDNUT YIELD


Standardized residuals / PUNDA MARIA- GROUNDNUT YIELD

Appendix 4.21: Summary Statistics for Ttest on soybean yields -Ofcolaco

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Ofcolaco 2017 soybean	3	0	3	1154.400	1223.100	1181.367	36.653
observed yield Ofcolaco 2018 soybean	3	0	3	933.700	1000.900	978.400	38.712

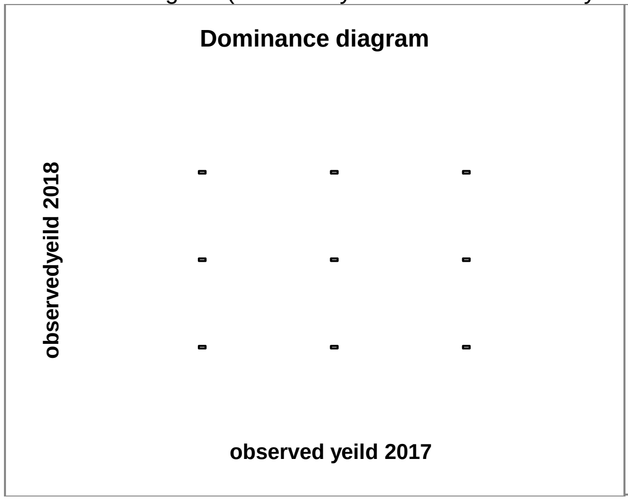
t-test for two independent samples / Two-tailed test:
95% confidence interval on the difference between the means:
[117.510,288.423]-0.609]

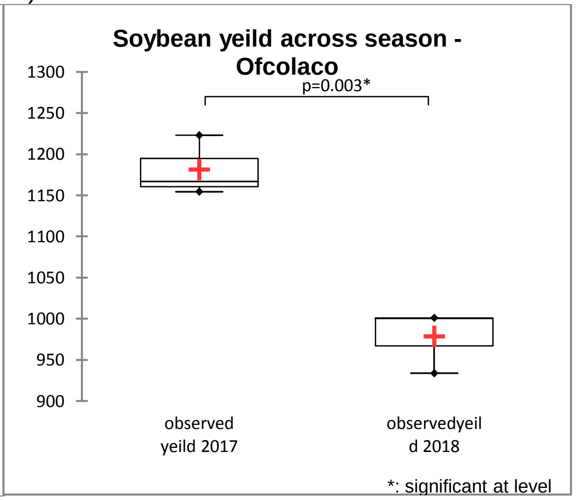
[117.510,	288.423], -0.609]
Difference	202.967

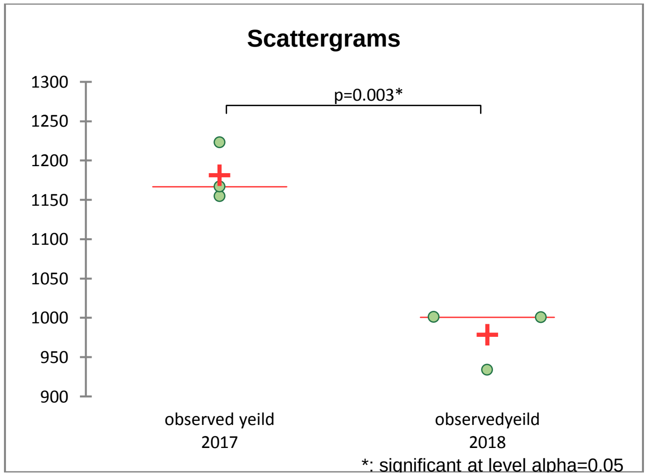
Difference	202.967
t (Observed value)	6.594
|t| (Critical value)	2.776
DF	4
p-value (Two-	0.003

tailed)	
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Dominance diagram (observed yield ofcolaco 2017 soybean):







Appendix 4.22: Summary Statistics for Ttest on sunflower yields -Ofcolaco

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed yield Ofcolaco 2017 sunflower	3	0	3	1192.100	1560.700	1383.467	184.706
observed yield Ofcolaco 2018 sunflower	3	0	3	1090.500	1319.800	1211.067	115.107

t-test for two independent samples / Two-tailed test:
95% confidence interval on the difference between the means:
[-176.468 ,521.268]-3.437]

[-176.468
, 521.268],-3.437]

Difference	172.400

Difference	172.400
t (Observed value)	1.372
|t| (Critical value)	2.776
DF	4
p-value (Two-tailed)	0.242
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
Dominance diagram (observed yield Ofcolaco 2017 sunflower):
Figure: Dominance diagram

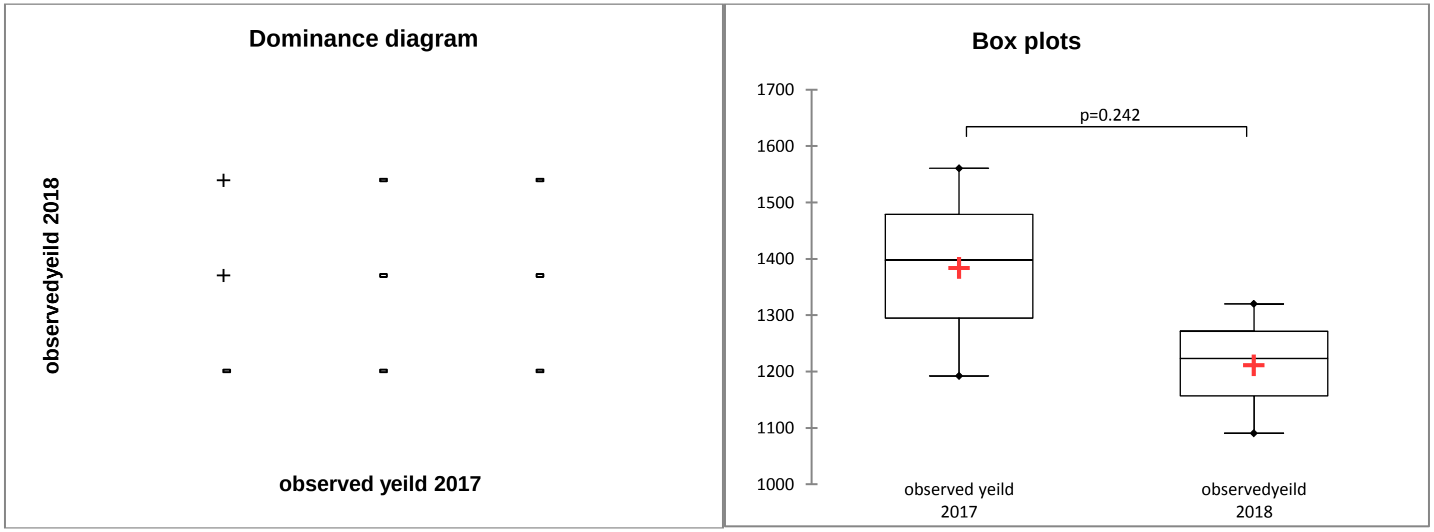
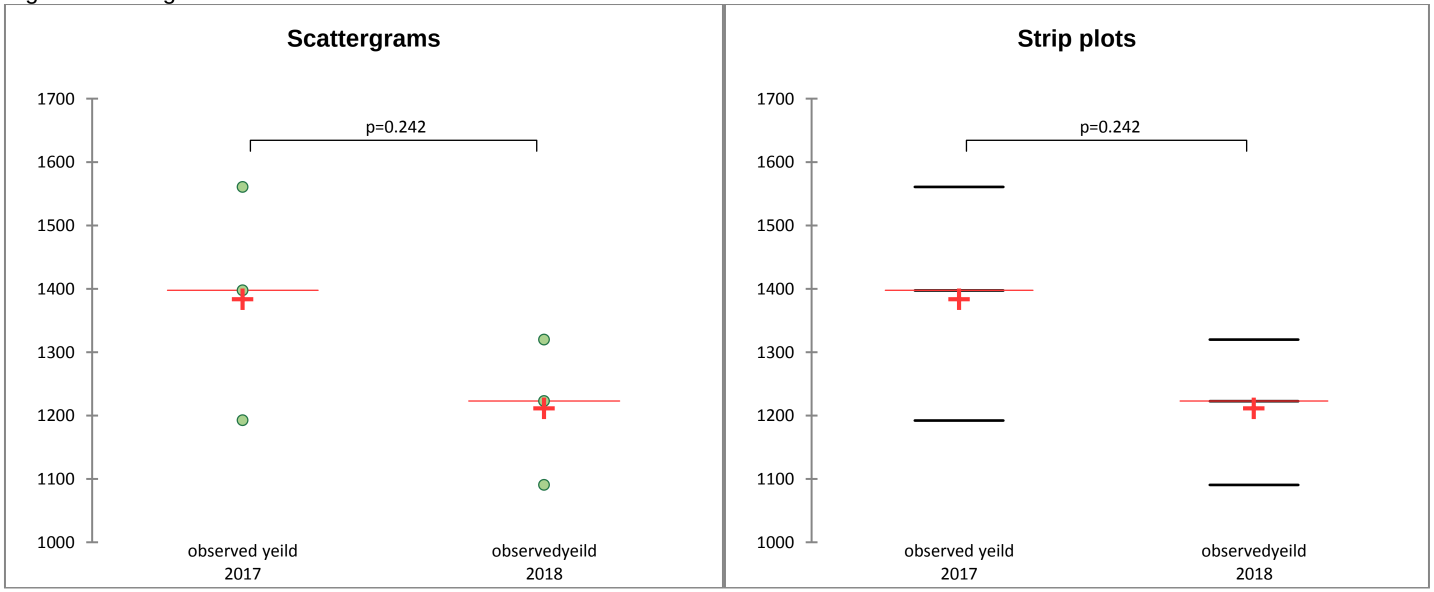


Figure: Scattergrams



Appendix 4.23: Summary Statistics for Ttest on groundnut yields -Ofcolaco

Summary statistics:

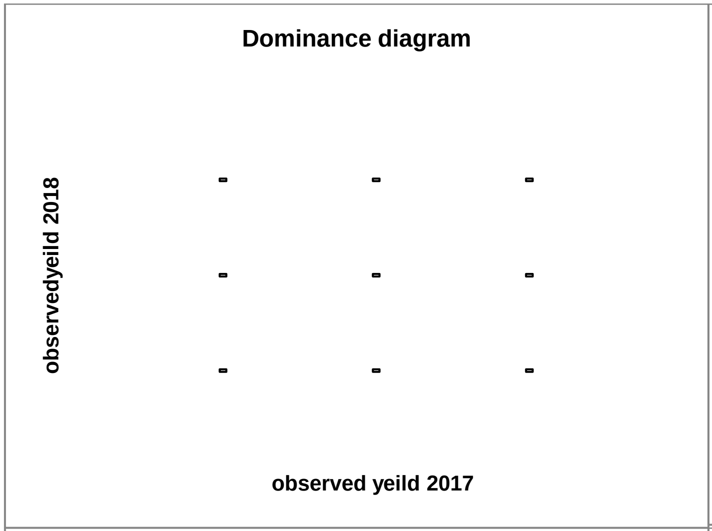
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed yield 2017	3	0	3	2034.700	2195.900	2142.117	93.026
Observed yield 2018	3	0	3	1560.500	1678.600	1621.600	59.157

t-test for two independent samples / Two-tailed test:
95% confidence interval on the difference between the means:
[343.801,697.232]-3.281]

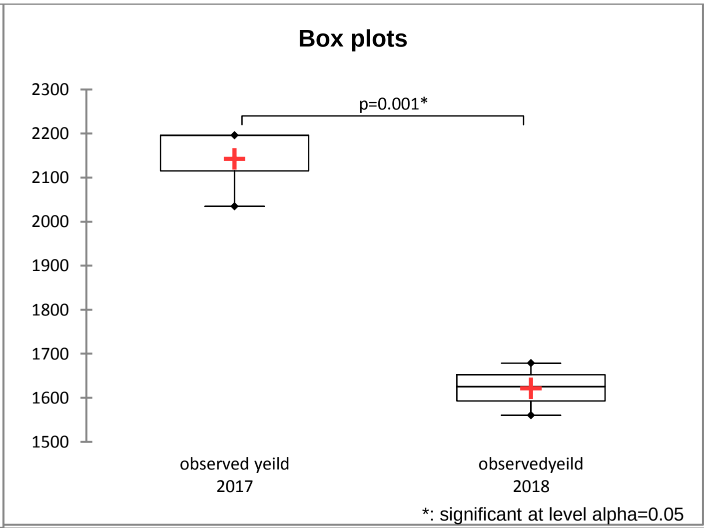
[343.801, 697.232],-3.281]

Difference	520.517
Difference	520.517
t (Observed value)	8.178
|t| (Critical value)	2.776
DF	4
p-value (Two-tailed)	0.001
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
Dominance diagram (observed yield 2017):
Figure: Dominance diagram

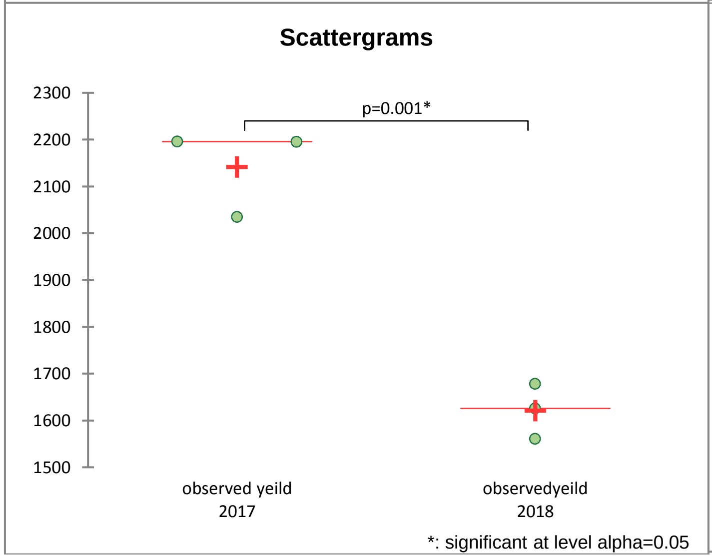


Dominance diagram



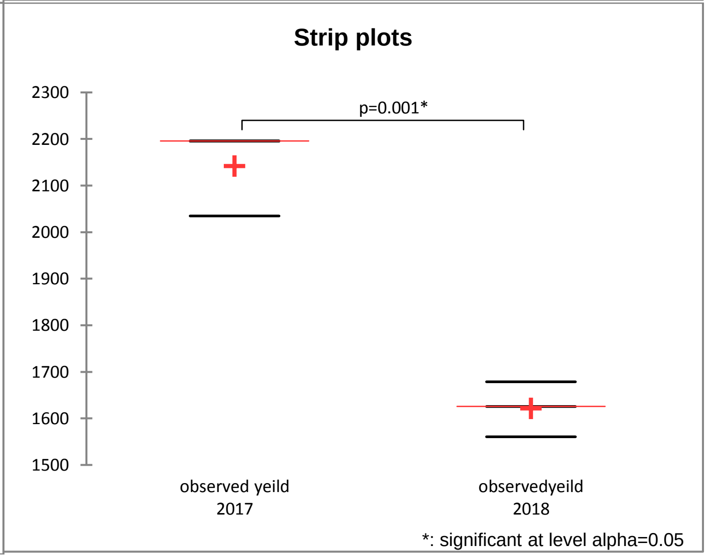
Box plots

*: significant at level alpha=0.05



Scattergrams

*: significant at level alpha=0.05



Strip plots

*: significant at level alpha=0.05

Appendix 4.24: Summary Statistics for Ttest on soybean yields -Syferkuil

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed yield soybean Syferkuil 2017	3	0	3	1103.100	2004.400	1584.800	453.848
Observed yield soybean 2018	3	0	3	1003.700	1601.100	1261.567	306.959

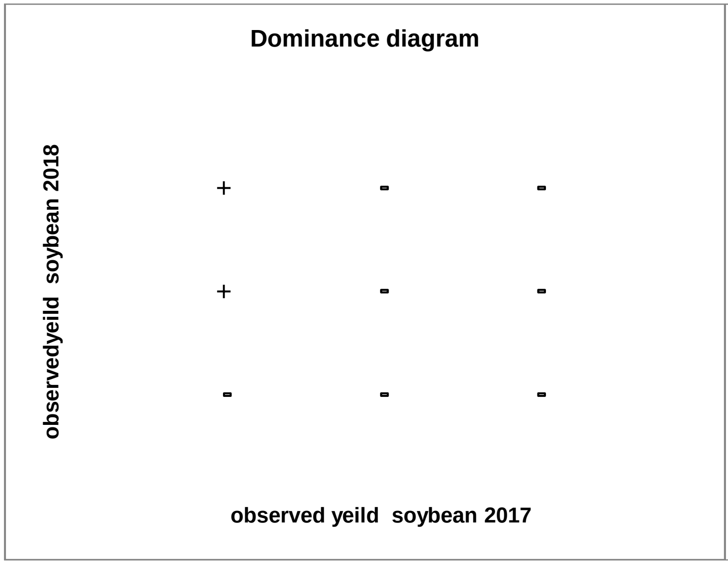
t-test for two independent samples / Two-tailed test:
95% confidence interval on the difference between the means:
[-555.050 ,1201.517]-1.570]

[-555.050, 1201.517], -1.570]

Difference	323.233

Difference	323.233
t (Observed value)	1.022
|t| (Critical value)	2.776
DF	4
p-value (Two-tailed)	0.365
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
Dominance diagram (observed yield soybean 2017):
Figure: Dominance diagram


Dominance diagram

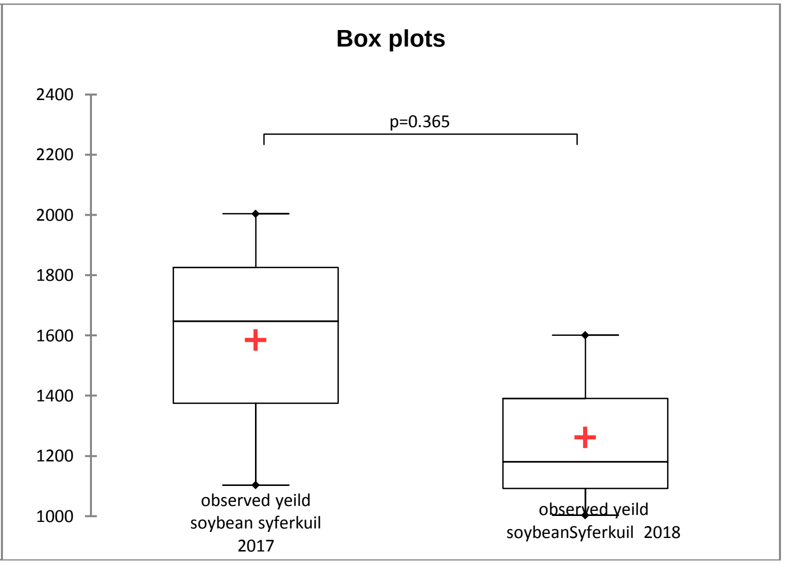
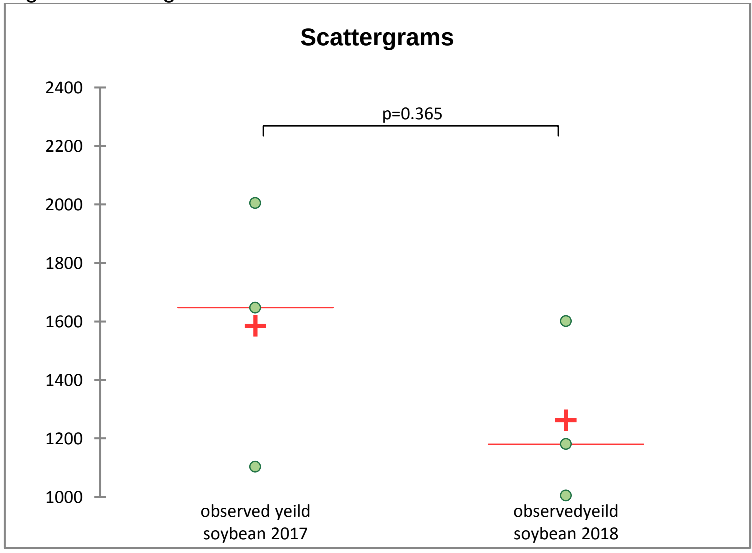
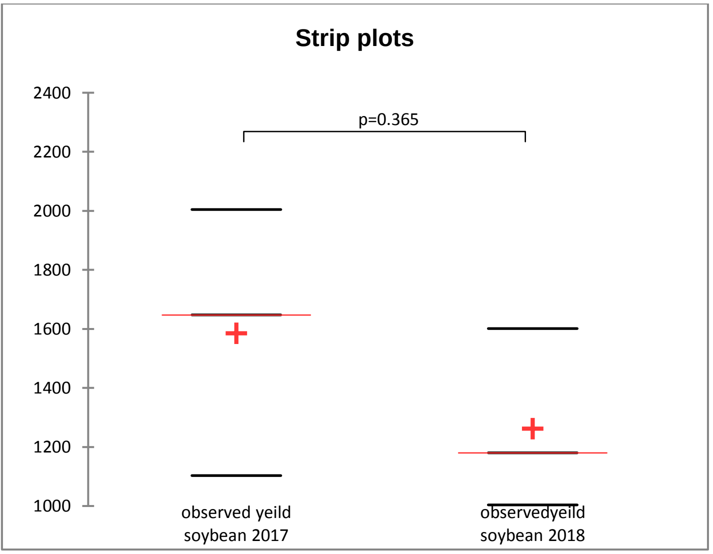

Box plots

Figure: Scattergrams


Scattergrams


Strip plots

Appendix 4.25: Summary Statistics for Ttest on sunflower yields -Syferkuil

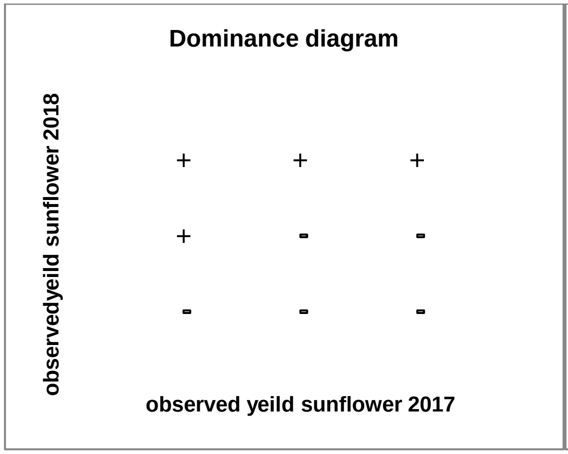
Summary statistics:

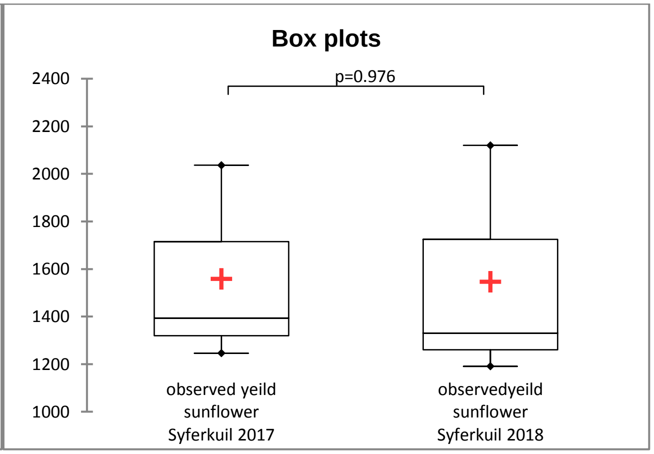
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed yield sunflower Syferkuil 2017	3	0	3	1245.800	2036.500	1558.600	420.411
Observed yield sunflower Syferkuil 2018	3	0	3	1190.500	2119.800	1546.733	501.161

t-test for two independent samples / Two-tailed test:
95% confidence interval on the difference between the means:
[-1036.717 ,1060.450]-8.119]
[- 1060.450],-8.119
1036.717 ,]

Difference	11.867
Difference	11.867
t (Observed value)	0.031
|t| (Critical value)	2.776
DF	4
p-value (Two-tailed)	0.976
alpha	0.05

Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
Dominance diagram (observed yield sunflower 2017):
Figure: Dominance diagram





Appendix 4.26: Summary Statistics for Ttest on groundnut yields -Syferkuil

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
observed yield groundnut Syferkuil 2017	3	0	3	1248.200	1461.700	1346.300	107.796
Observed yield groundnut 2018	3	0	3	1021.700	1208.300	1134.167	99.030

t-test for two independent samples / Two-tailed test:
95% confidence interval on the difference between the means:
[-22.511 ,446.777]-1.808]

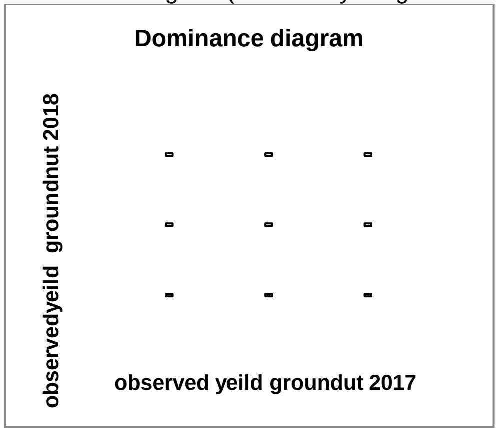
[-22.511 , 446.777],-1.808]

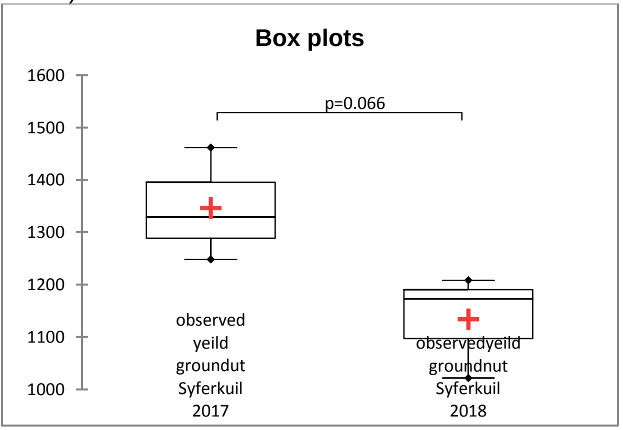
Difference 212.133

Difference	212.133
t (Observed value)	2.510

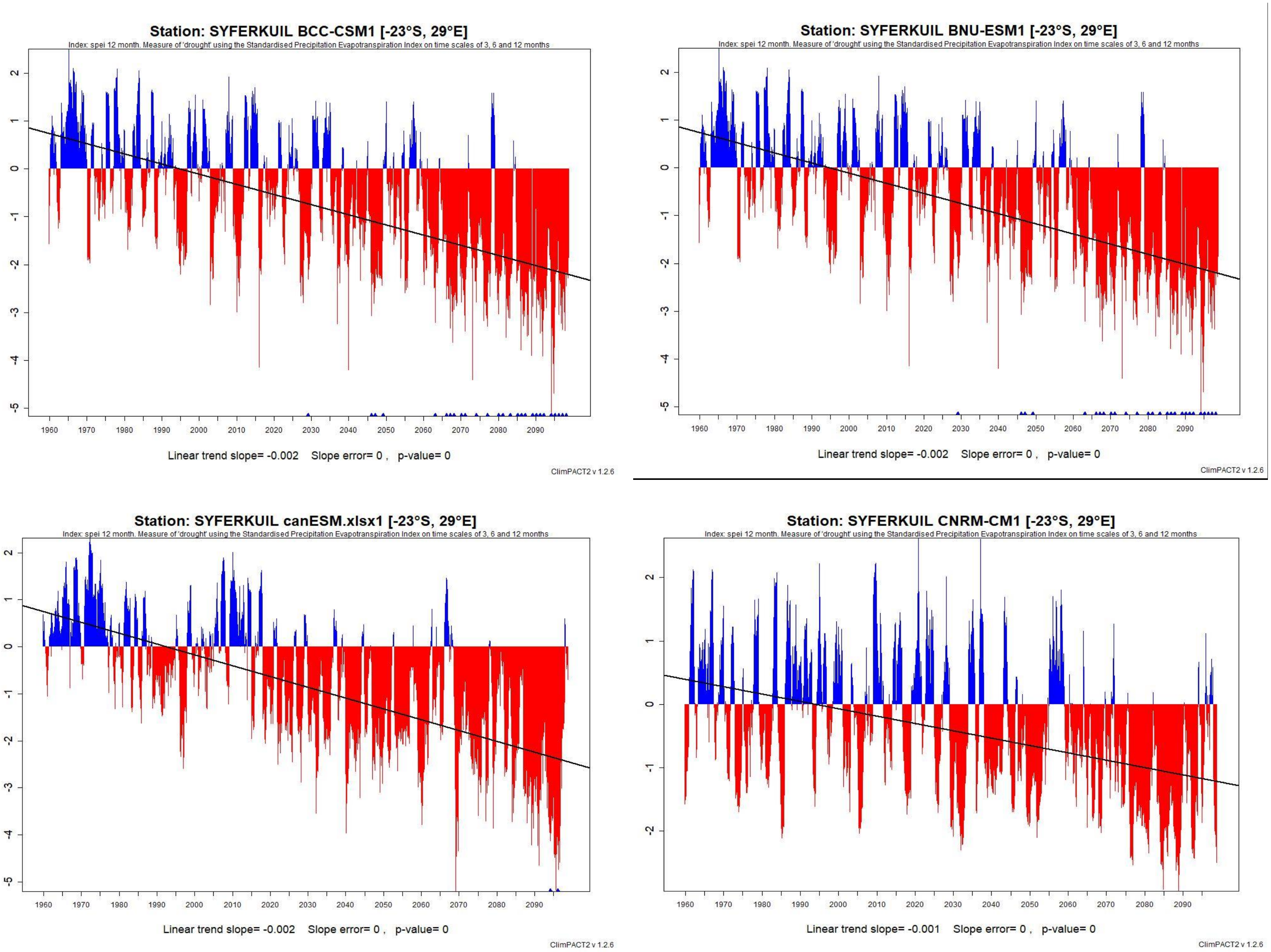
|t| (Critical value)	2.776
DF	4
p-value (Two-tailed)	0.066
alpha	0.05

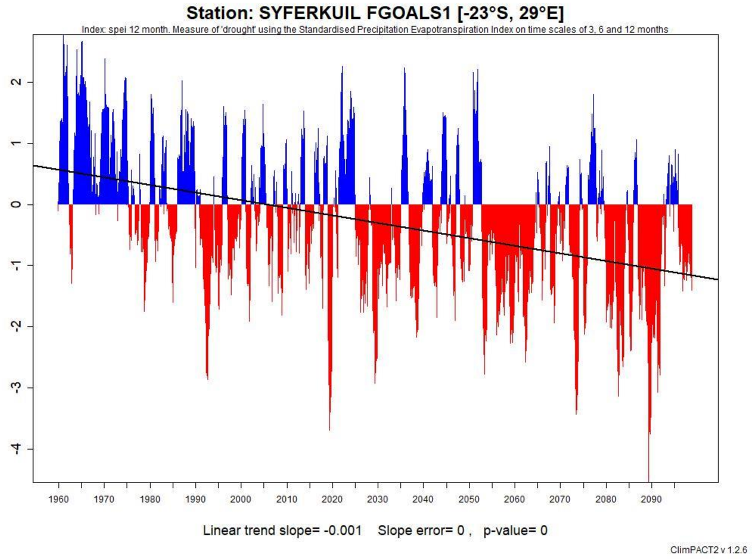
Test interpretation:
H0: The difference between the means is equal to 0.
Ha: The difference between the means is different from 0.
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
Dominance diagram (observed yield groundnut 2017):





Appendix 4.27: 12 month SPEI as projected by various models for Syferkuil

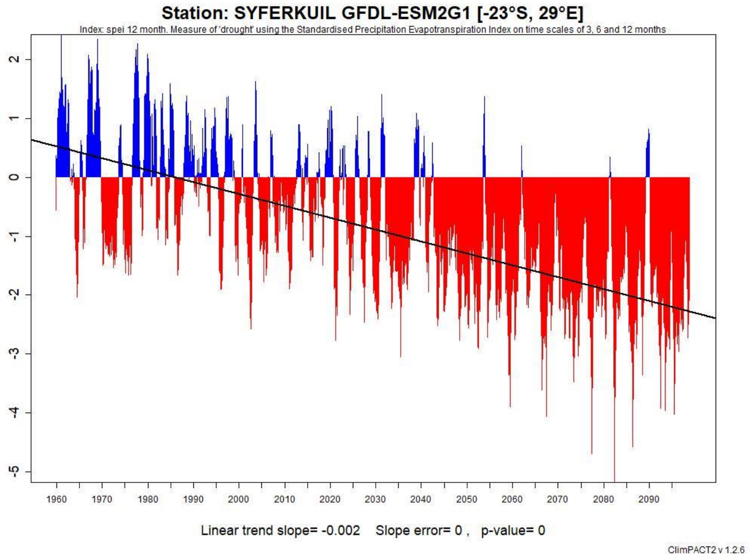



Station: SYFERKUIL FGOALS1 [-23°S, 29°E]

Index: spei 12 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months

Linear trend slope= -0.001 Slope error= 0 , p-value= 0

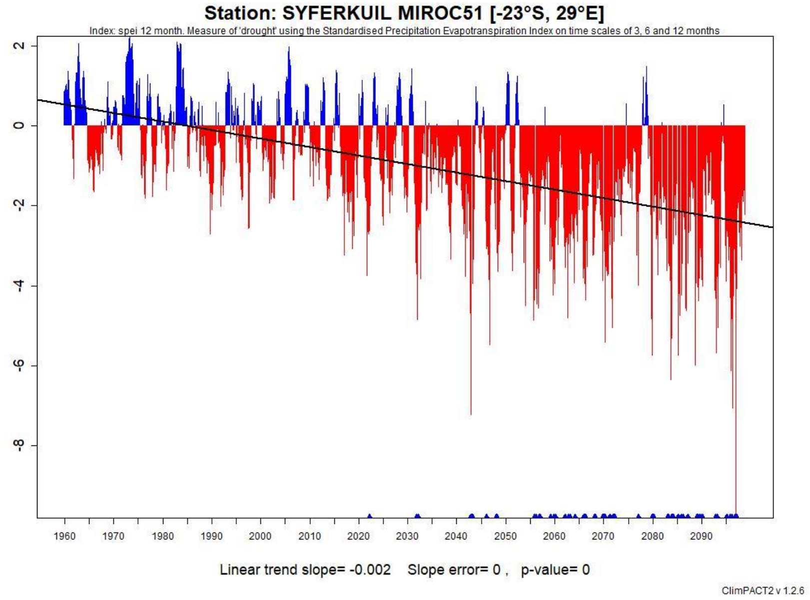
ClimPACT2 v 1.2.6


Station: SYFERKUIL GFDL-ESM2G1 [-23°S, 29°E]

Index: spei 12 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months

Linear trend slope= -0.002 Slope error= 0 , p-value= 0

ClimPACT2 v 1.2.6

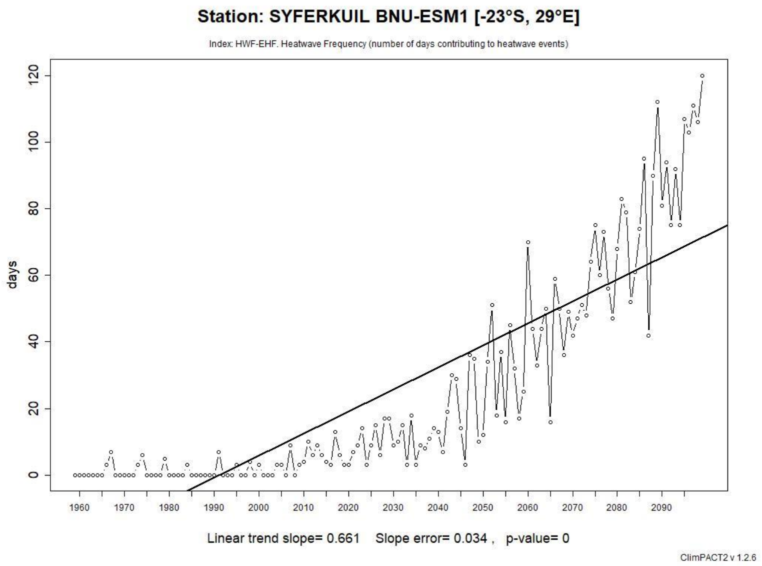

Station: SYFERKUIL MIROC51 [-23°S, 29°E]

Index: spei 12 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months

Linear trend slope= -0.002 Slope error= 0 , p-value= 0

ClimPACT2 v 1.2.6

Appendix 4.28: Heatwave days as projected by various models for Syferkuil

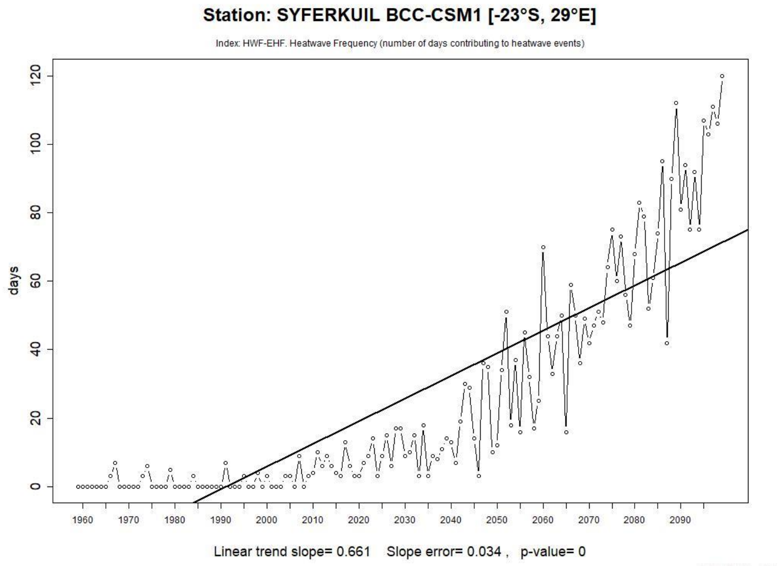


Station: SYFERKUIL BNU-ESM1 [-23°S, 29°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.661 Slope error= 0.034 , p-value= 0

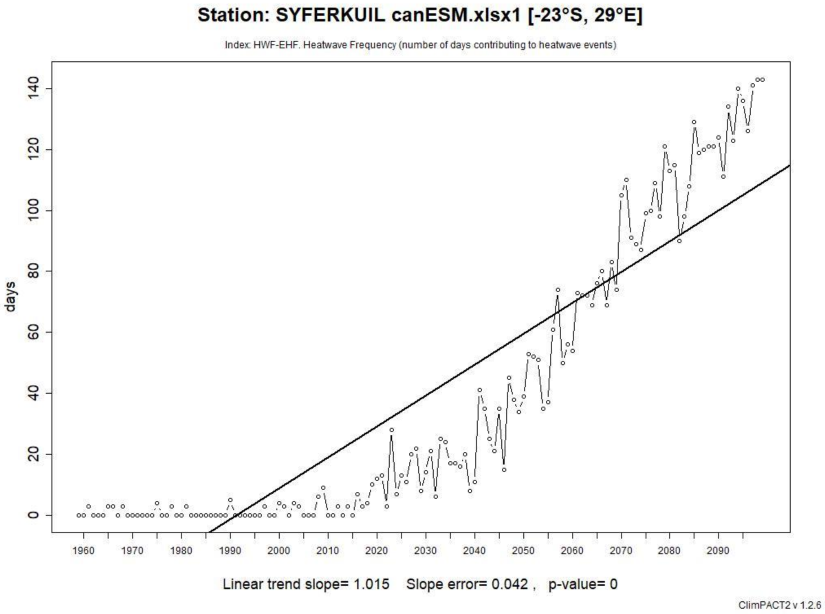
ClimPACT2 v 1.2.6



Station: SYFERKUIL BCC-CSM1 [-23°S, 29°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.661 Slope error= 0.034 , p-value= 0

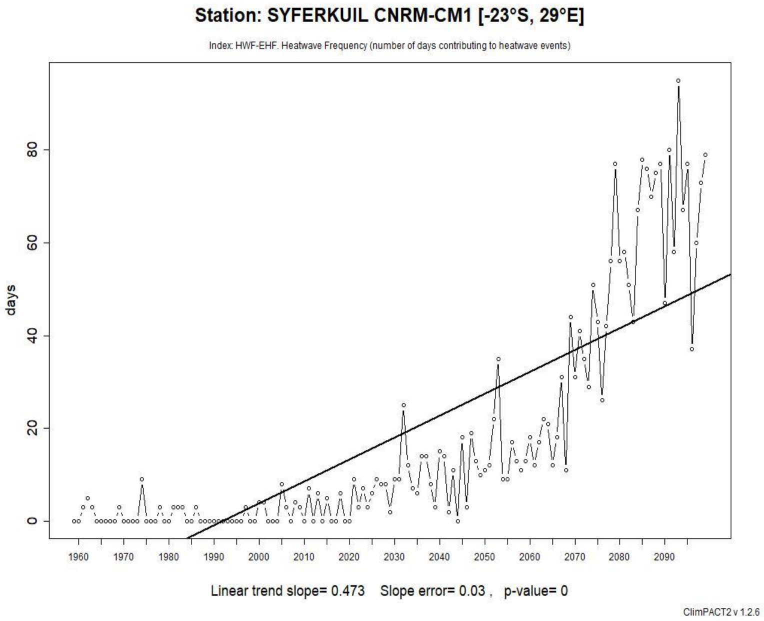


Station: SYFERKUIL canESM.xlsx1 [-23°S, 29°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 1.015 Slope error= 0.042 , p-value= 0

ClimPACT2 v 1.2.6

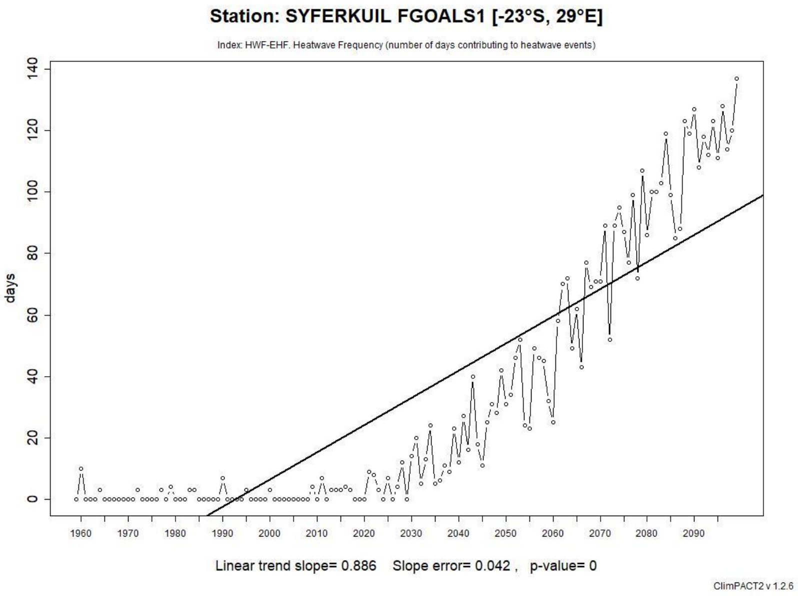


Station: SYFERKUIL CNRM-CM1 [-23°S, 29°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.473 Slope error= 0.03 , p-value= 0

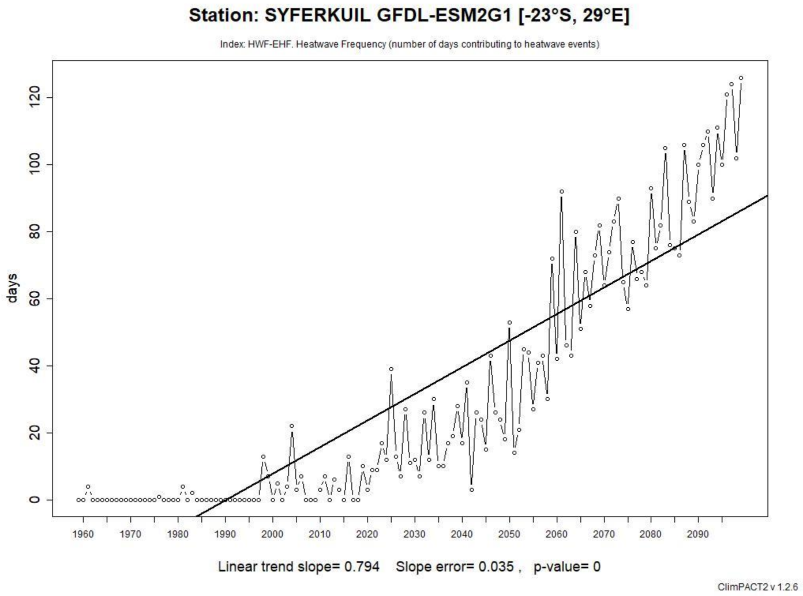
ClimPACT2 v 1.2.6


Station: SYFERKUIL FGOALS1 [-23°S, 29°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.886 Slope error= 0.042 , p-value= 0

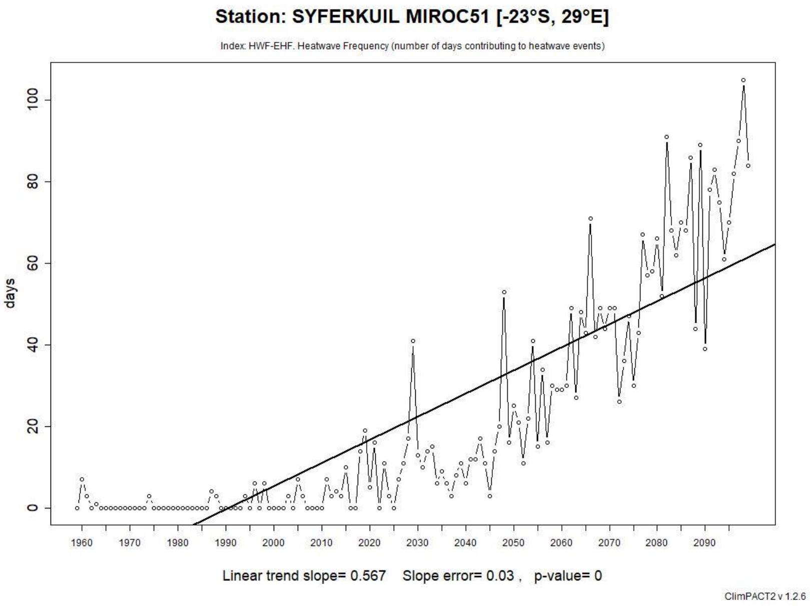
ClimPACT2 v 1.2.6


Station: SYFERKUIL GFDL-ESM2G1 [-23°S, 29°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.794 Slope error= 0.035 , p-value= 0

ClimPACT2 v 1.2.6


Station: SYFERKUIL MIROC51 [-23°S, 29°E]

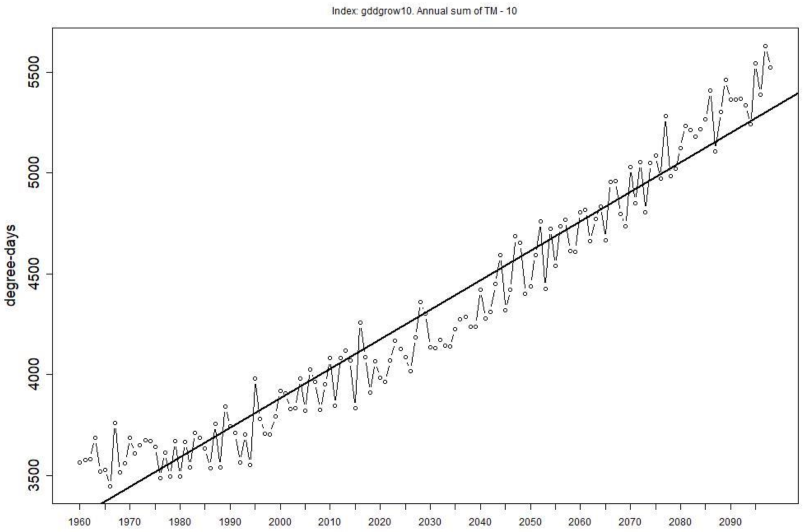
Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.567 Slope error= 0.03 , p-value= 0

ClimPACT2 v 1.2.6

Appendix 4.29: Growing degree days as projected by various models for Syferkuil

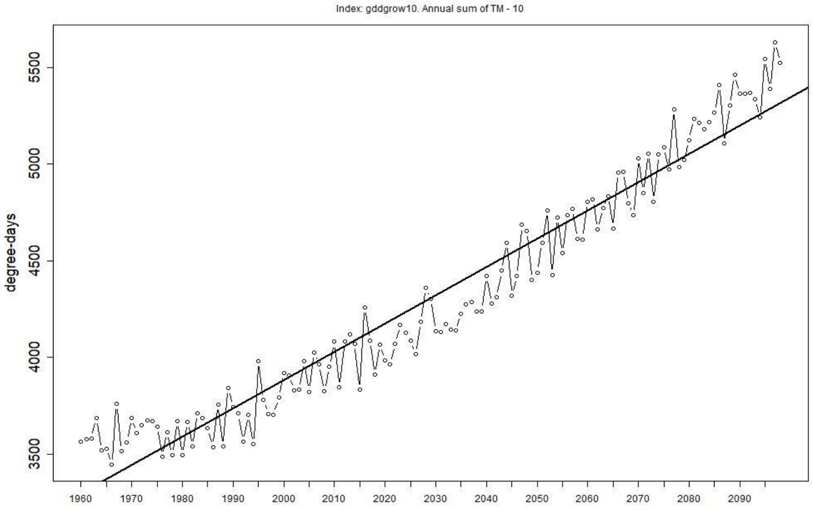
Station: SYFERKUIL BCC-CSM1 [-23°S, 29°E]



Linear trend slope= 14.625 Slope error= 0.317 , p-value= 0

ClimPACT2 v 1.2.6

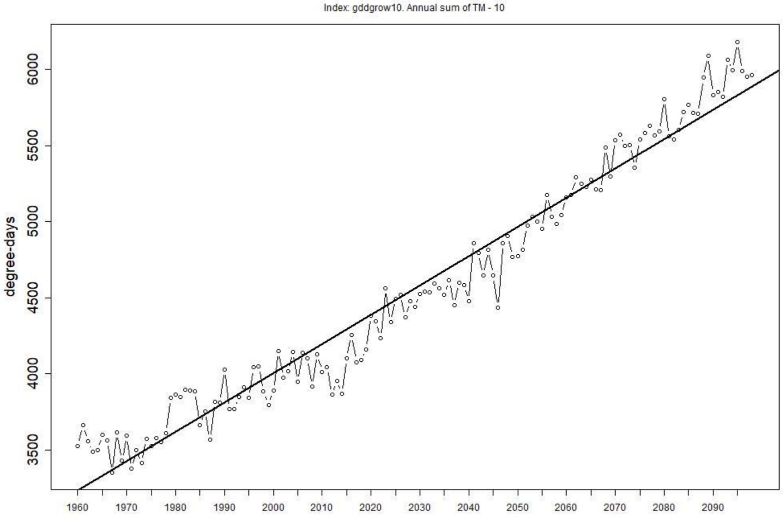
Station: SYFERKUIL BNU-ESM1 [-23°S, 29°E]



Linear trend slope= 14.625 Slope error= 0.317 , p-value= 0

ClimPACT2 v 1.2.6

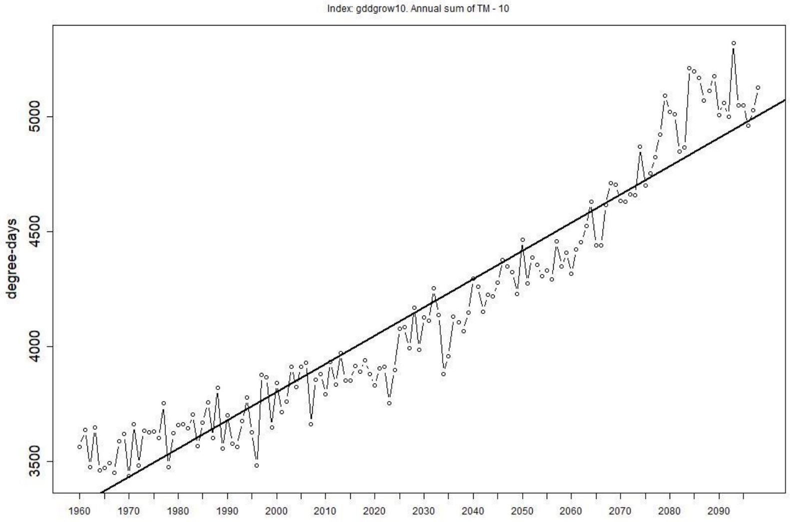
Station: SYFERKUIL canESM.xlsx1 [-23°S, 29°E]



Linear trend slope= 19.228 Slope error= 0.338 , p-value= 0

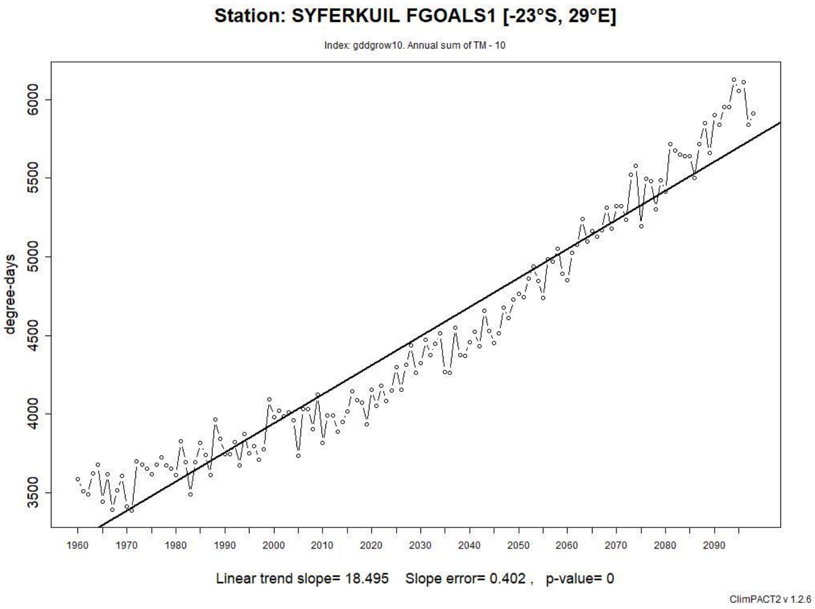
ClimPACT2 v 1.2.6

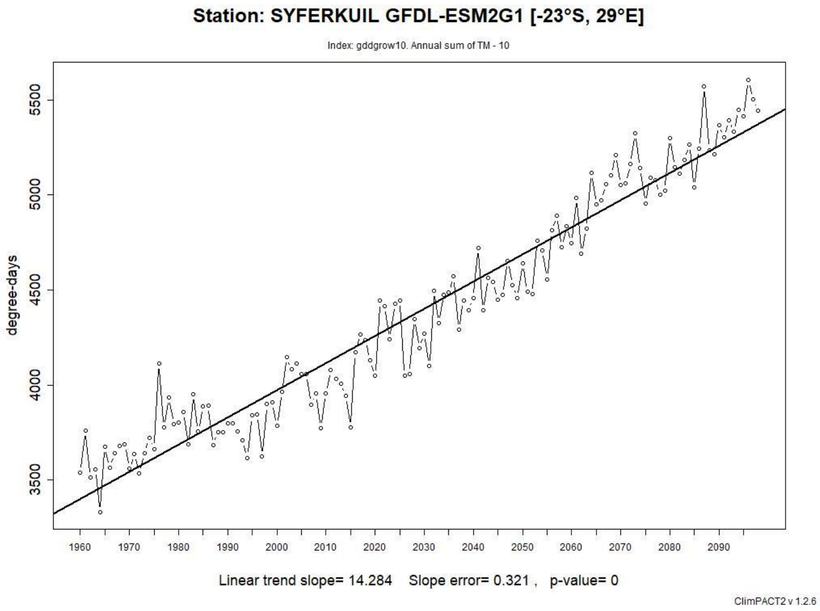
Station: SYFERKUIL CNRM-CM1 [-23°S, 29°E]

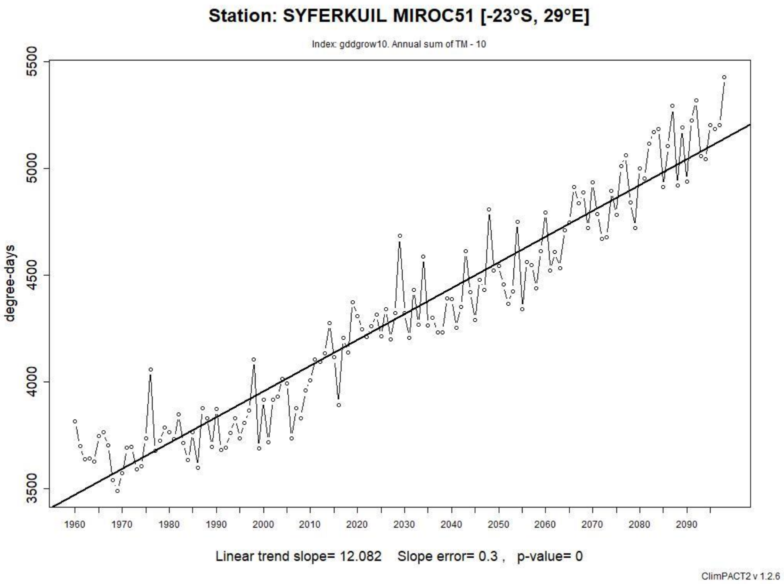


Linear trend slope= 12.288 Slope error= 0.315 , p-value= 0

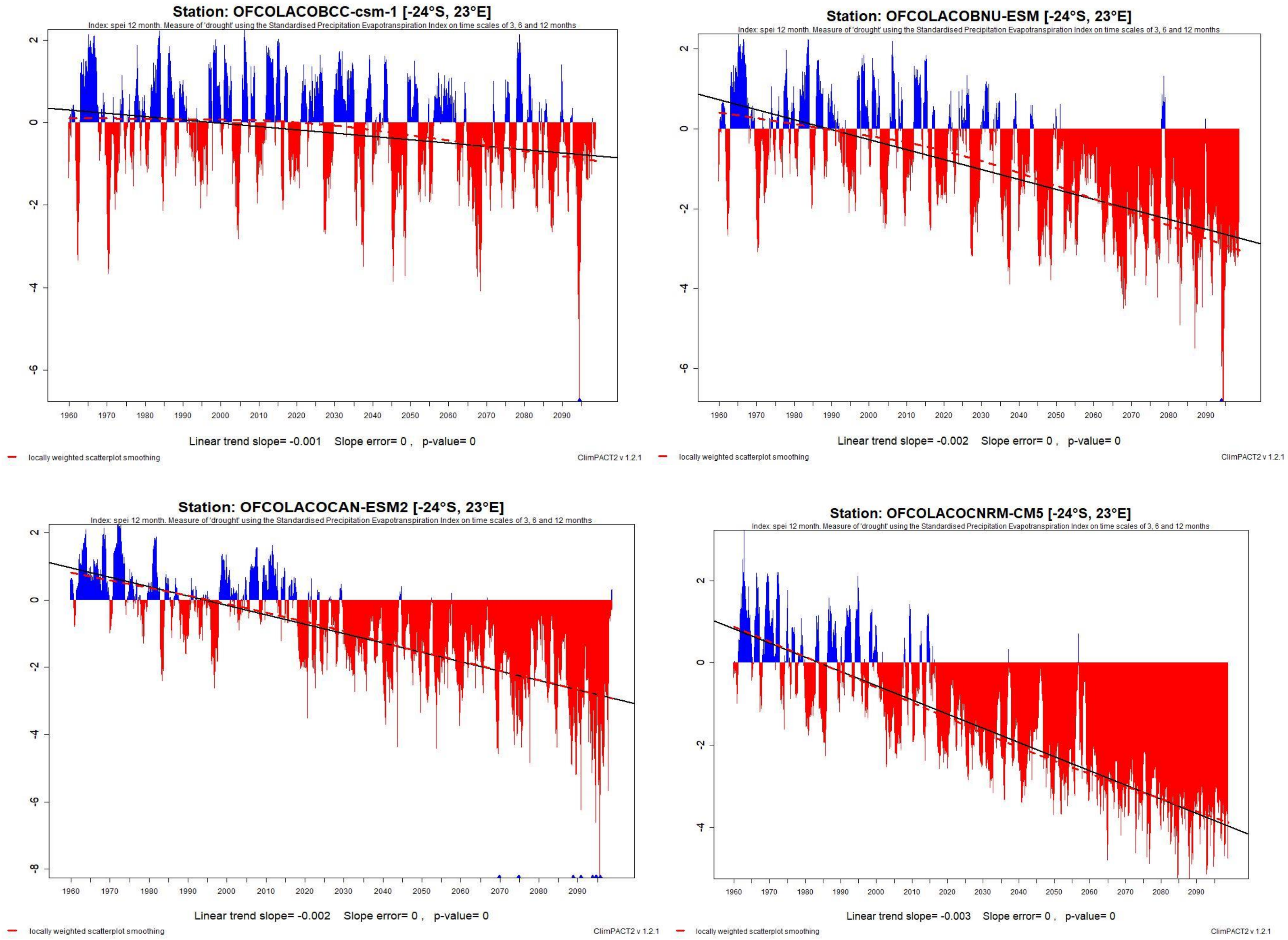
ClimPACT2 v 1.2.6

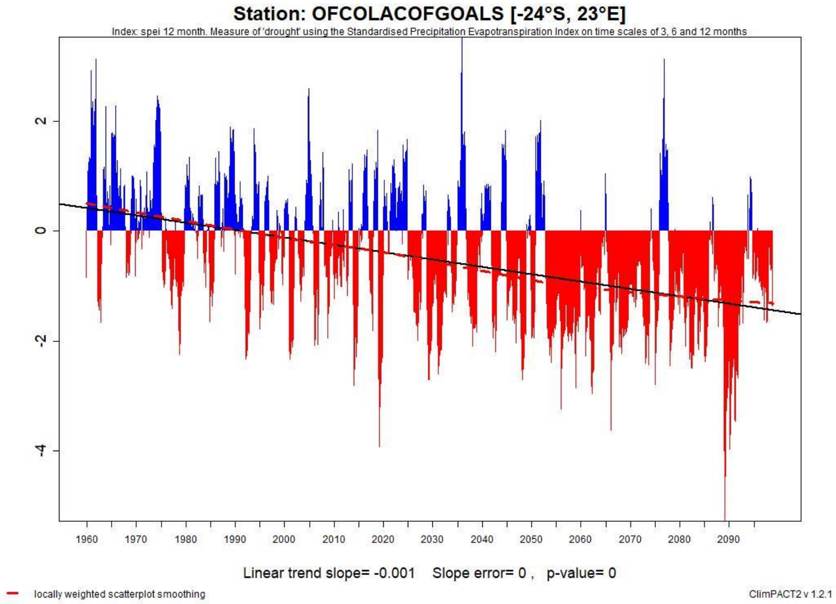

Station: SYFERKUIL FGOALS1 [-23°S, 29°E]
Index: gddgrow10. Annual sum of TM - 10
degree-days
3500
4000
4500
5000
5500
6000
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= 18.495 Slope error= 0.402 , p-value= 0
ClimPACT2 v 1.2.6

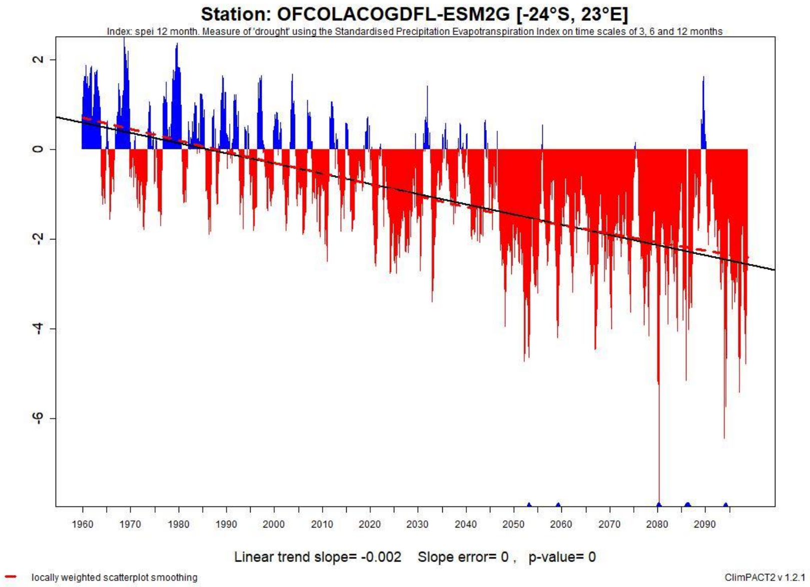

Station: SYFERKUIL GFDL-ESM2G1 [-23°S, 29°E]
Index: gddgrow10. Annual sum of TM - 10
degree-days
3500
4000
4500
5000
5500
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= 14.284 Slope error= 0.321 , p-value= 0
ClimPACT2 v 1.2.6

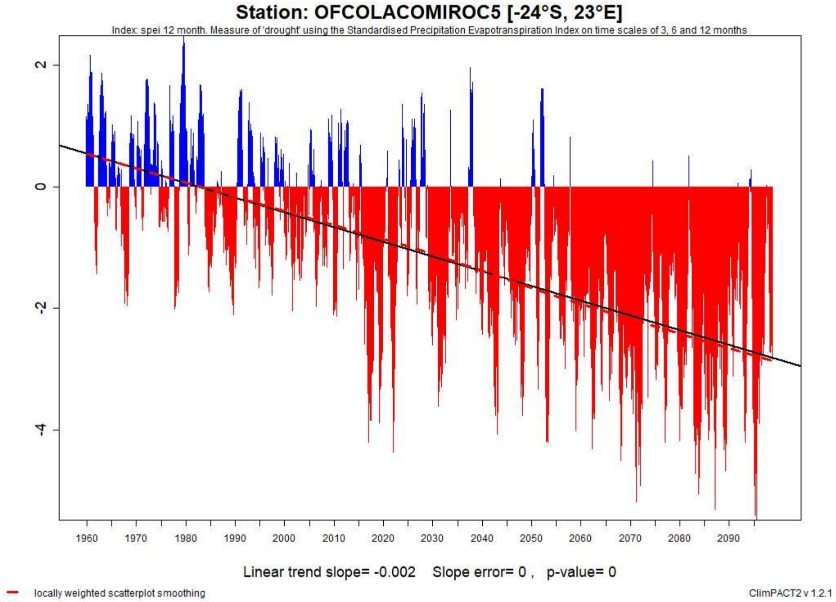

Station: SYFERKUIL MIROC51 [-23°S, 29°E]
Index: gddgrow10. Annual sum of TM - 10
degree-days
3500
4000
4500
5000
5500
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= 12.082 Slope error= 0.3 , p-value= 0
ClimPACT2 v 1.2.6

Appendix 4.30: 12 month SPEI as projected by various models for Ofcolaco

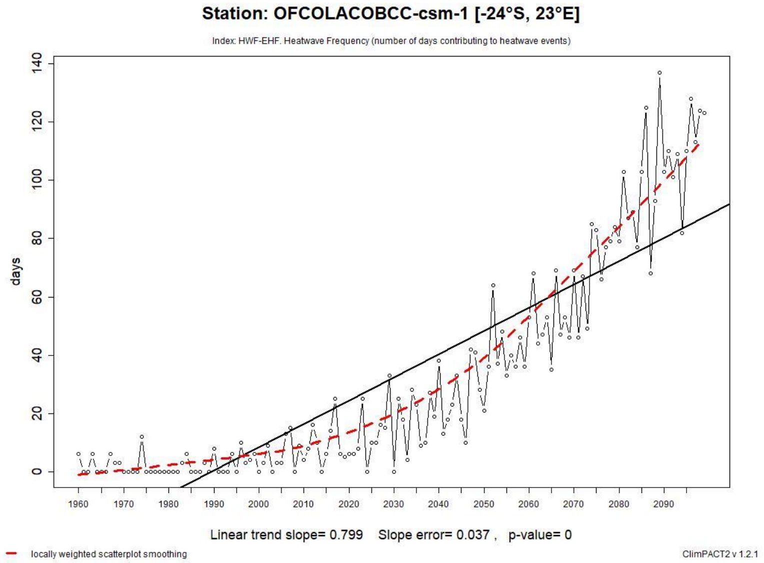



Station: OFCOLACOFGOALS [-24°S, 23°E]
Index: spei 12 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months
2
0
-2
-4
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= -0.001 Slope error= 0 , p-value= 0
locally weighted scatterplot smoothing
ClimPACT2 v 1.2.1


Station: OFCOLACOGDFL-ESM2G [-24°S, 23°E]
Index: spei 12 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months
2
0
-2
-4
-6
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= -0.002 Slope error= 0 , p-value= 0
locally weighted scatterplot smoothing
ClimPACT2 v 1.2.1


Station: OFCOLACOMIROC5 [-24°S, 23°E]
Index: spei 12 month. Measure of 'drought' using the Standardised Precipitation Evapotranspiration Index on time scales of 3, 6 and 12 months
2
0
-2
-4
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= -0.002 Slope error= 0 , p-value= 0
locally weighted scatterplot smoothing
ClimPACT2 v 1.2.1

Appendix 4.31: Growing degree days as projected by various models for Ofcolaco

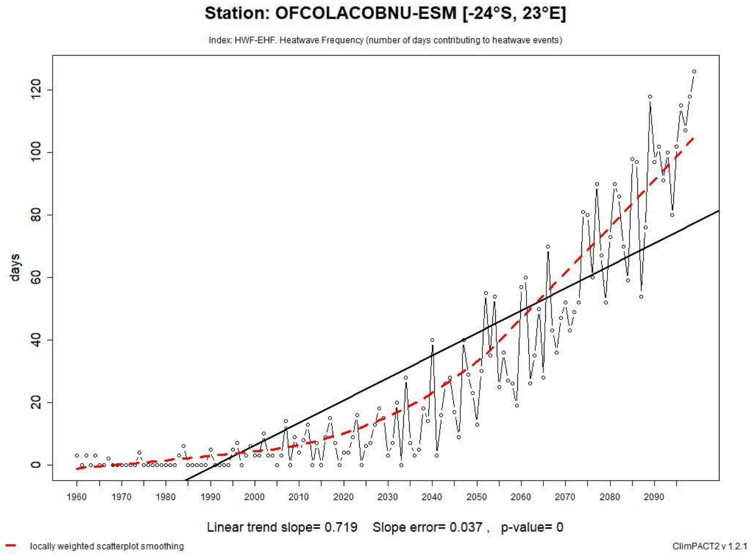

Station: OFCOLACOBCC-csm-1 [-24°S, 23°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.799 Slope error= 0.037 , p-value= 0

locally weighted scatterplot smoothing

ClimPACT2 v 1.2.1

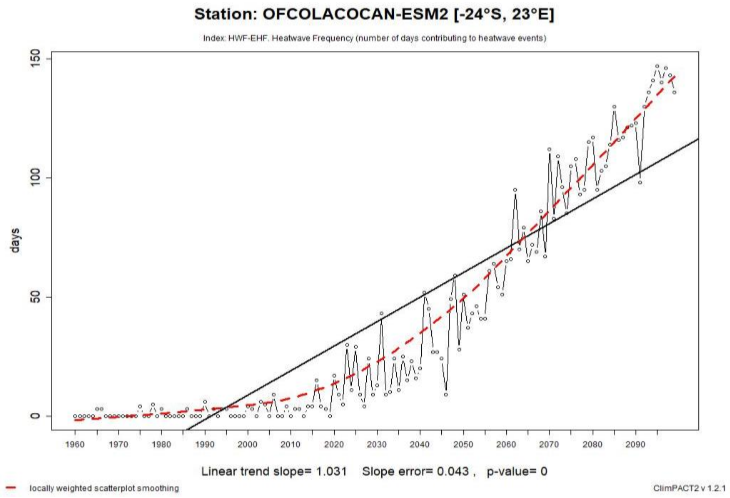

Station: OFCOLACOBNU-ESM [-24°S, 23°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.719 Slope error= 0.037 , p-value= 0

locally weighted scatterplot smoothing

ClimPACT2 v 1.2.1

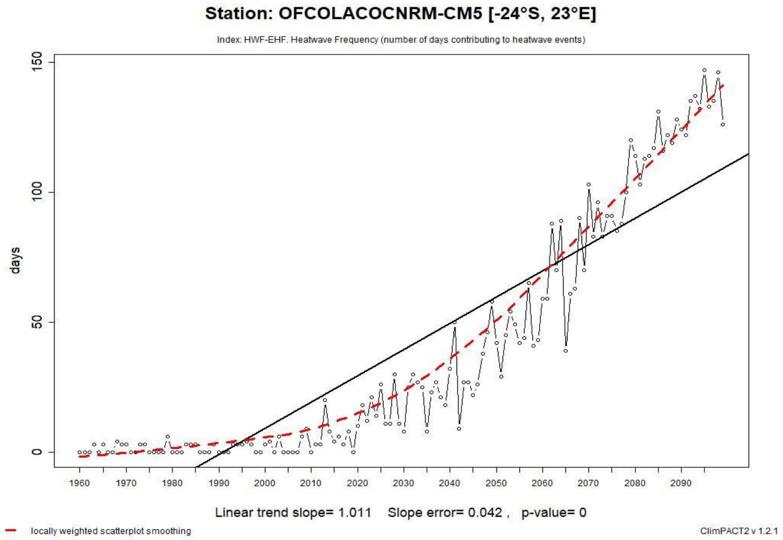

Station: OFCOLACOCAN-ESM2 [-24°S, 23°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 1.031 Slope error= 0.043 , p-value= 0

locally weighted scatterplot smoothing

ClimPACT2 v 1.2.1

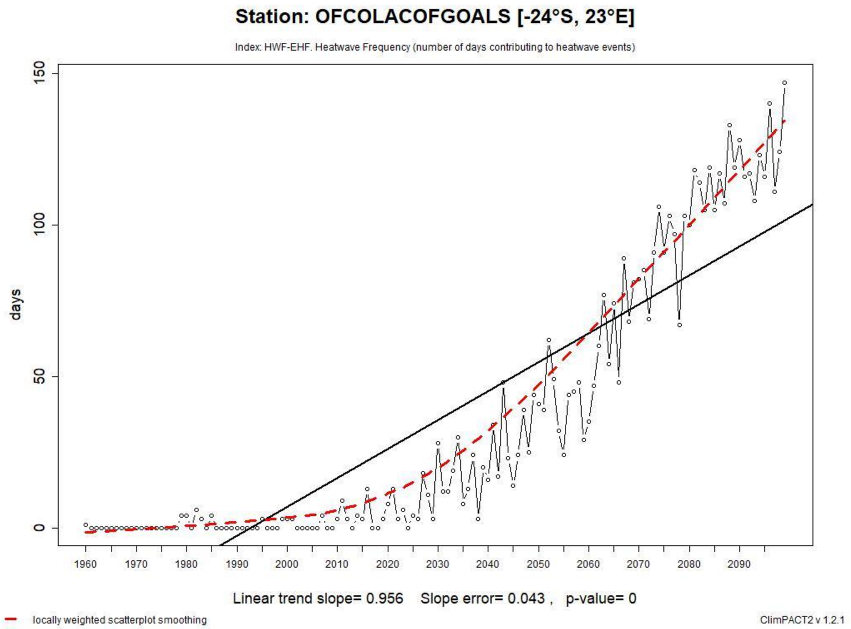

Station: OFCOLACOCNRM-CM5 [-24°S, 23°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 1.011 Slope error= 0.042 , p-value= 0

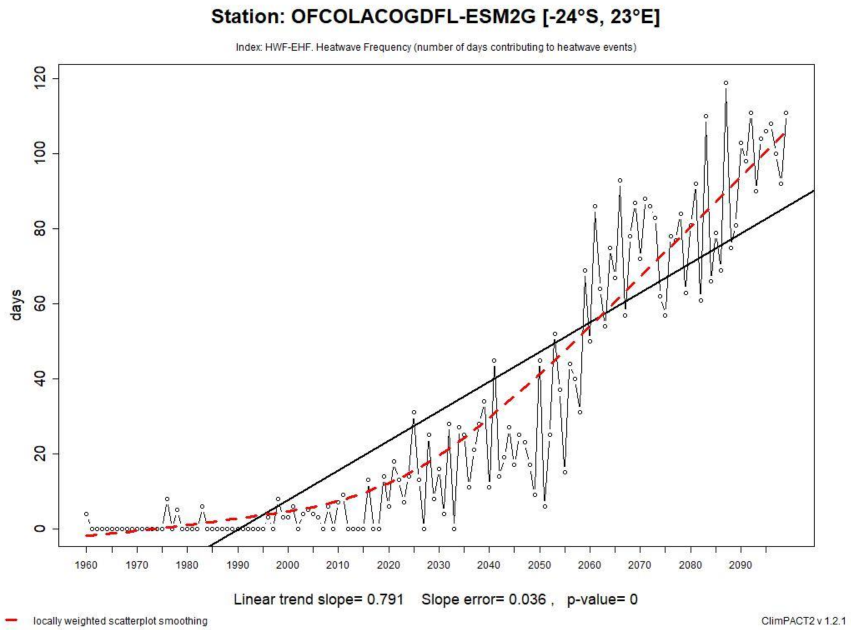
locally weighted scatterplot smoothing

ClimPACT2 v 1.2.1


Station: OFCOLACOFGOALS [-24°S, 23°E]

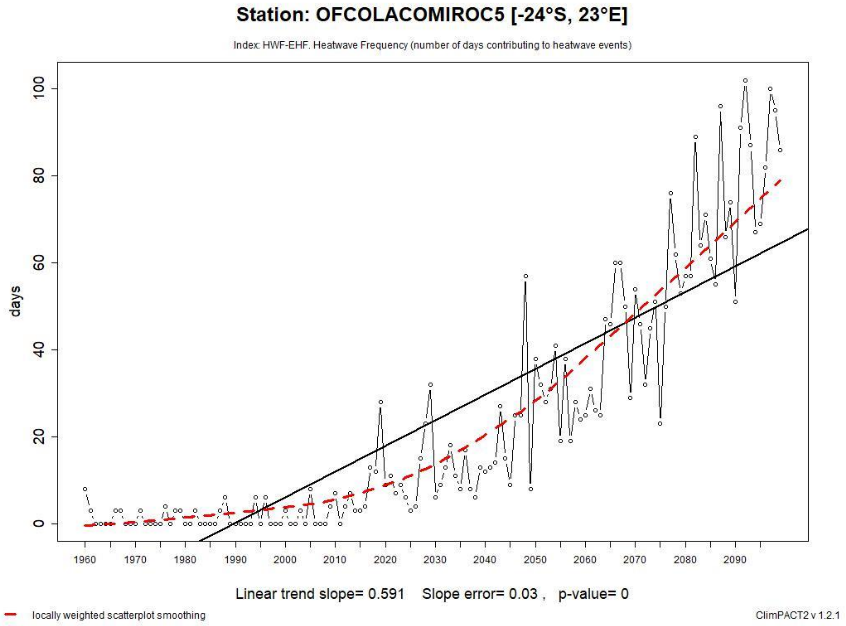
Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

Linear trend slope= 0.956 Slope error= 0.043 , p-value= 0


Station: OFCOLACOGDFL-ESM2G [-24°S, 23°E]

Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

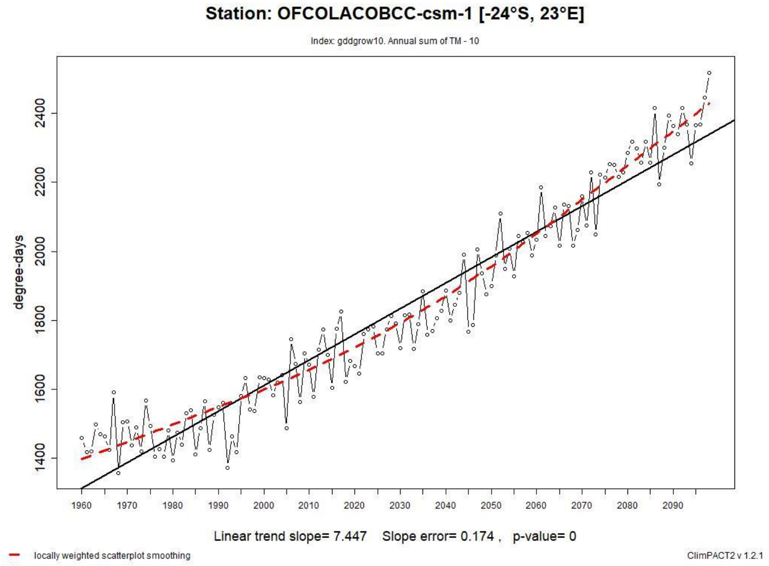
Linear trend slope= 0.791 Slope error= 0.036 , p-value= 0

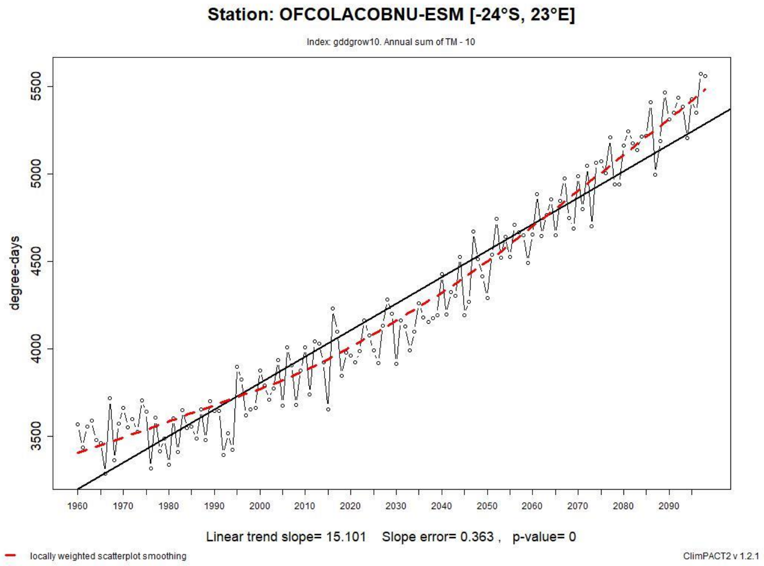

Station: OFCOLACOMIROC5 [-24°S, 23°E]

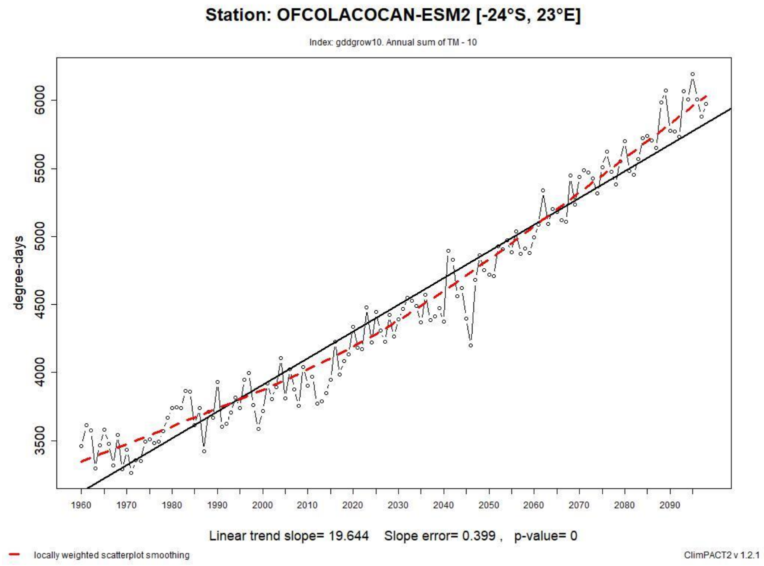
Index: HWF-EHF. Heatwave Frequency (number of days contributing to heatwave events)

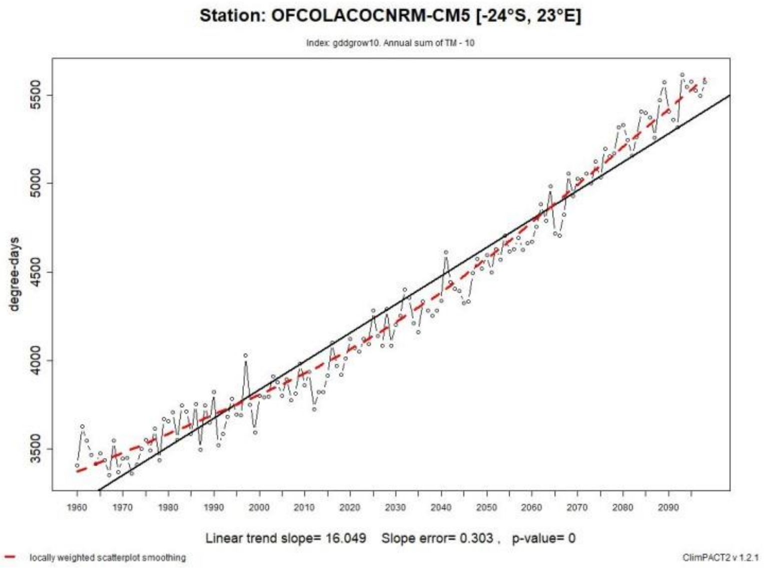
Linear trend slope= 0.591 Slope error= 0.03 , p-value= 0

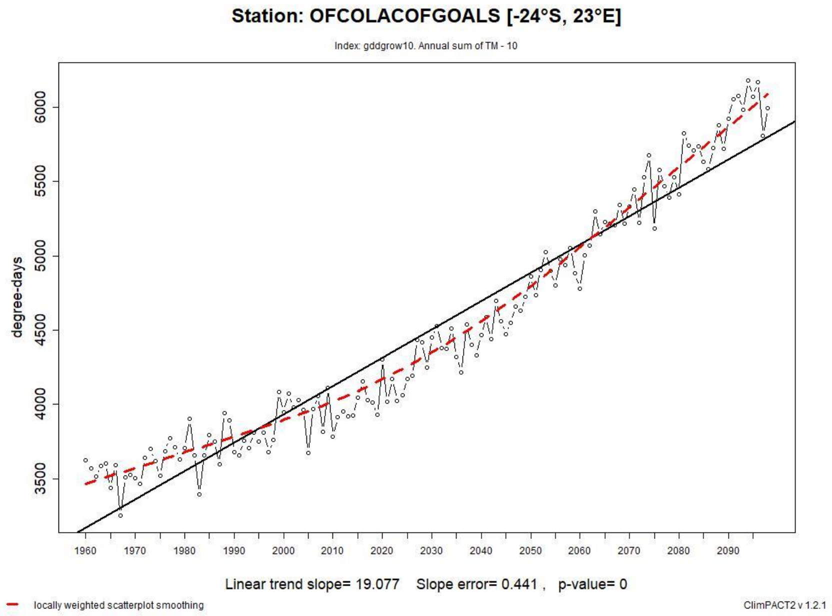
Appendix 4.32: Heatwave days as projected by various models climate models for Ofcolaco

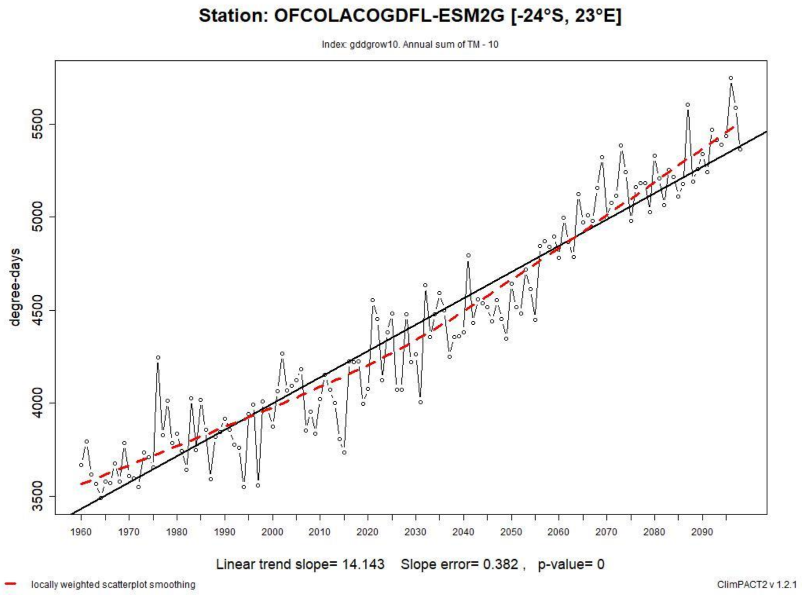

Station: OFCOLACOBCC-csm-1 [-24°S, 23°E]

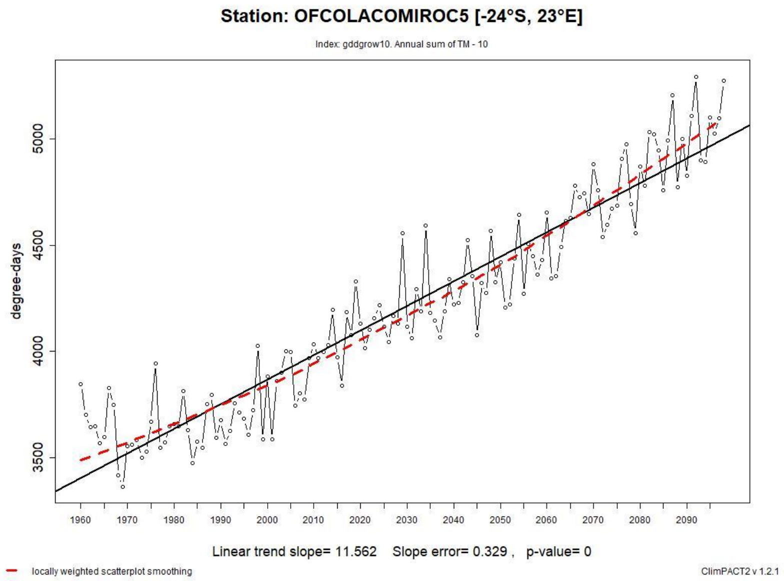

Station: OFCOLACOBNU-ESM [-24°S, 23°E]


Station: OFCOLACOCAN-ESM2 [-24°S, 23°E]

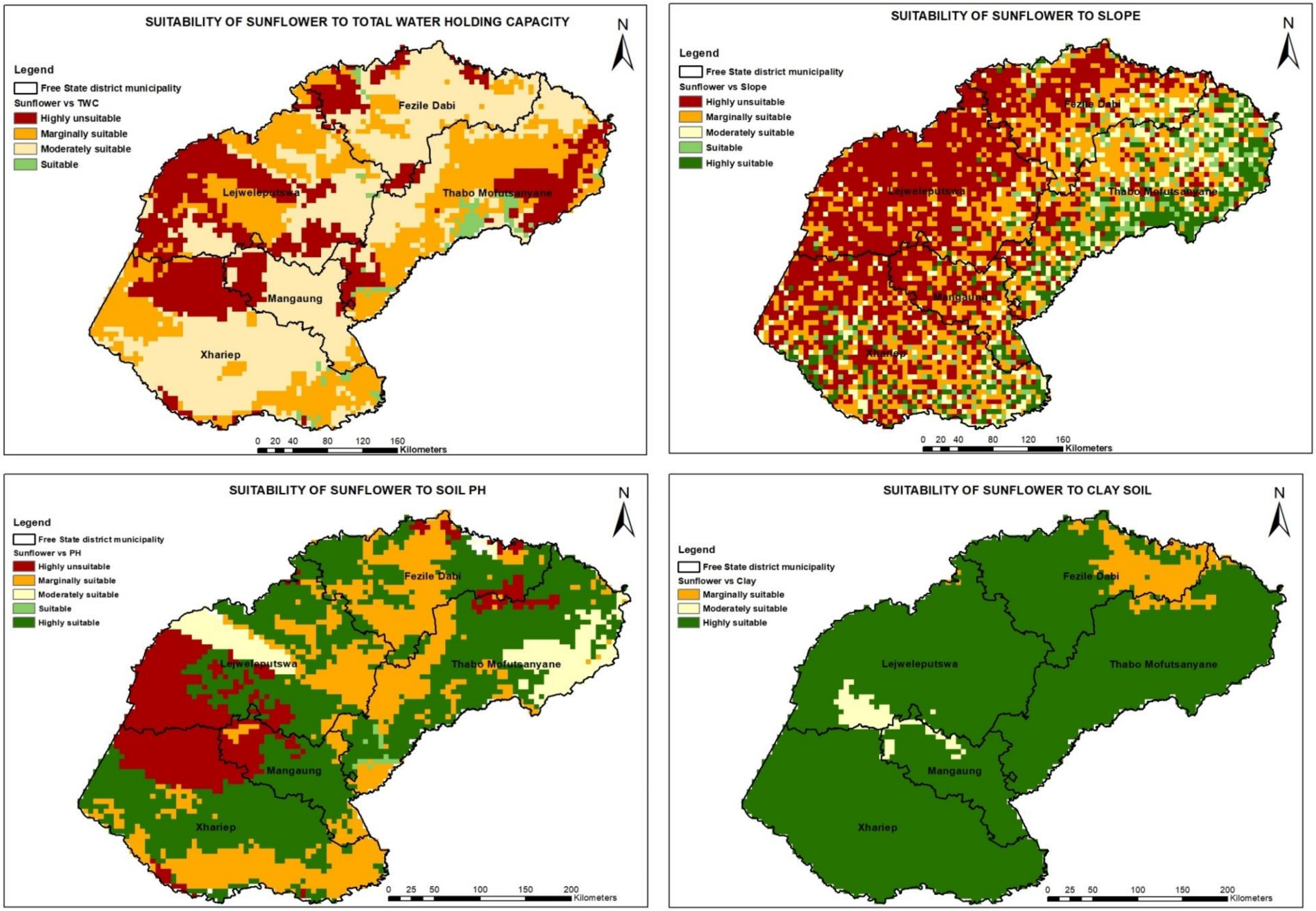

Station: OFCOLACOCNRM-CM5 [-24°S, 23°E]

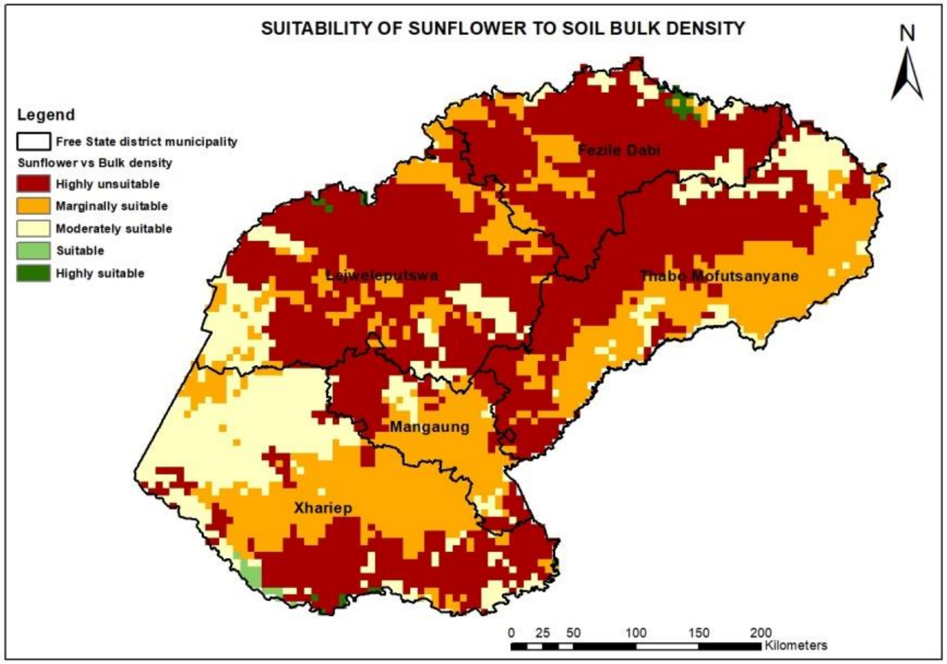

Station: OFCOLACOFGOALS [-24°S, 23°E]
Index: gddgrow10. Annual sum of TM - 10
degree-days
3500
4000
4500
5000
5500
6000
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= 19.077 Slope error= 0.441 , p-value= 0
locally weighted scatterplot smoothing
ClimPACT2 v 1.2.1


Station: OFCOLACOGDFL-ESM2G [-24°S, 23°E]
Index: gddgrow10. Annual sum of TM - 10
degree-days
3500
4000
4500
5000
5500
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= 14.143 Slope error= 0.382 , p-value= 0
locally weighted scatterplot smoothing
ClimPACT2 v 1.2.1

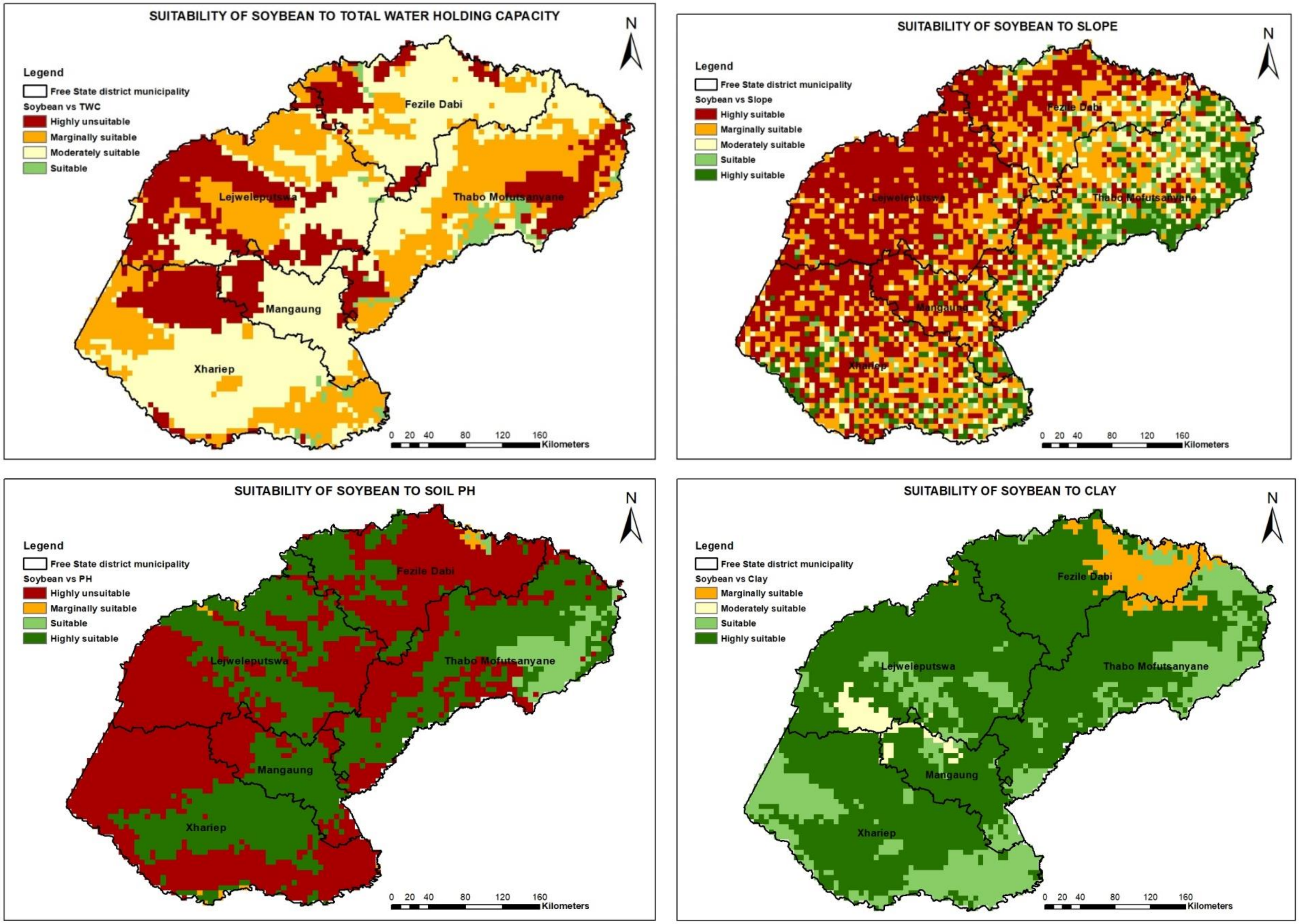

Station: OFCOLACOMIROC5 [-24°S, 23°E]
Index: gddgrow10. Annual sum of TM - 10
degree-days
3500
4000
4500
5000
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
Linear trend slope= 11.562 Slope error= 0.329 , p-value= 0
locally weighted scatterplot smoothing
ClimPACT2 v 1.2.1

Appendix 4.33: Suitability indicators for sunflower production in the Free state Province

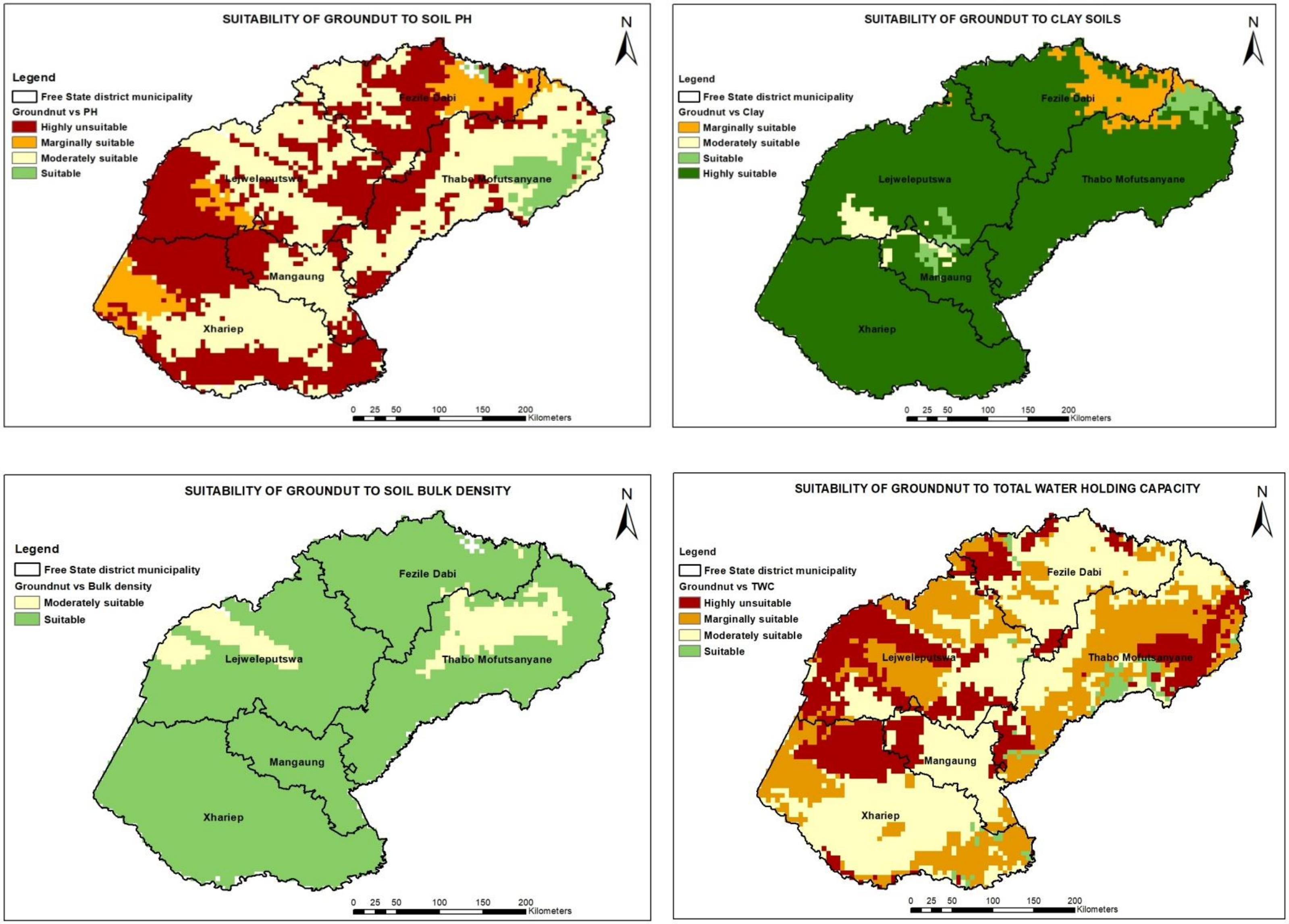


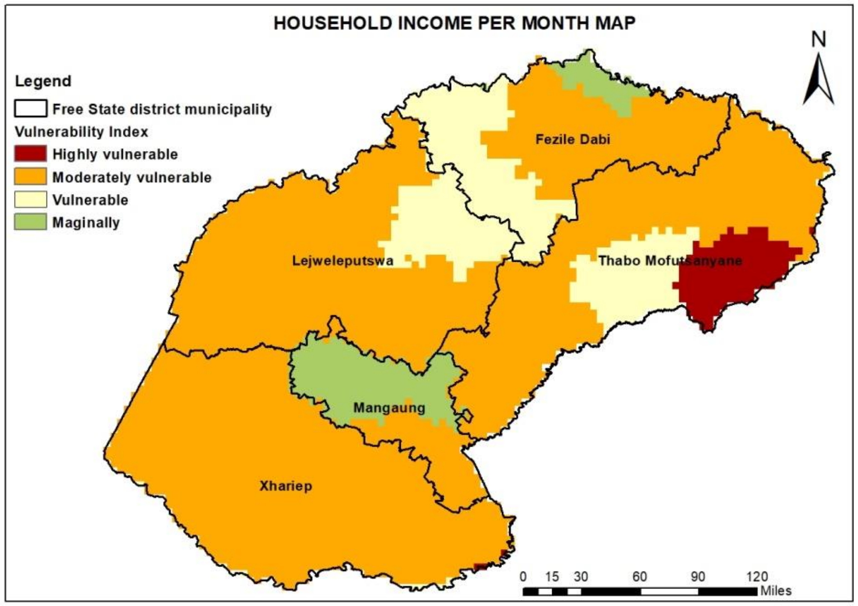

SUITABILITY OF SUNFLOWER TO SOIL BULK DENSITY
N
Legend
Free State district municipality
Sunflower vs Bulk density
Highly unsuitable
Marginally suitable
Moderately suitable
Suitable
Highly suitable
Fezile Dabi
Lejweleputswa
Thabo Mofutsanyane
Mangaung
Xhariep
0 25 50 100 150 200
Kilometers

Appendix 4.34: Suitability indicators for soybean production in the Free State Province

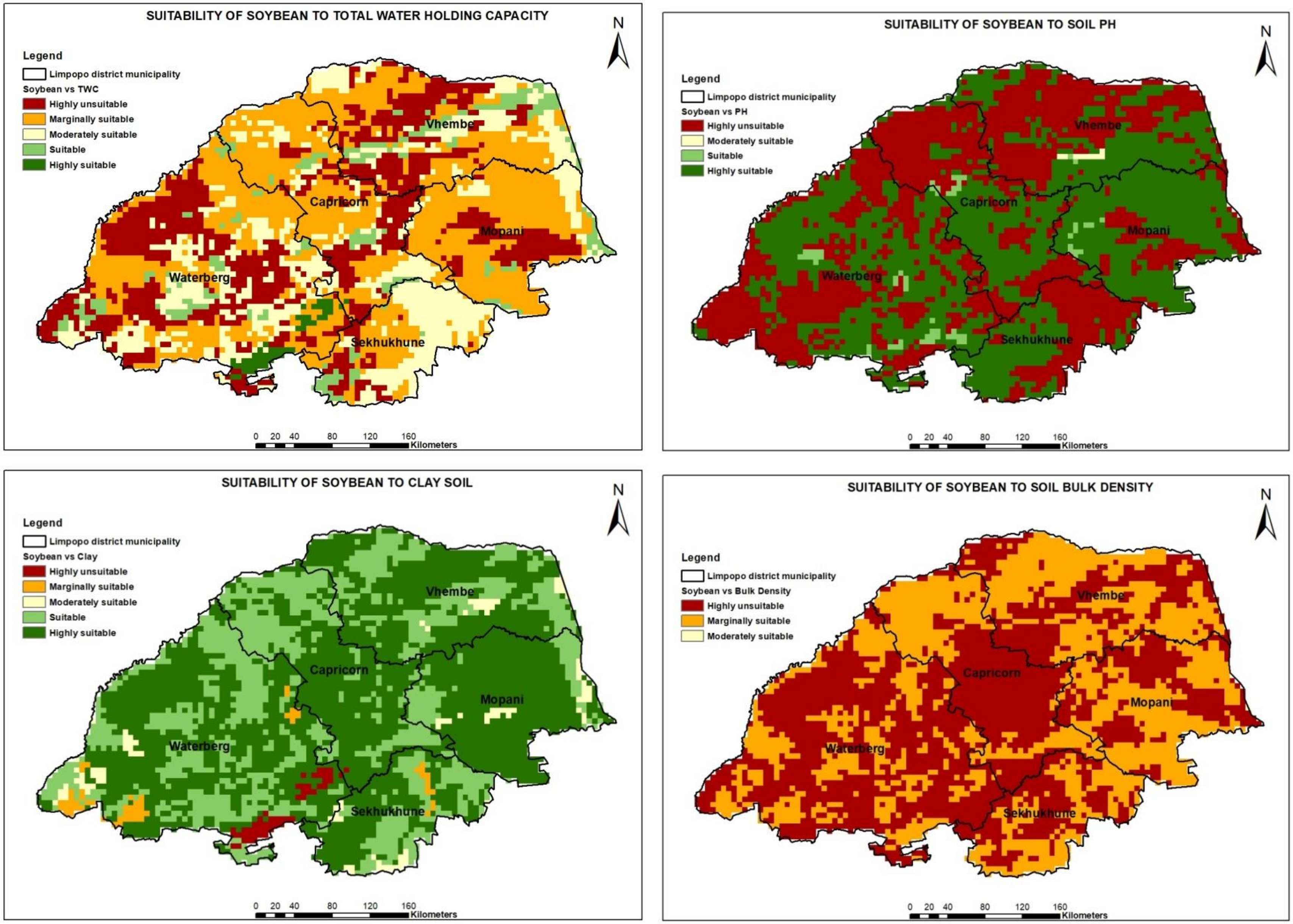


Appendix 4.35: Suitability indicators for sunflower production in the Free State Province

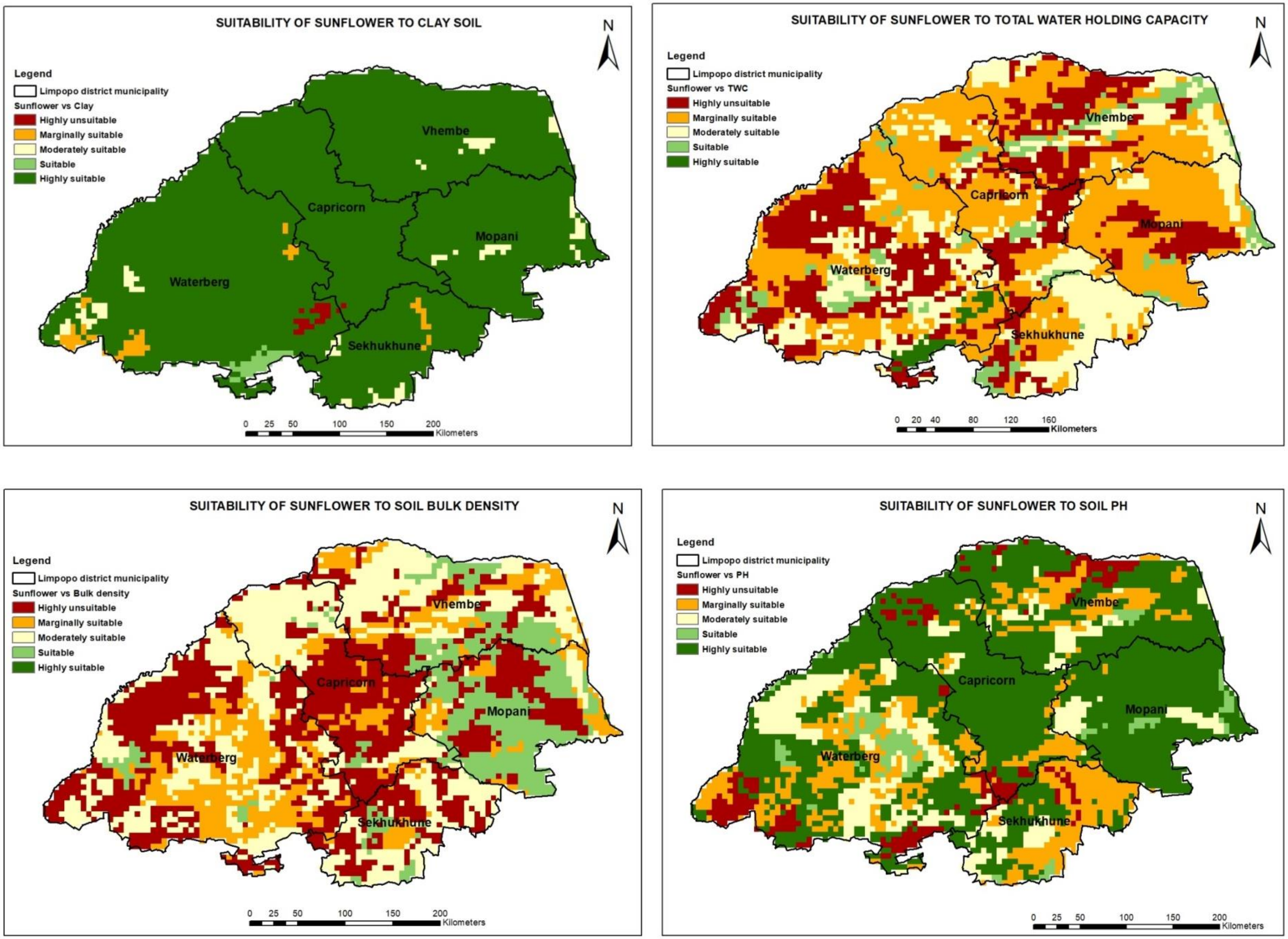



HOUSEHOLD INCOME PER MONTH MAP
Legend
Free State district municipality
Vulnerability Index
Highly vulnerable
Moderately vulnerable
Vulnerable
Maginally
N
Fezile Dabi
Lejweleputswa
Thabo Mofutsanyane
Mangaung
Xhariep
0 15 30 60 90 120
Miles

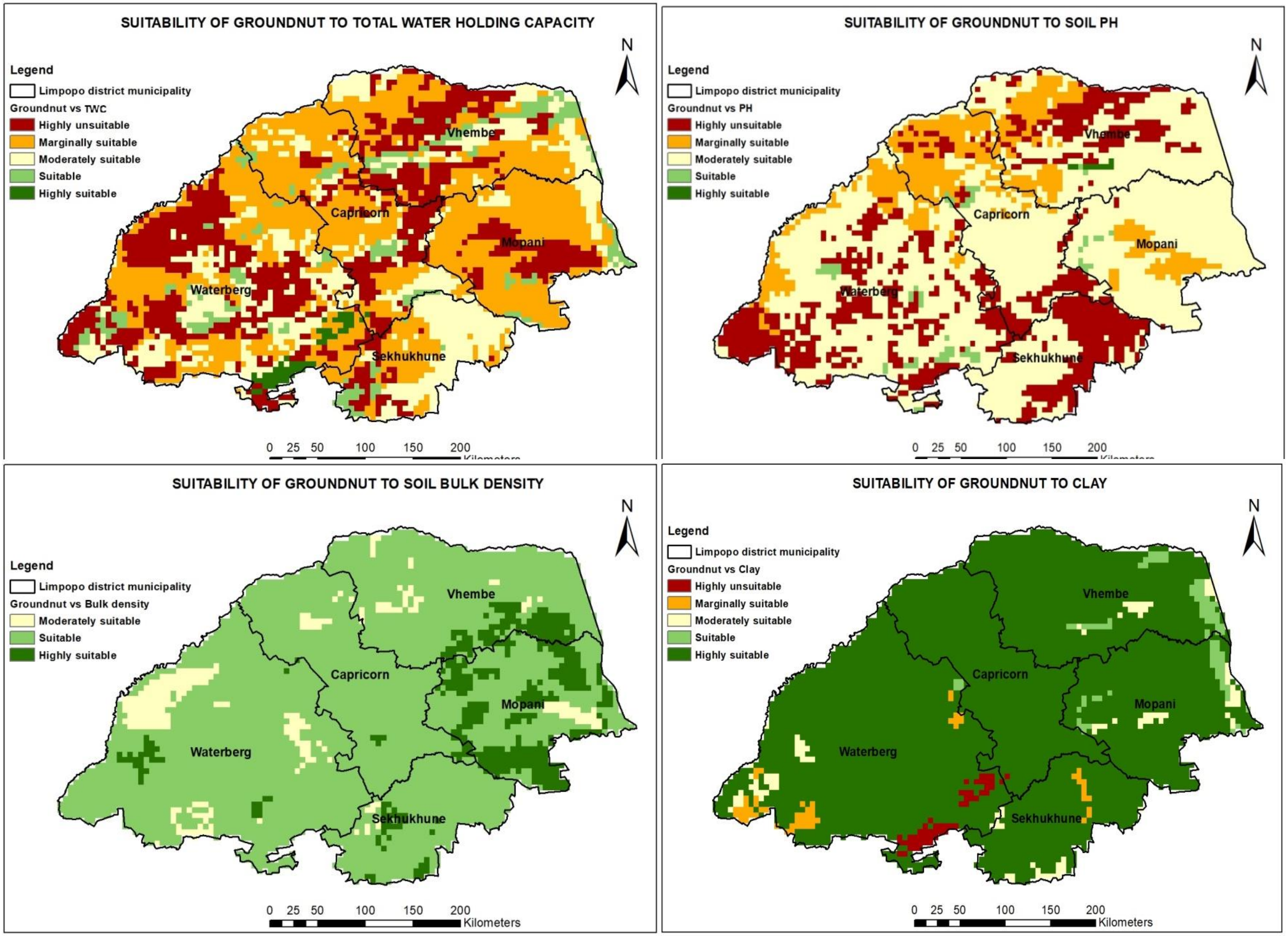
Appendix 4.36: Suitability indicators for soybean production in the Limpopo Province



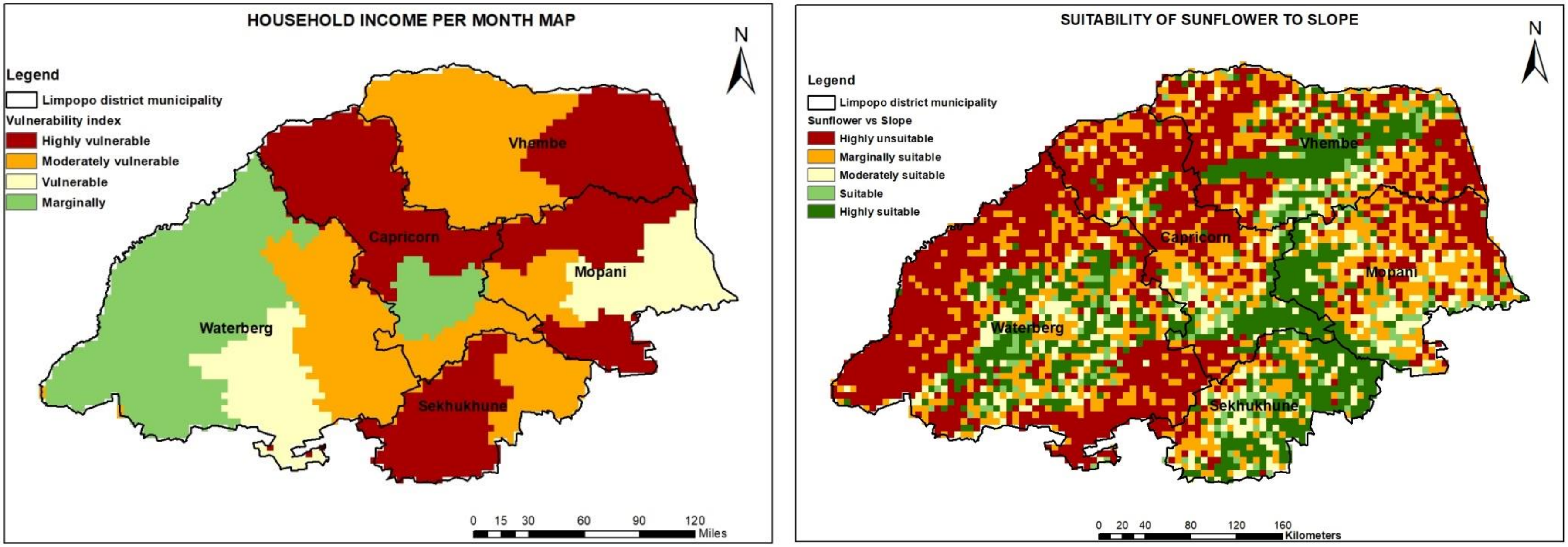
Appendix 4.37: Suitability indicators for sunflower production in the Limpopo Province



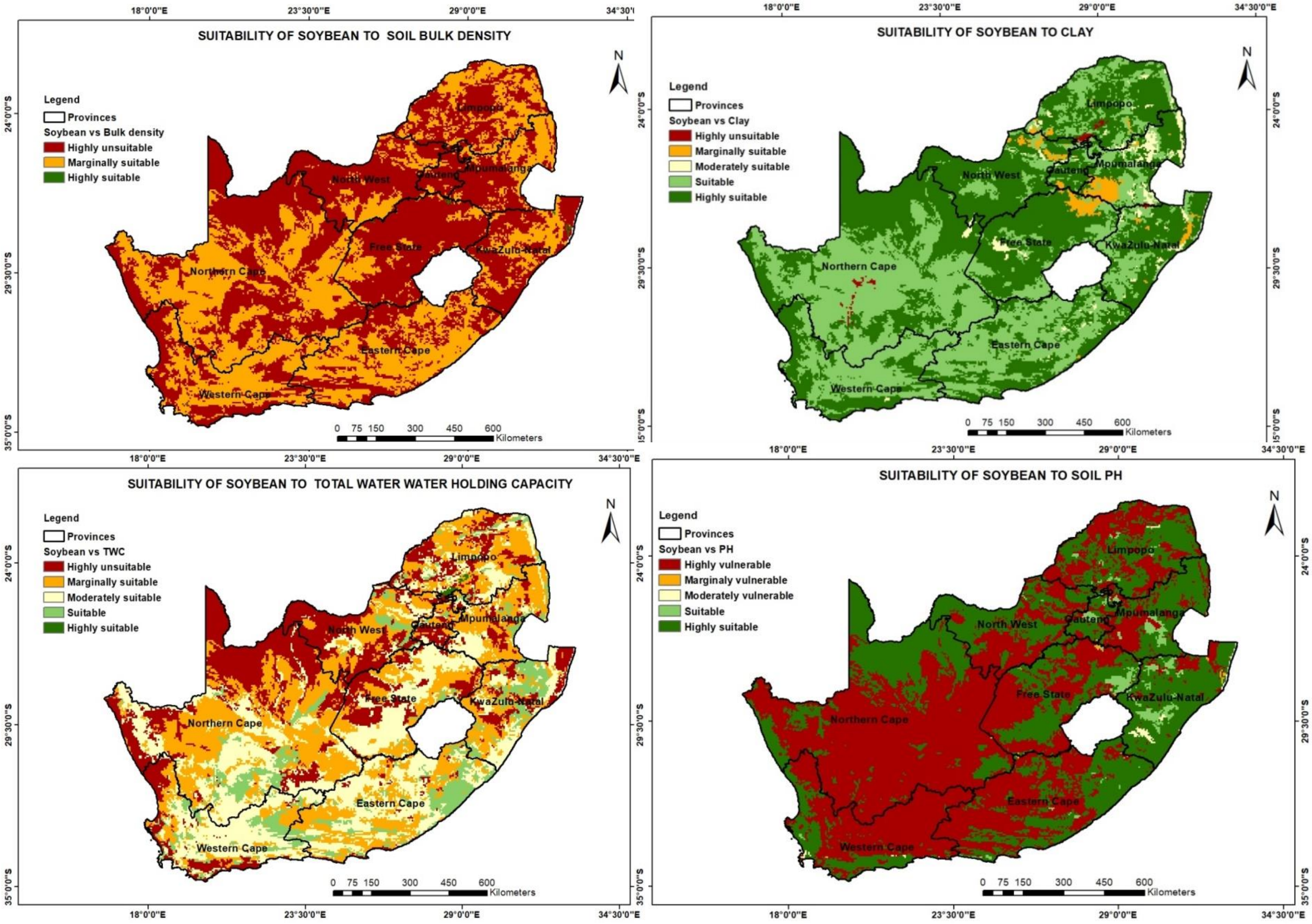
Appendix 4.38: Suitability indicators for groundnut production in the Limpopo Province



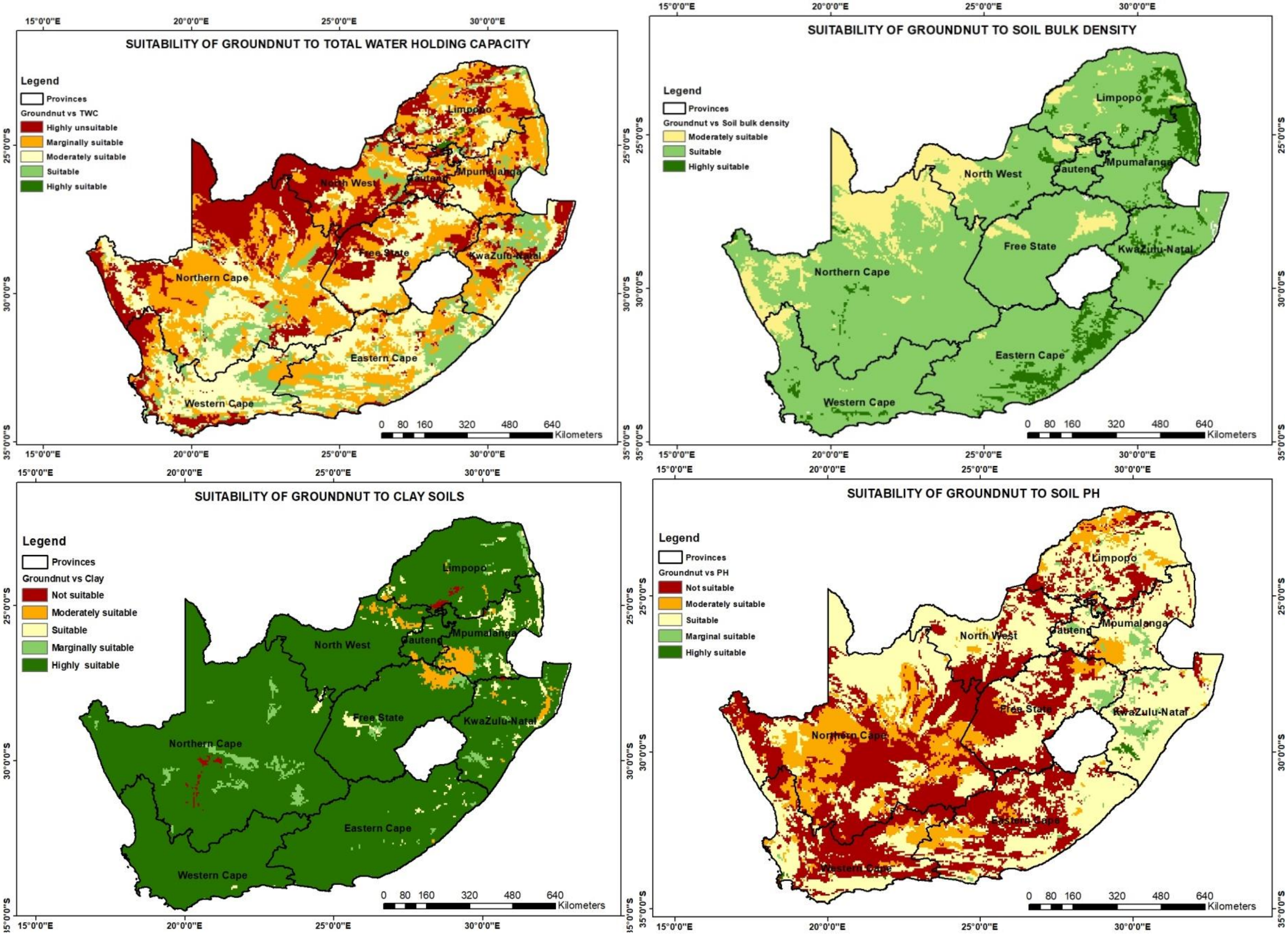
Appendix 4.39: Household income and slope suitability in Limpopo



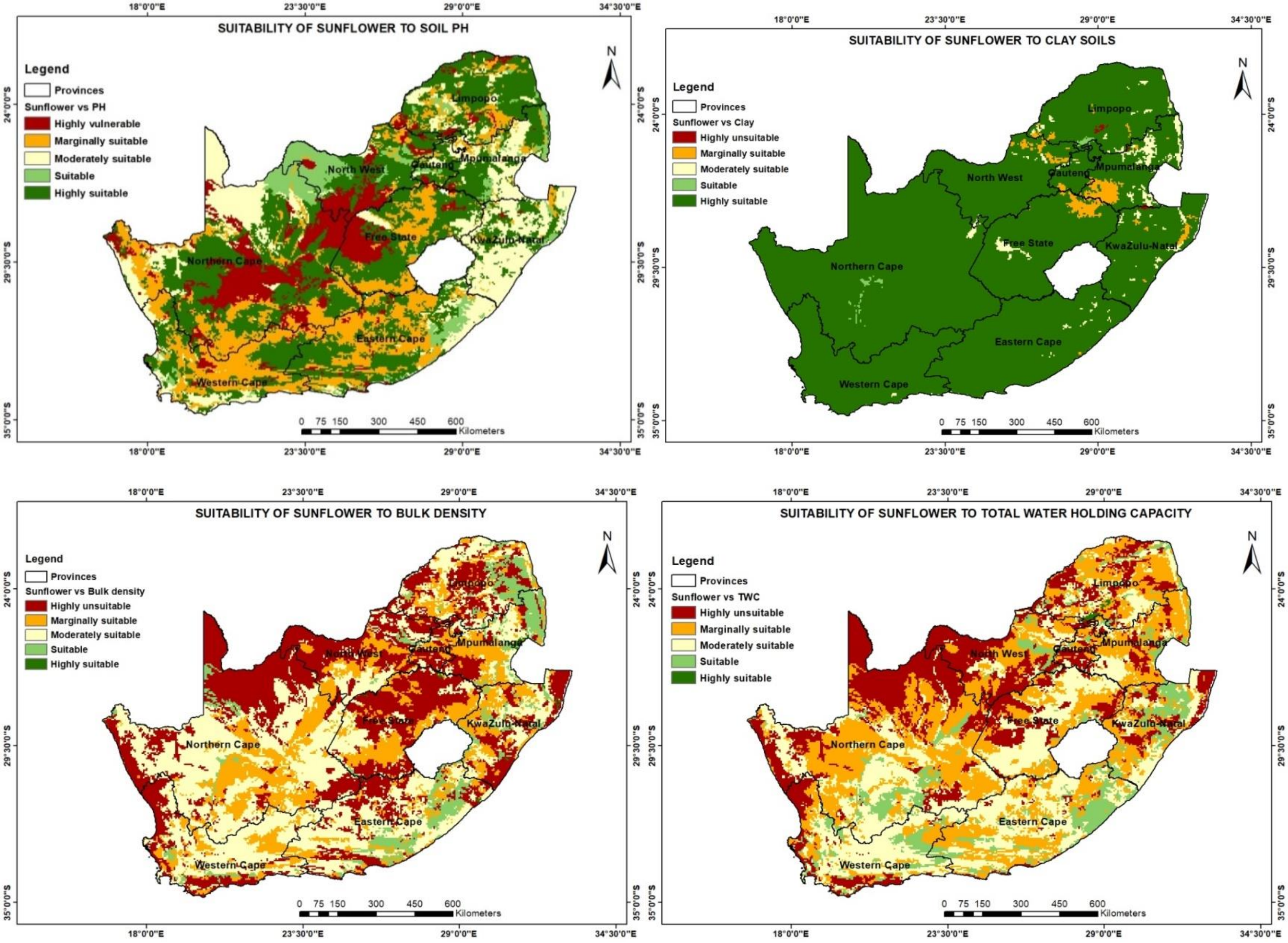
Appendix 4.40: Suitability indicators for soybean production in the South Africa Province

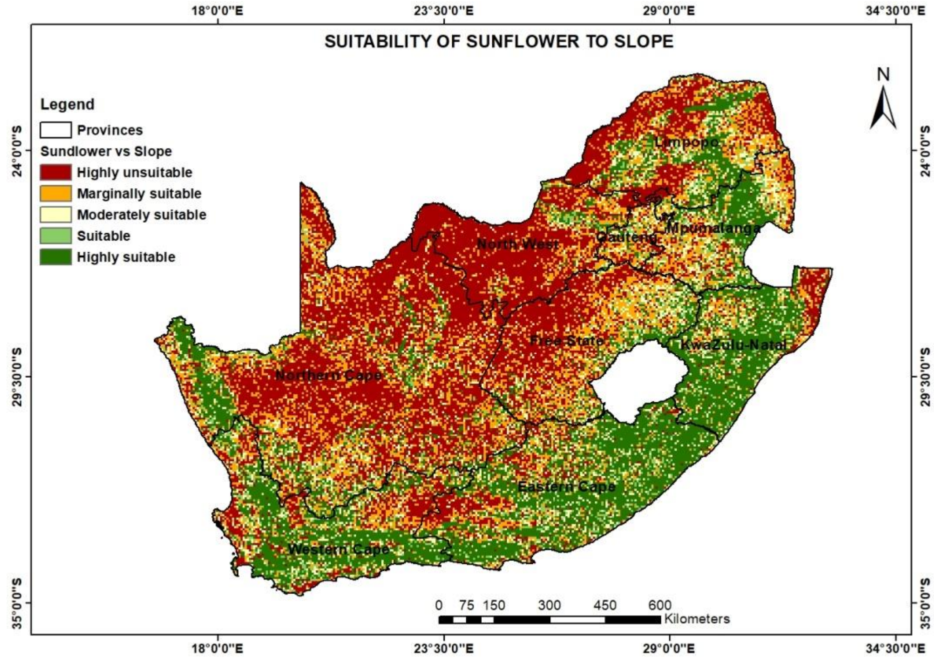


Appendix 4.41: Suitability indicators for groundnut production in the Limpopo Province

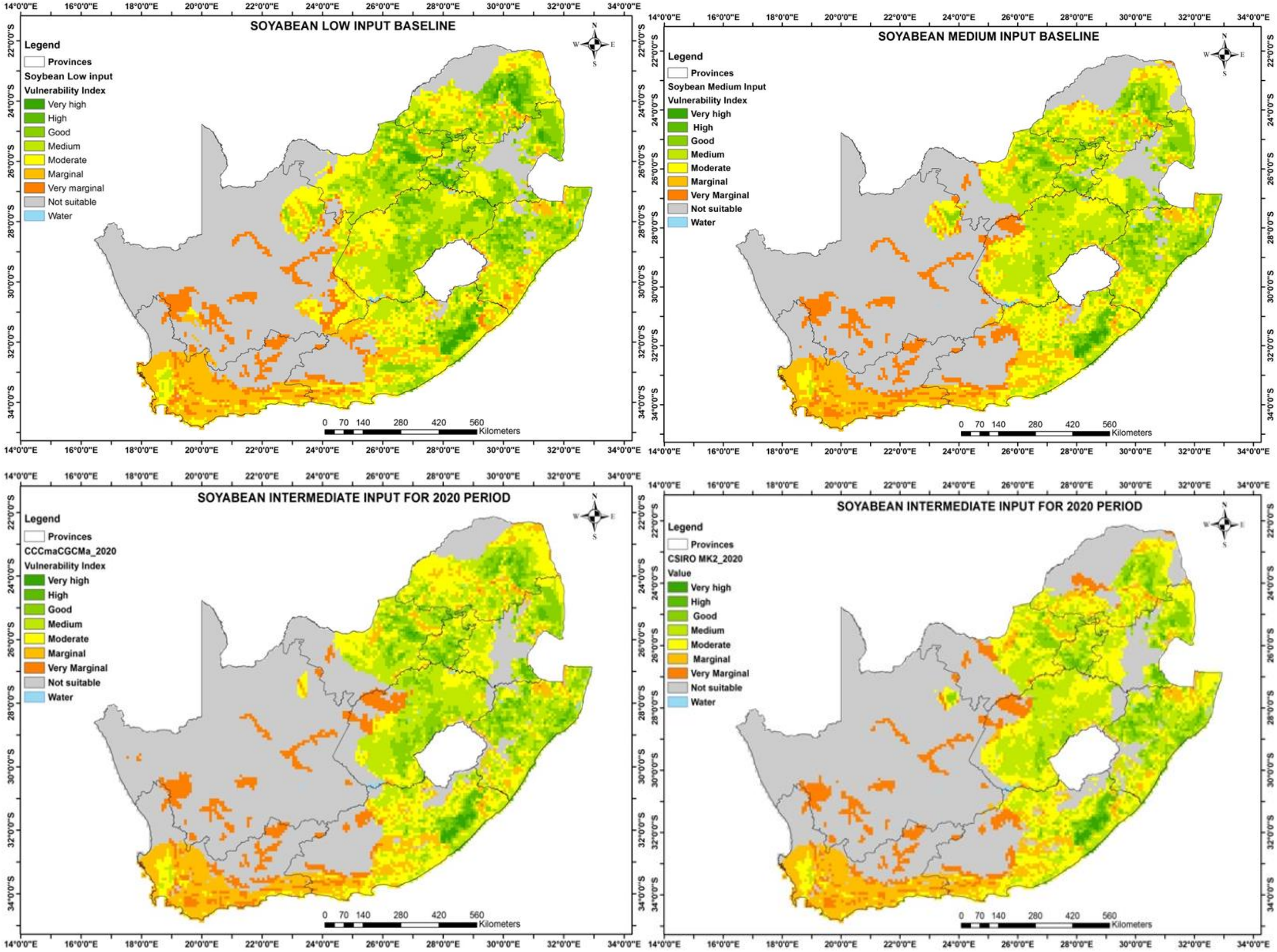


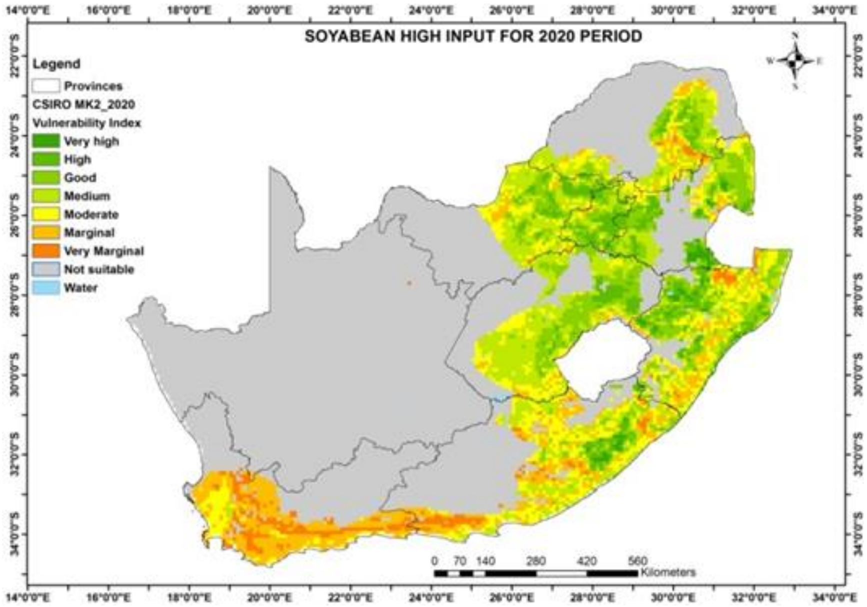
Appendix 4.42: Suitability indicators for sunflower production in South Africa

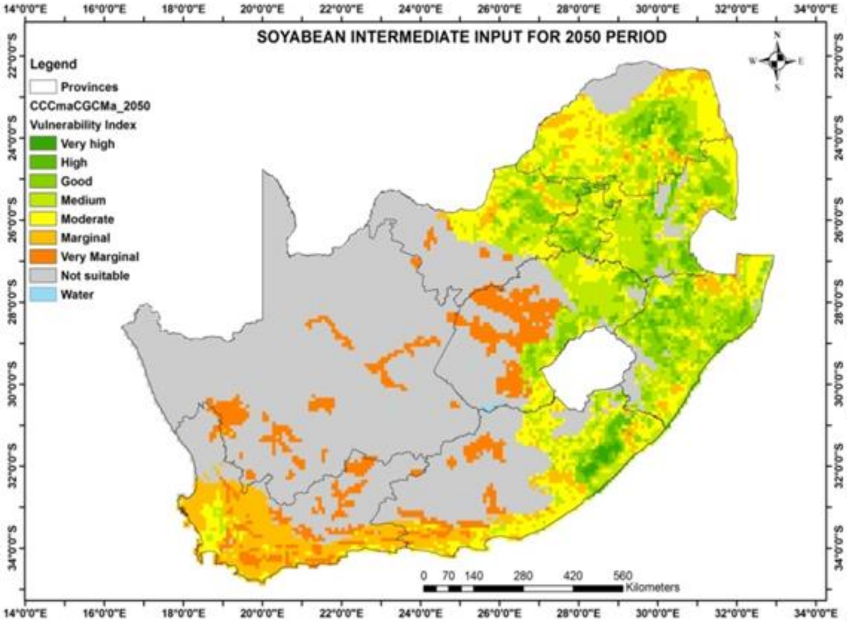



SUITABILITY OF SUNFLOWER TO SLOPE
Legend
Provinces
Sundlower vs Slope
Highly unsuitable
Marginally suitable
Moderately suitable
Suitable
Highly suitable
N
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 75 150 300 450 600
Kilometers
18°0'0"E
23°30'0"E
29°0'0"E
34°30'0"E
24°0'0"S
29°30'0"S
35°0'0"S

Appendix 4.43: Distribution of Soybean based on three climate models and time frames




SOYABEAN HIGH INPUT FOR 2020 PERIOD
Legend
Provinces
CSIRO MK2_2020
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very Marginal
Not suitable
Water
0 70 140 280 420 560
Kilometers
N
S
E
W
14°0'0"E
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
22°0'0"S
24°0'0"S
26°0'0"S
28°0'0"S
30°0'0"S
32°0'0"S
34°0'0"S


SOYABEAN INTERMEDIATE INPUT FOR 2050 PERIOD
Legend
Provinces
CCCmaCGCMa_2050
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very Marginal
Not suitable
Water
0 70 140 280 420 560
Kilometers
14°0'0"E
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
22°0'0"S
24°0'0"S
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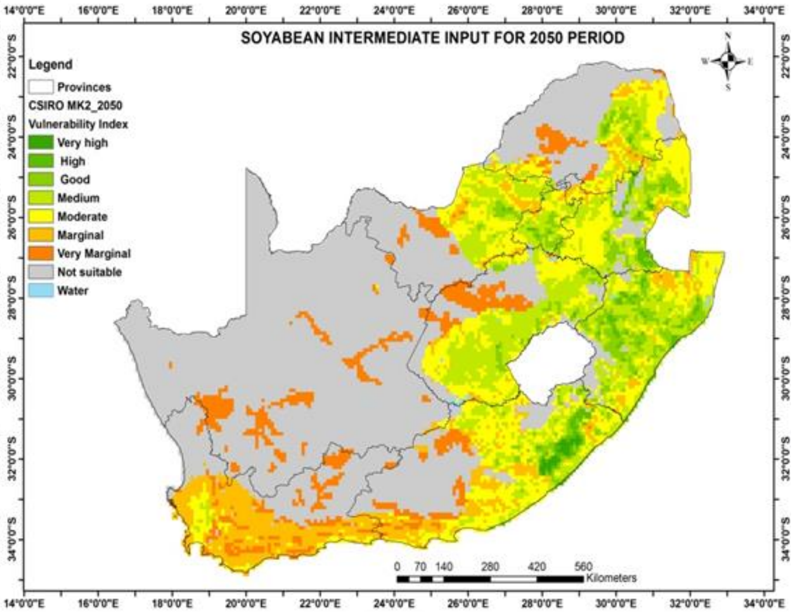
32°0'0"S
34°0'0"S
N
S
E
W


SOYABEAN INTERMEDIATE INPUT FOR 2050 PERIOD
Legend
Provinces
CSIRO MK2_2050
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very Marginal
Not suitable
Water
0 70 140 280 420 560
Kilometers
14°0'0"E
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
22°0'0"S
24°0'0"S
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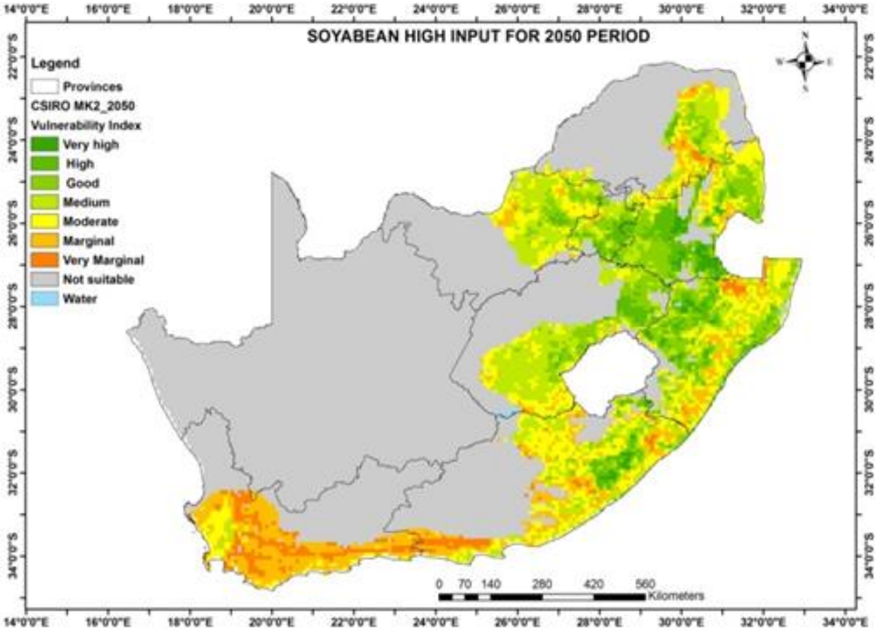
32°0'0"S
34°0'0"S
N
S
E
W


SOYABEAN HIGH INPUT FOR 2050 PERIOD
Legend
Provinces
CSIRO MK2_2050
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very Marginal
Not suitable
Water
0 70 140 280 420 560
Kilometers
14°0'0"E
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
22°0'0"S
24°0'0"S
26°0'0"S
28°0'0"S
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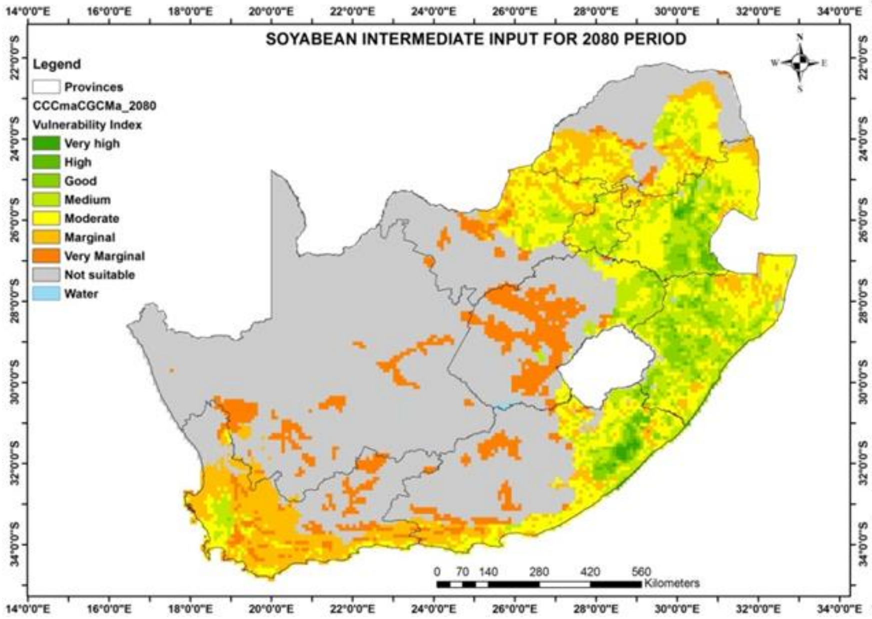
32°0'0"S
34°0'0"S
N
S
E
W


SOYABEAN INTERMEDIATE INPUT FOR 2080 PERIOD
Legend
Provinces
CCCmaCGCMa_2080
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very Marginal
Not suitable
Water
N
S
E
W
0 70 140 280 420 560
Kilometers
14°0'0"E
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
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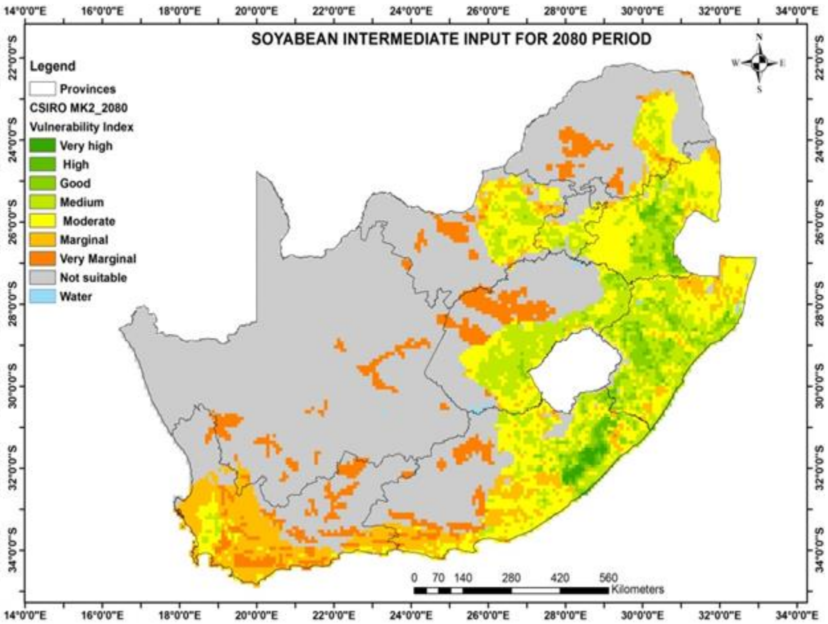
28°0'0"S
30°0'0"S
32°0'0"S
34°0'0"S


SOYABEAN INTERMEDIATE INPUT FOR 2080 PERIOD
Legend
Provinces
CSIRO MK2_2080
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very Marginal
Not suitable
Water
N
S
E
W
0 70 140 280 420 560
Kilometers
14°0'0"E
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
22°0'0"S
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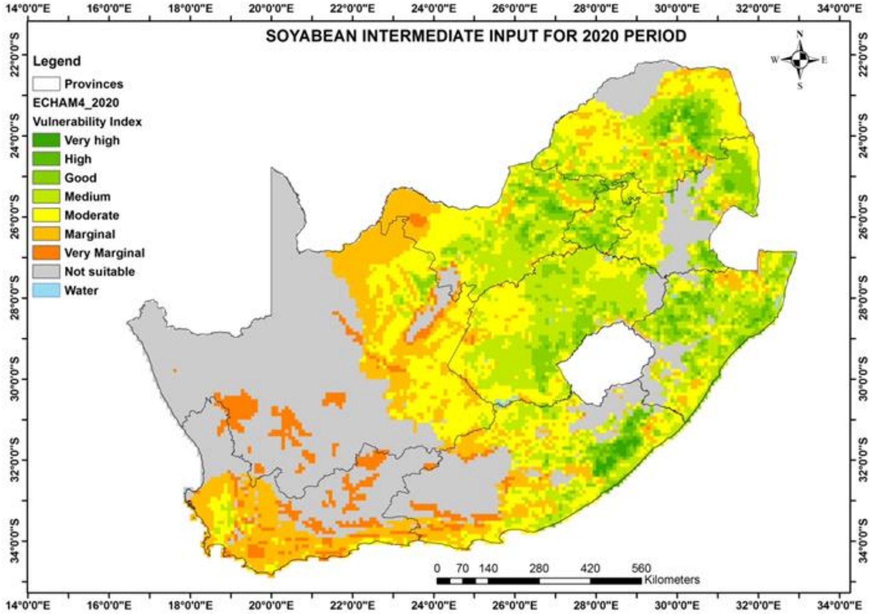
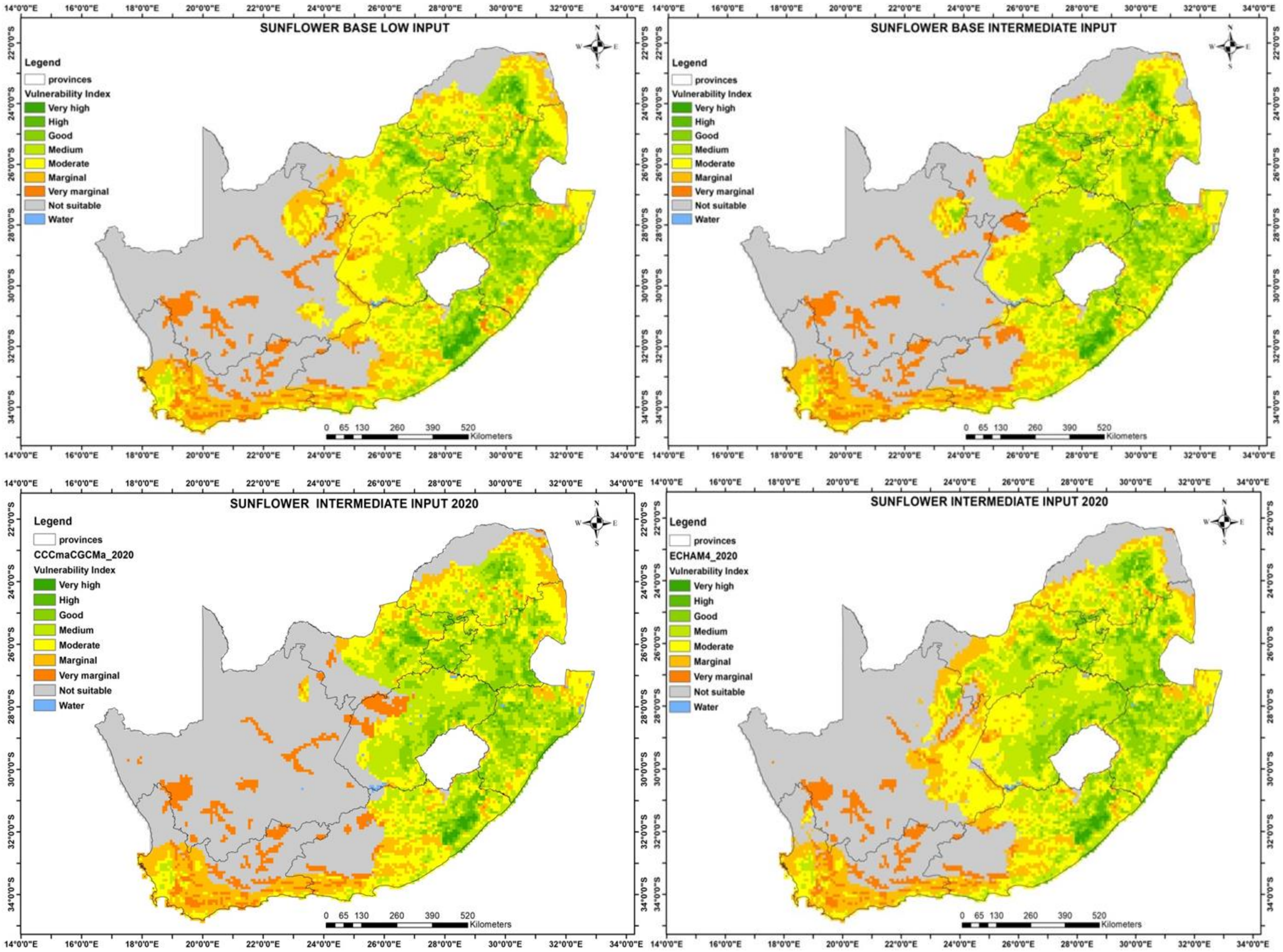
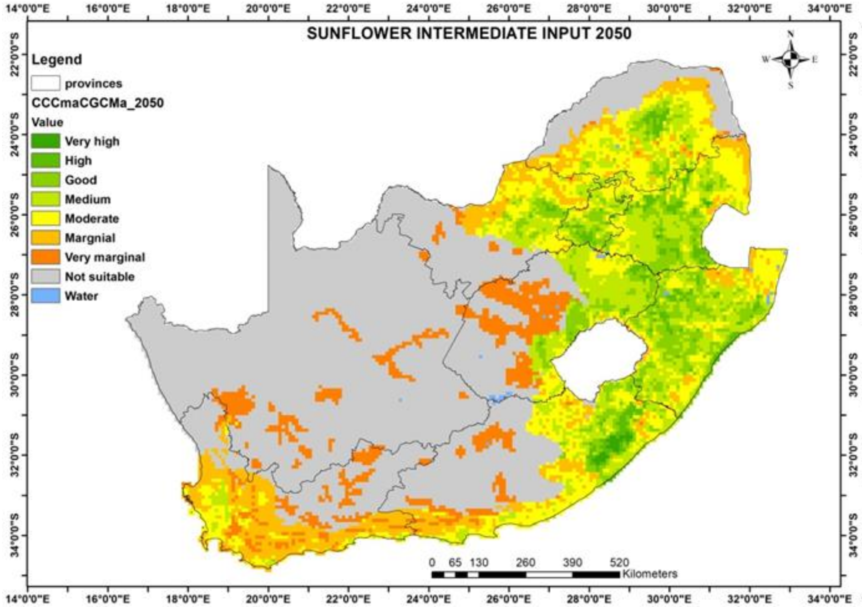
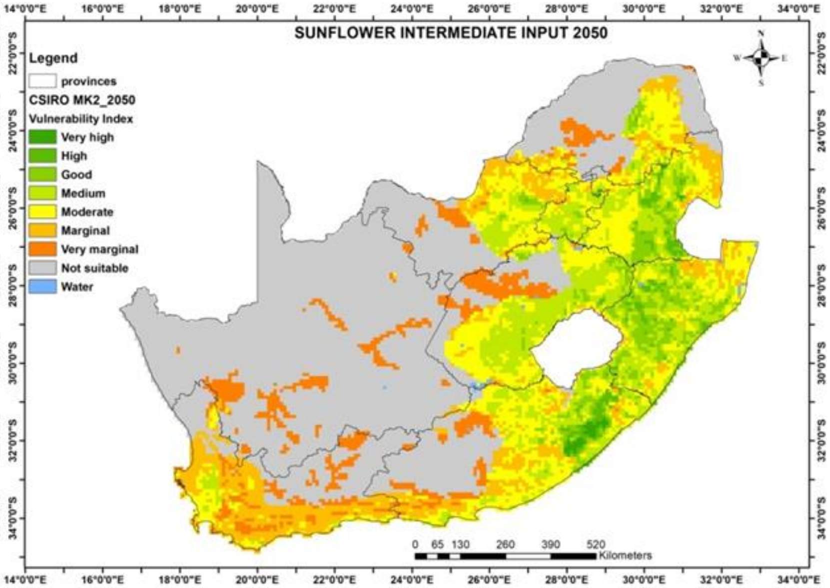
26°0'0"S
28°0'0"S
30°0'0"S
32°0'0"S
34°0'0"S

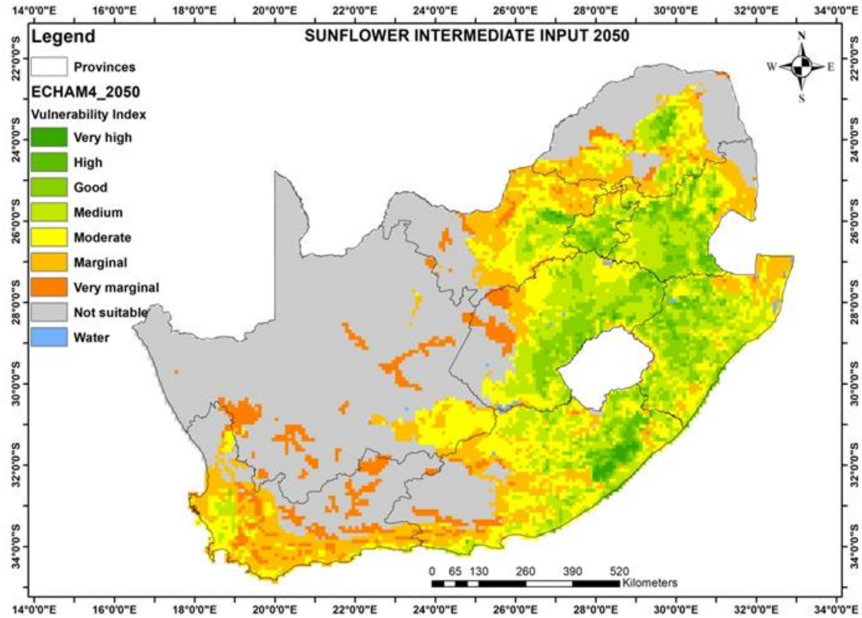

SOYABEAN INTERMEDIATE INPUT FOR 2020 PERIOD
Legend
Provinces
ECHAM4_2020
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very Marginal
Not suitable
Water
N
S
E
W
0 70 140 280 420 560
Kilometers
14°0'0"E
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
22°0'0"S
24°0'0"S
26°0'0"S
28°0'0"S
30°0'0"S
32°0'0"S
34°0'0"S

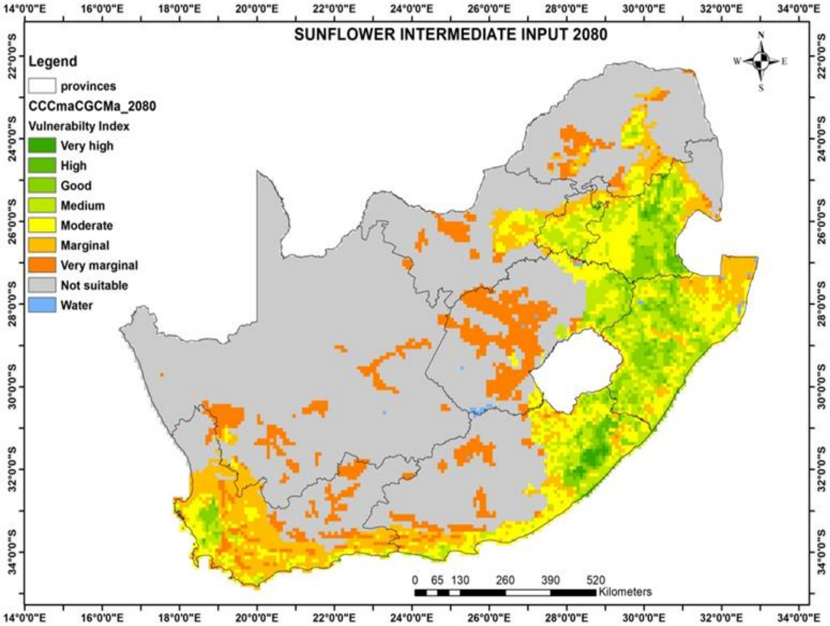
Appendix 4.44: Distribution of sunflower based on three climate models and time frames.

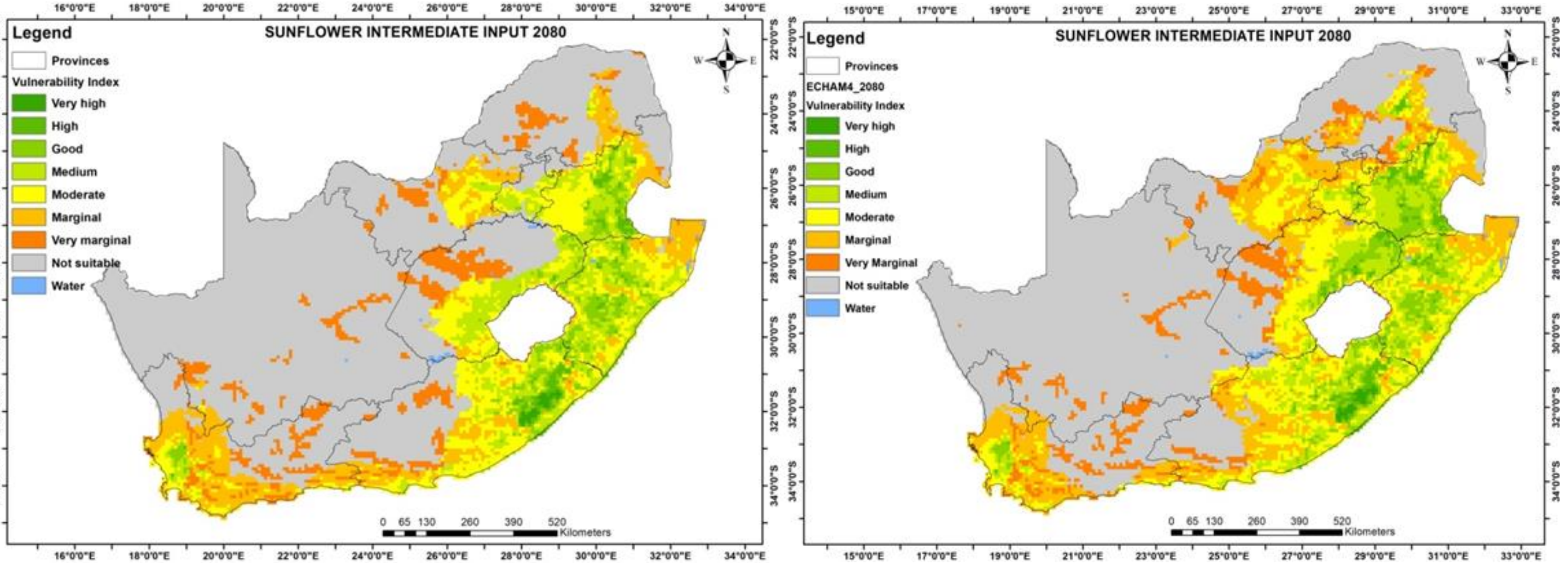



SUNFLOWER INTERMEDIATE INPUT 2050
Legend
provinces
CCCmaCGCMa_2050
Value
Very high
High
Good
Medium
Moderate
Margnial
Very marginal
Not suitable
Water
0 65 130 260 390 520 Kilometers

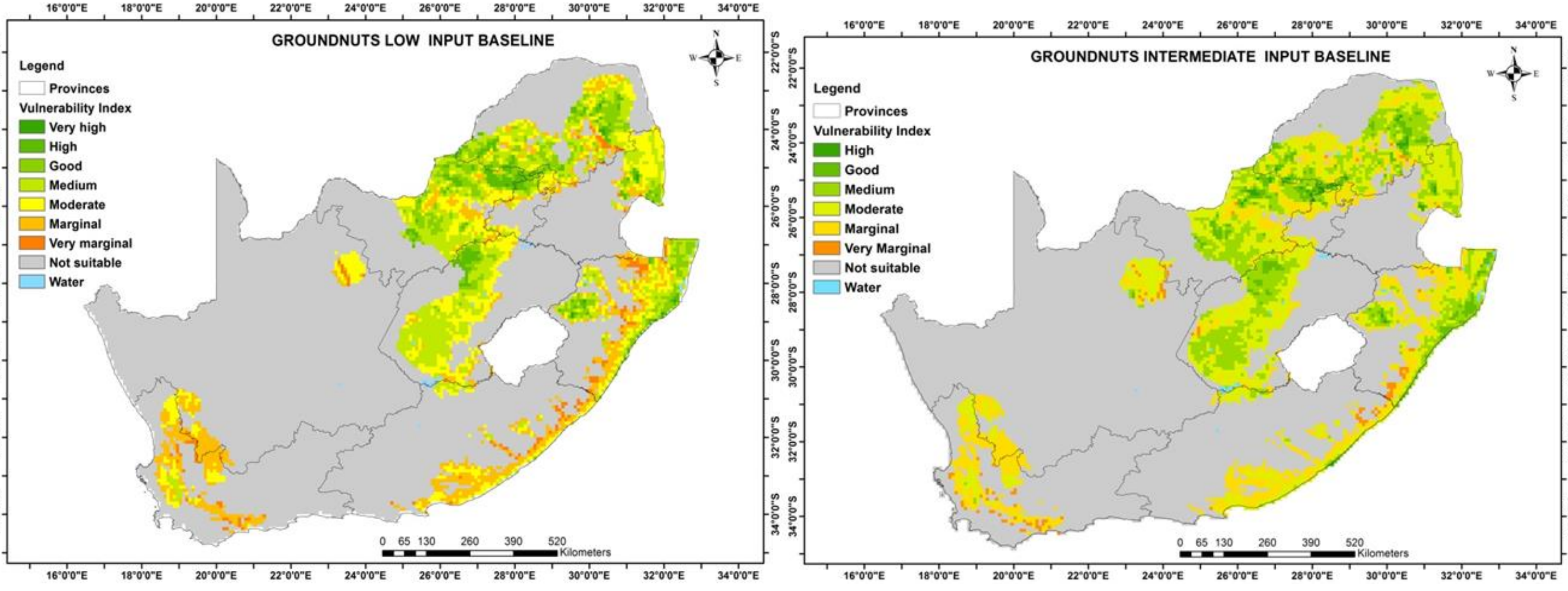

SUNFLOWER INTERMEDIATE INPUT 2050
Legend
provinces
CSIRO MK2_2050
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
0 65 130 260 390 520 Kilometers

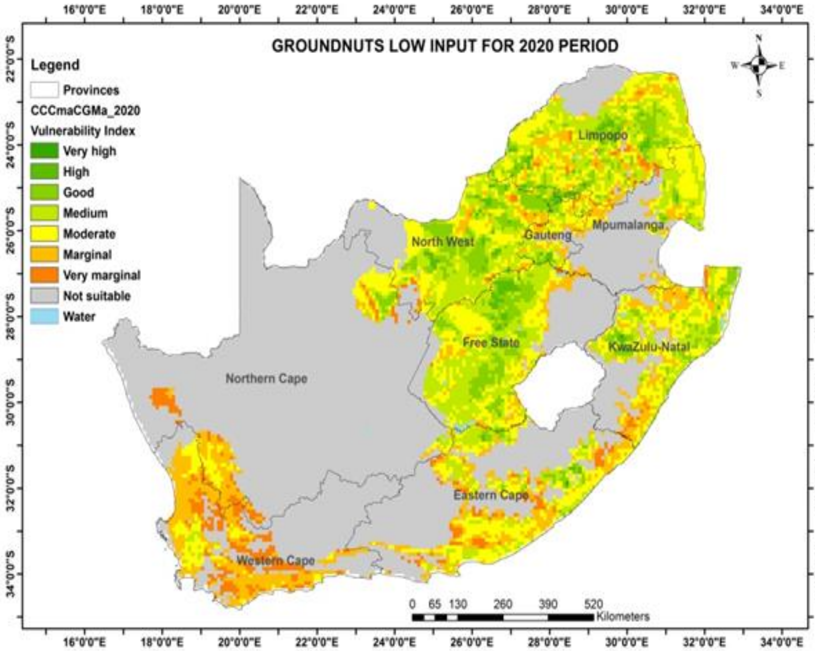

SUNFLOWER INTERMEDIATE INPUT 2050
Legend
Provinces
ECHAM4_2050
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
0 65 130 260 390 520 Kilometers


SUNFLOWER INTERMEDIATE INPUT 2080
Legend
provinces
CCCmaCGCMa_2080
Vulnerabilty Index
Very high
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
0 65 130 260 390 520 Kilometers



Appendix 4.45: Distribution of groundnut based on three climate models and time frames.




GROUNDNUTS LOW INPUT FOR 2020 PERIOD
Legend
Provinces
CCCmaCGMa_2020
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520
Kilometers
N
S
E
W
16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
22°0'0"S
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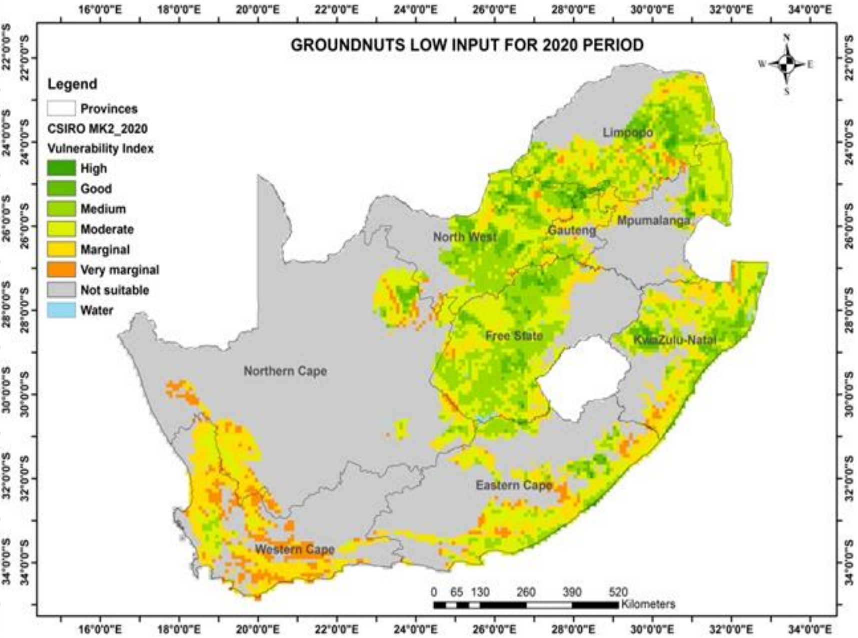
26°0'0"S
28°0'0"S
30°0'0"S
32°0'0"S
34°0'0"S


GROUNDNUTS LOW INPUT FOR 2020 PERIOD
Legend
Provinces
CSIRO MK2_2020
Vulnerability Index
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520
Kilometers
N
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16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
26°0'0"E
28°0'0"E
30°0'0"E
32°0'0"E
34°0'0"E
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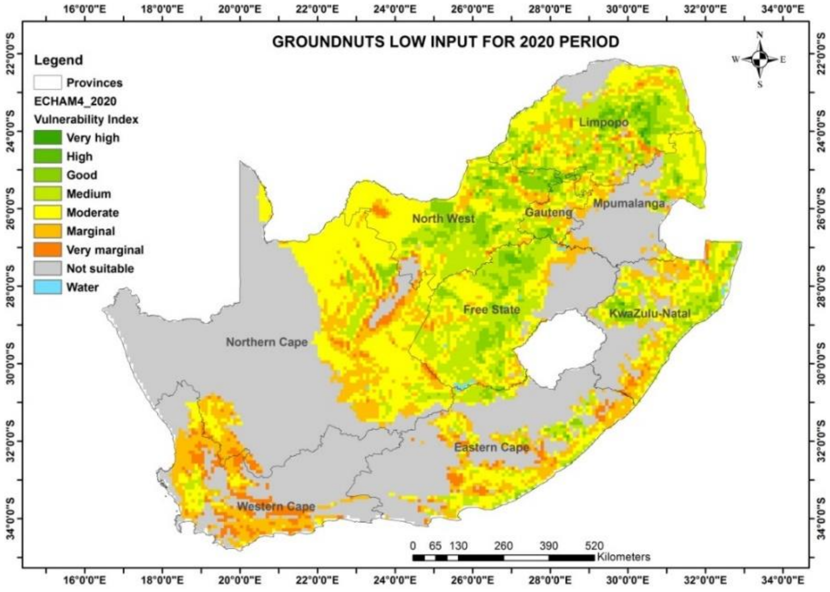
GROUNDNUTS LOW INPUT FOR 2020 PERIOD
Legend
Provinces
ECHAM4_2020
Vulnerability Index
Very high
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520
Kilometers
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16°0'0"E
18°0'0"E
20°0'0"E
22°0'0"E
24°0'0"E
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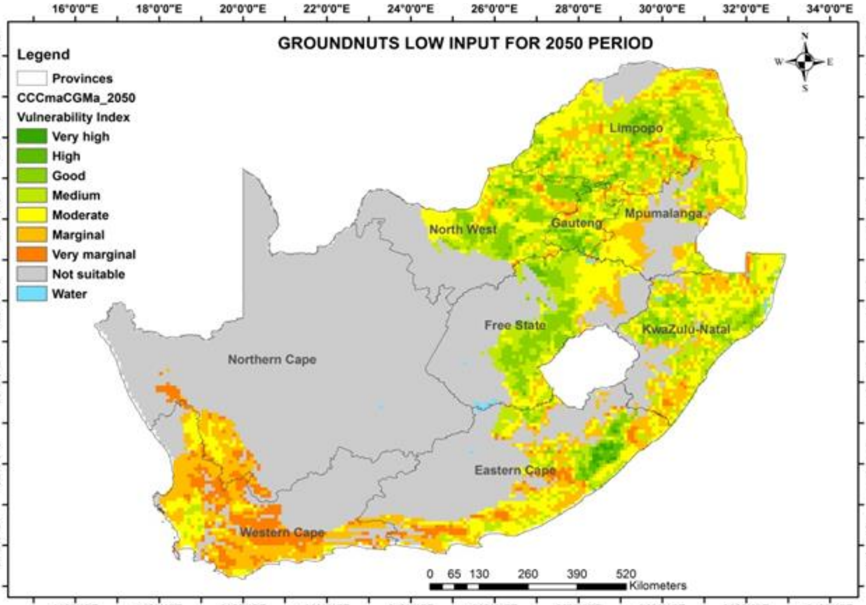
GROUNDNUTS LOW INPUT FOR 2050 PERIOD
Legend
Provinces
CCCmaCGMa_2050
Vulnerability Index
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Good
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Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
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Kilometers
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22°0'0"E
24°0'0"E
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28°0'0"E
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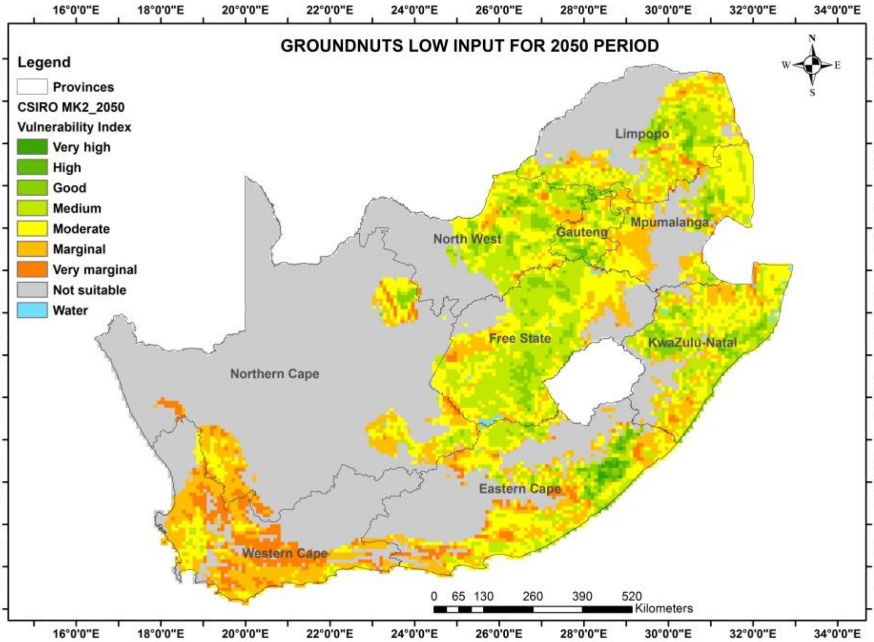
GROUNDNUTS LOW INPUT FOR 2050 PERIOD
Legend
Provinces
CSIRO MK2_2050
Vulnerability Index
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Moderate
Marginal
Very marginal
Not suitable
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North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
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0 65 130 260 390 520
Kilometers
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18°0'0"E
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22°0'0"E
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26°0'0"E
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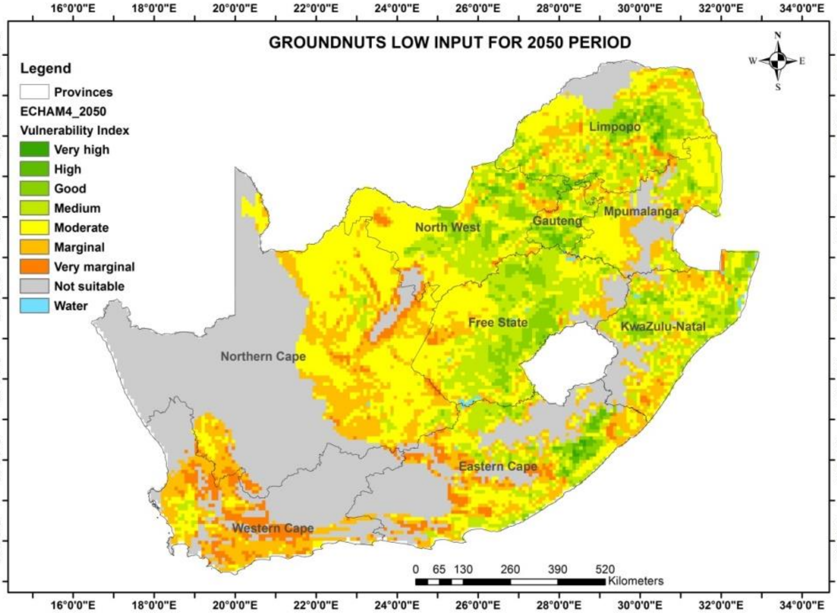
GROUNDNUTS LOW INPUT FOR 2050 PERIOD
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Very marginal
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North West
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Western Cape
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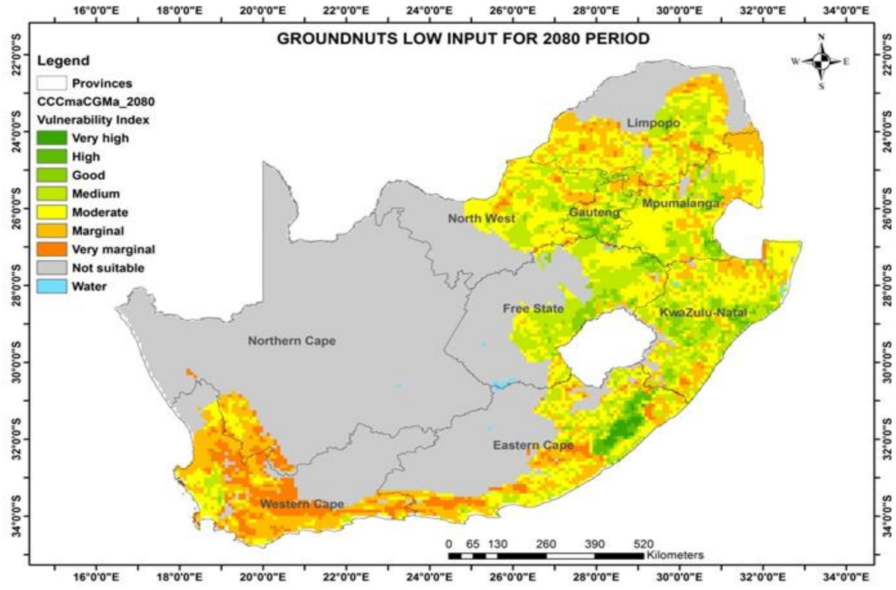
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Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
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Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
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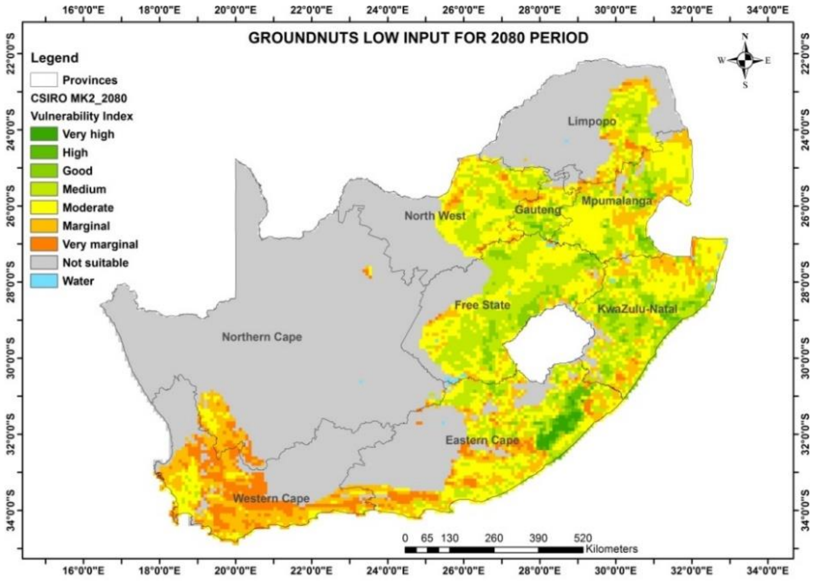
GROUNDNUTS LOW INPUT FOR 2080 PERIOD
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Very marginal
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Western Cape
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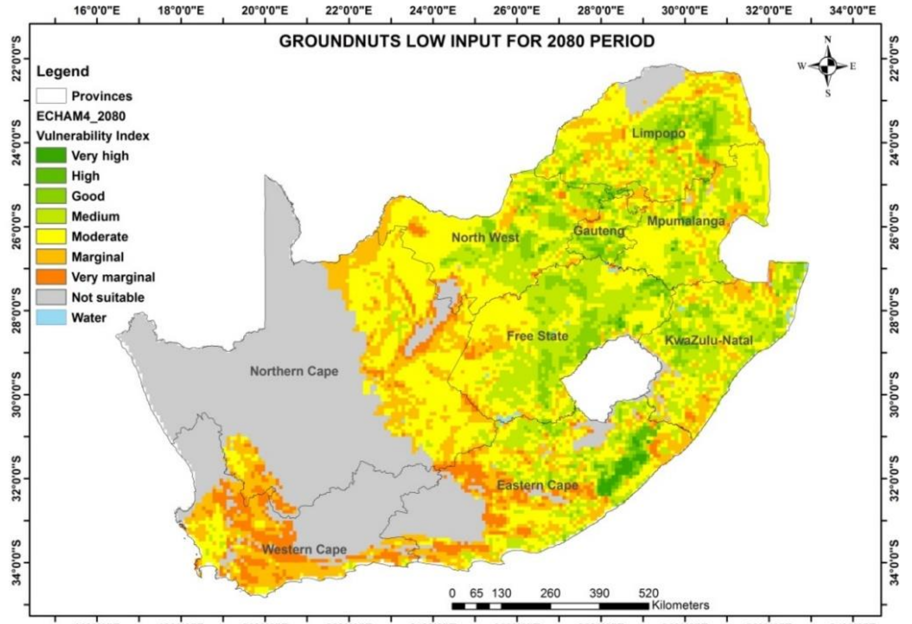
GROUNDNUTS LOW INPUT FOR 2080 PERIOD
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Vulnerability Index
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Eastern Cape
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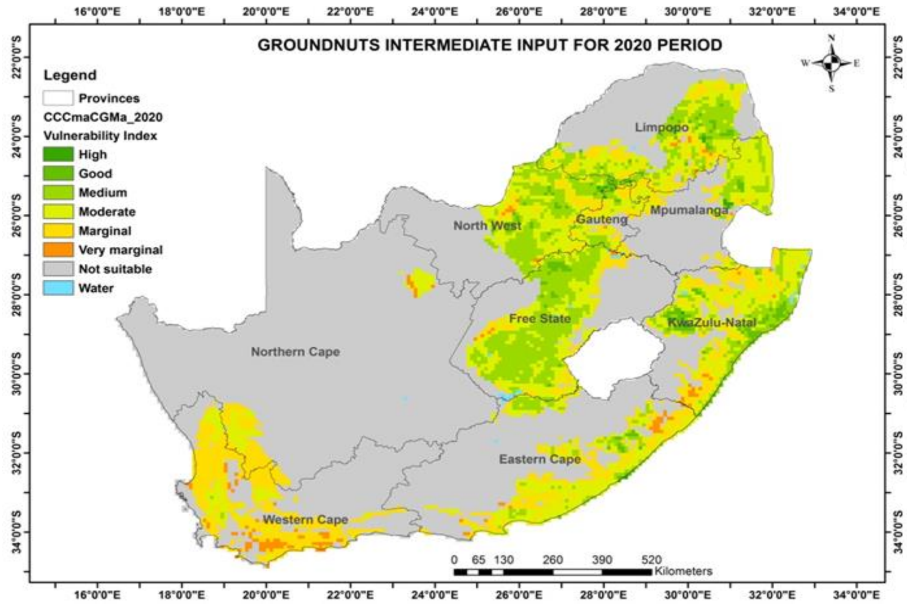
GROUNDNUTS INTERMEDIATE INPUT FOR 2020 PERIOD
Legend
Provinces
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Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
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Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
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Kilometers
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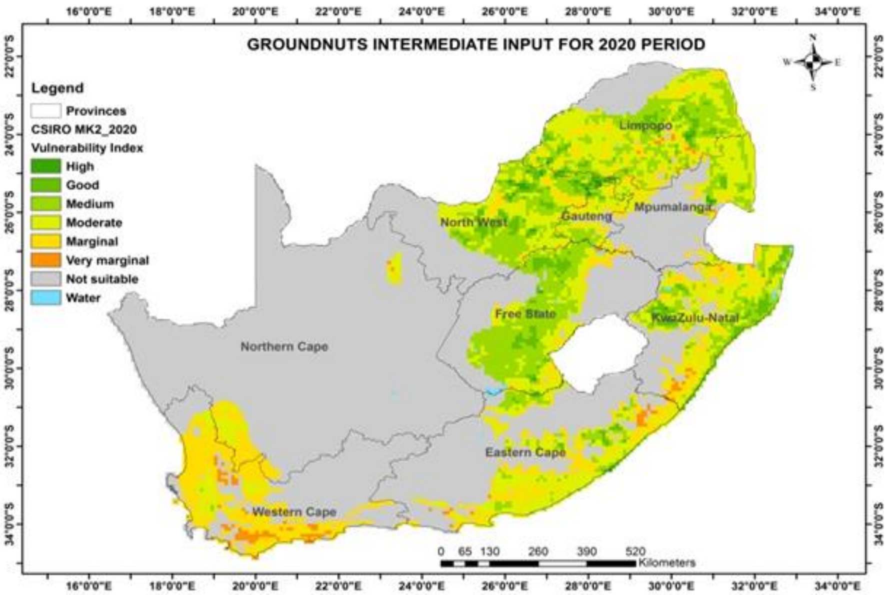
GROUNDNUTS INTERMEDIATE INPUT FOR 2020 PERIOD
Legend
Provinces
CSIRO MK2_2020
Vulnerability Index
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Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
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Western Cape
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Kilometers
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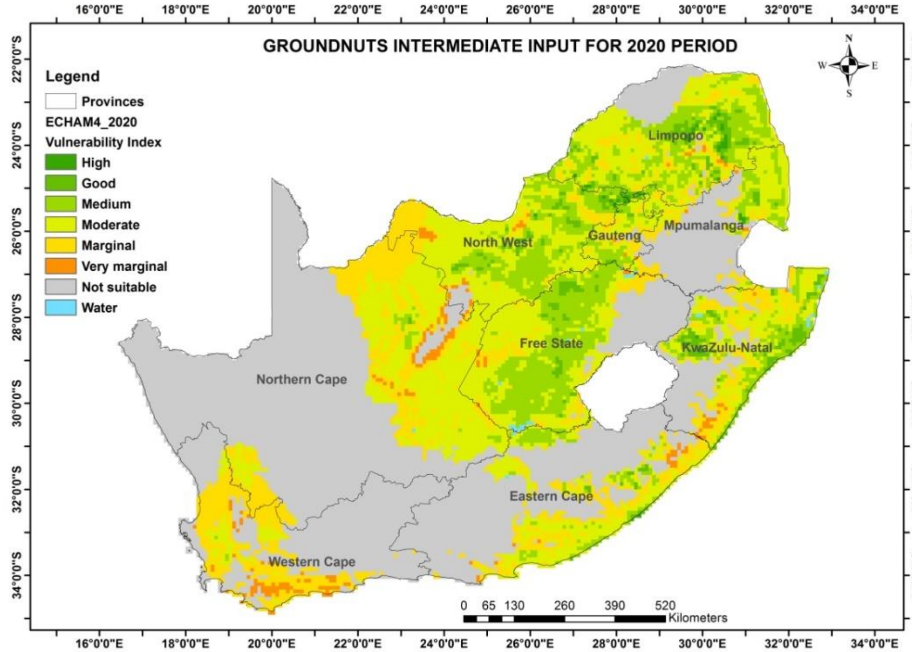
GROUNDNUTS INTERMEDIATE INPUT FOR 2020 PERIOD
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Provinces
ECHAM4_2020
Vulnerability Index
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Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520
Kilometers
16°0'0"E
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22°0'0"E
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26°0'0"E
28°0'0"E
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34°0'0"E
22°0'0"S
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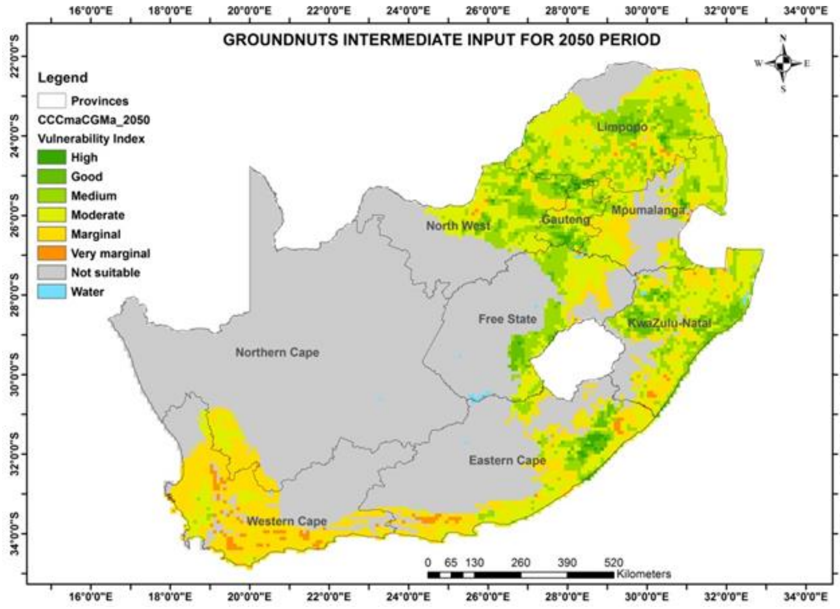
GROUNDNUTS INTERMEDIATE INPUT FOR 2050 PERIOD
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Provinces
CCCmaCGMa_2050
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Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520 Kilometers
16°0'0"E
18°0'0"E
20°0'0"E
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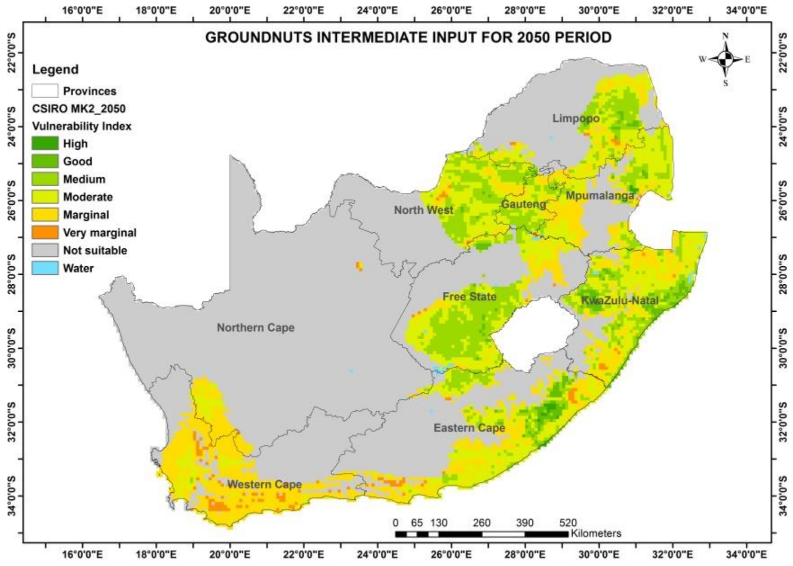
GROUNDNUTS INTERMEDIATE INPUT FOR 2050 PERIOD
Legend
Provinces
CSIRO MK2_2050
Vulnerability Index
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520 Kilometers
16°0'0"E
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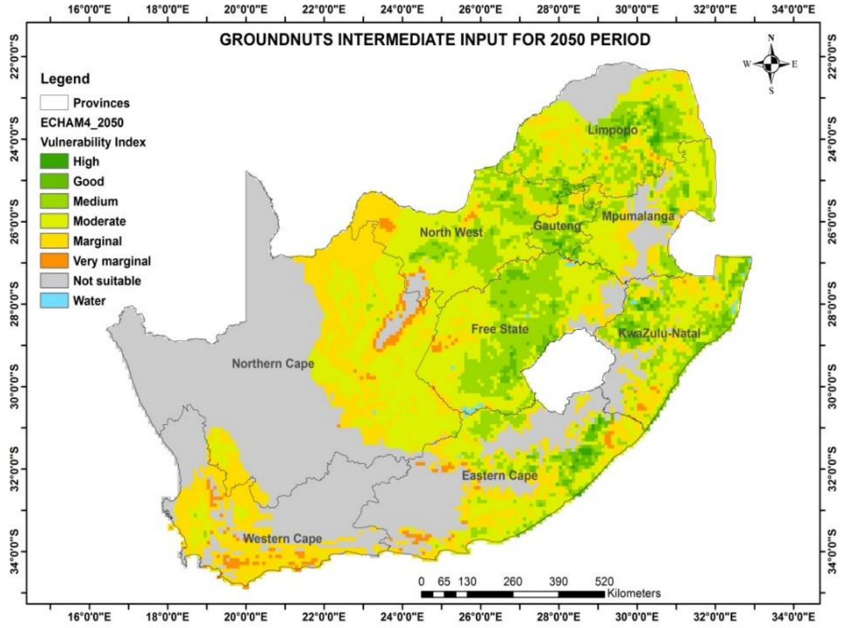
GROUNDNUTS INTERMEDIATE INPUT FOR 2050 PERIOD
Legend
Provinces
ECHAM4_2050
Vulnerability Index
High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
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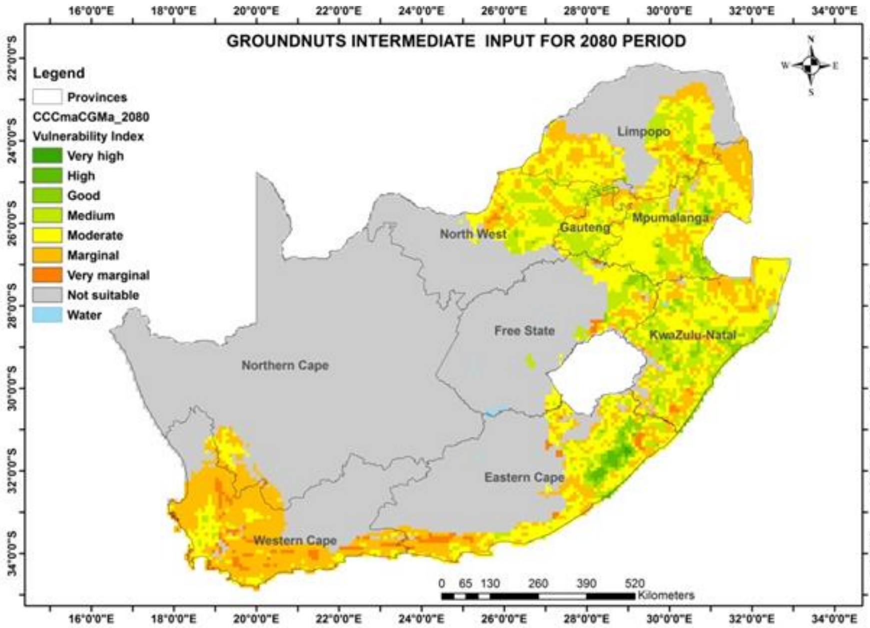
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Provinces
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High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520
Kilometers
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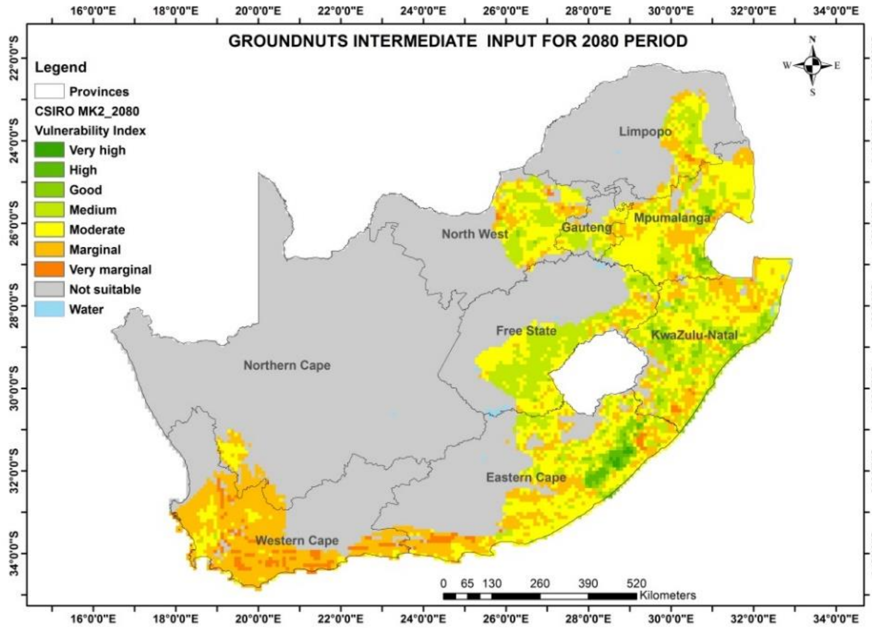
GROUNDNUTS INTERMEDIATE INPUT FOR 2080 PERIOD
Legend
Provinces
CSIRO MK2_2080
Vulnerability Index
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High
Good
Medium
Moderate
Marginal
Very marginal
Not suitable
Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
Northern Cape
Eastern Cape
Western Cape
0 65 130 260 390 520
Kilometers
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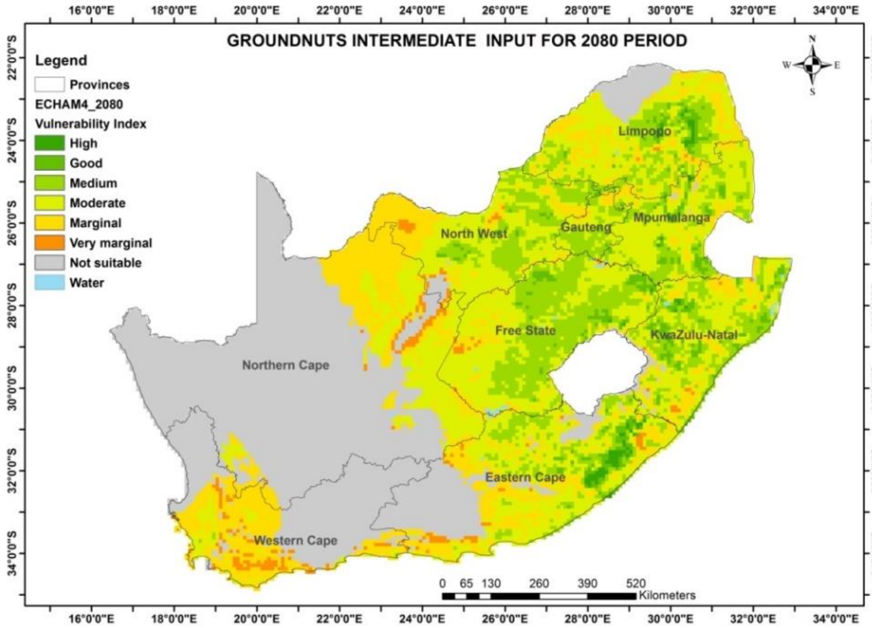
GROUNDNUTS INTERMEDIATE INPUT FOR 2080 PERIOD
Legend
Provinces
ECHAM4_2080
Vulnerability Index
High
Good
Medium
Moderate
Marginal
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Water
Limpopo
North West
Gauteng
Mpumalanga
Free State
KwaZulu-Natal
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Appendix 4.46: Factors influencing yield reduction amongst subsistence and smallholder farmers in Limpopo

Factor pattern after Varimax rotation:		
	D1	D2
Conventional tillage	**0.963**	0.270
does not know crop variety grown	0.091	**0.996**
time of fertilizer application for chemical fertilizer	**0.837**	0.547
chemical fertilizer application	-0.158	**0.987**
rate of chemical application	0.211	**0.977**
time of fertilizer application for other fertilizers	**0.886**	0.463
rate of other fertilizer application	-0.050	**0.999**
Herbicide application	0.678	**0.735**
Herbicide application rate	**0.996**	0.084
pesticides application	**0.956**	-0.292
pesticides application rate	**0.885**	0.466
fungicides application	**0.980**	0.197
fungicides rate	0.651	**-0.759**
weed control	0.483	**0.876**
effectiveness of control	0.589	**0.808**
times of weeding	**0.801**	0.598
methods of weeding	0.378	**0.926**
do not Employ water management techniques	**1.000**	0.001
different varieties	**0.980**	0.197
Late rains	0.292	**0.956**
water logging	0.682	**0.732**
Frost	**0.989**	0.147
Drought	0.292	**0.956**