**University of Cape Town**

# The Impacts of Drought on Wheat Yield and Farmers' Livelihood in the Swartland Region of the Western Cape South Africa

**By**

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# *Plagiarism Declaration*

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I know the meaning of plagiarism and declare that all of the work in the dissertation, save for what is properly acknowledged, is my own.

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# *Abstract*

Drought-induced crop loss has been a major concern among crop farmers in the Western Cape province of South Africa. This is because the frequency and intensity of drought have increased in recent years, which have led to declines in crop yields and have negative implications on the production of non-irrigated crops such as wheat. This study examined the sensitivity of winter wheat to drought during its growing season in the Swartland region, to assess the drought-induced declines in wheat yield. Rainfall, temperature and standardized precipitation evapotranspiration index (SPEI) at 1- to 6-month lags were used to quantitatively assess drought during the period 1994-2018. Using Pearson correlation analysis, a relationship was examined between drought at various timescales and wheat yield for the region for 1994- 2018. Also, semi-structured interviews were conducted with the Swartland wheat farmers to corroborate the findings of this study. The most correlated growth period was the wheat- growing stage (June-August), which shows the period that winter wheat is most sensitive to water deficit. Based on this analysis, the timing and distribution of rainfall during the wheat production season (April to September) was identified as a significant indicator of wheat yield. This revealed that during the reproductive stages, drought may significantly reduce wheat yields.

It was found that the majority of the Swartland wheat farmers have a very good understanding of recent climate variability and change in terms of more variable rainfall intensity, higher temperatures and the increased drought occurrence. As a result, farmers adopted some on- farm coping strategies in form of crop and soil management practices. Therefore there is a need to strengthen farmers' coping capacity for better adaptation and resilience to the impacts of droughts to ensure sustainable wheat production. It is recommended that an early warning system that disseminates agro-meteorological information to farmers in real-time will aid successful farming decisions during these times of climate change. Farmers in Swartland could obtain useful information through this research to help them make more informed decisions.

# *CHAPTER ONE: INTRODUCTION*

## 1.1 Background

Global warming has led to increasing drought globally as the warming has contributed largely to the increasing trend of the areas being affected by drought, leading to about 8% increase in the areas under drought by the first decade of 21st century (Dai, 2012; Li et al., 2020). This can also cause a large-scale reduction in crop yield and even crop failure, exposing the economy to the risk of food insecurity and threatening sustainable agricultural development (Wang et al., 2016; Li et al. 2020). Drought has far-reaching consequences on the economy and the environment, the agricultural sector is extremely responsive to drought and water scarcity (Parsons et al., 2019; Wilhite et al., 2014) as it relies on precipitation and evapotranspiration.

Agriculture in South Africa is assumed to be an advanced and successful sector that is dominated by commercial farms which are capital intensive and produce surpluses, accounting for 90% of value-added products and 86% agricultural land cover. Also, the small-scale farms worked by the larger percentage of the farming population (86%) are subsistence and rely heavily on the traditional (non-mechanized) farming method (Benhin, 2006). South African agricultural production is hindered by water shortages. Rainfall is unevenly distributed throughout the country and the annual average rainfall is approximately 450mm, which is lower than the world's annual average of 860mm, and evaporation is also relatively high (DWAF, 2004; Benhin, 2006). Increasing temperature is also a major factor affecting crop production as statistical evidence showed that temperature has been rising since the past 50 years in South Africa (Kruger and Shongwe, 2004; Benhin, 2006). A time series of temperature trends in South Africa revealed that the yearly average temperatures have been increasing since 1970 as shown in figure 1.1. These increases in temperature coupled with reduced rainfall are expected to negatively affect not only the agricultural sector but all sectors of the economy.

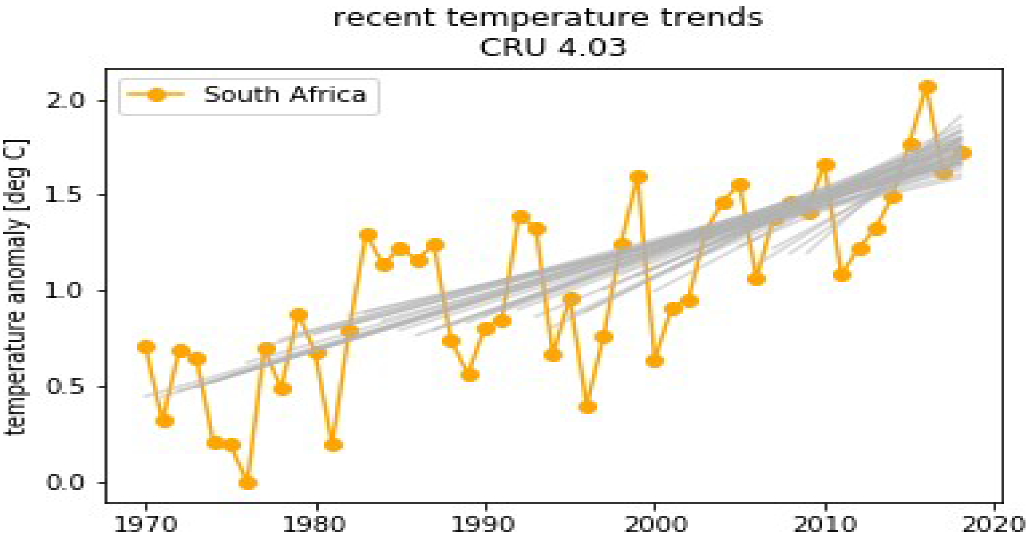


***Figure 1.1:*** *Yearly average temperature trend over South Africa (1970–2018).Source: (CSAG), UCT.*

Wheat is a major cereal worldwide supplying about 85% of the calories and about 82% of the protein to the global community (Hasanuzzaman et al., 2019; Chaves et al., 2013). It is the principal crop used in making staple products such as bread, cereal, pasta, biscuits and rusks in over 40 countries and it is grown across many regions of the world because of its vast adaptability (Chaves et al., 2013; Hasanuzzaman et al., 2019). The wheat crop is South Africa's second most important staple crop after maize (Kloppers, 2014; Meyer and Kirsten, 2005), and it contributed about 3% to the total agricultural production value in 2004/2005 (DAFF, 2006; Kloppers, 2014). Annual wheat production in South Africa ranges from 1.3 to 2 million t/ha at the rate of 2 to 2.5 t/ha under dryland and about 5 t/ha under irrigation (DAFF, 2016). Wheat is planted in the winter rainfall region between mid-April and mid-June (rainy season) and from mid-May to the end of July (dryseason) in the summer rainfall region, where it is irrigated (DAFF 2006; Kloppers, 2014). The 2015-2016 drought hit the Western Cape the most, being the largest wheat producing province which accounted for about 90% dryland production. Free State which is the second largest producer uses a mixture of dryland and irrigated production methods, where dryland production was predominant but now, irrigated wheat accounts for more than 50% of the total yield (Shew et al., 2020). The climate risks associated with wheat production include variability in rainfall, delay or insufficient rainfall during rainfall season in April to June, droughts, above average rainfall during harvest, strong winds, localized flooding and heat waves (Theron et al., 2021; Midgley et al., 2016).The Western Cape experienced below-average normal rainfall between 2015 and 2017 which led to a severe and lengthened drought and unusual water shortages (Otto et al., 2018; Wolski, 2018; Botai et al., 2017)and this caused a significant decrease in wheat yield in 2017/2018 (Archeret al., 2019). Considering the importance of wheat in the economy through job creation, food security and the interconnection with other industries which use wheat as a raw material in producing their staple products, it is appropriate to find measures to help farmers' adaptation and resilience to the adverse effect of drought on their productivity and livelihoods.

The three consecutive years' drought led to a loss of R5.9billion of Gross Value Added (GVA) in agricultural production and over 30,000 jobs were lost (Riedo, 2019; Pienaar and Bonzaaier, 2018). The agricultural sector plays a significant role in the Western Cape's economy, as it is the major employer of labour in the province and also helps the country to keep its food security repute (Botai et al., 2017). Therefore, the economy will be severe affected by regular drought conditions,causing job losses, rises in food prices and other socio-economic consequences (Botaiet al., 2017). Perennial crops such as berries, apples, oranges, banana, and avocados are expected to be negatively impacted by the medium to long-term effect of the drought, exposing the agricultural business to the risk of bankruptcy even when the drought is over (Pienaar and Bonzaaier, 2018). A survey conducted in 2017 showed that 6% of all farmers planned to discontinue farming if water allocation to agriculture remained cut by 60%. Indeed, farmers are trying to mitigate the impacts of water shortages by prioritising water allocation to only the crops that give the best production margin and abandoning some equally important farm produce such as vegetables (Pienaar and Bonzaaier, 2018). There is projection that South African winter region may experience drier conditions in the future due to frontal rain bands shift to the south (Engelbrecht et al., 2009). Consequently, there is increasing pressure on the agricultural sector to find measures to mitigate the impacts of the expected drier conditions on agricultural productivity.

This study focuses on investigating the impacts of drought on wheat yield in the Swartland region, located at the western edge of the Western Cape Province in South Africa (area shade in yellow in figure 1.1). The Swartland climate is being influenced by the cold Benguela upwelling system (Kloppers, 2014), which causes reduction in the sea-surface temperatures (SSTs) through the coast (Tyson and Preston-Whyte, 2000).

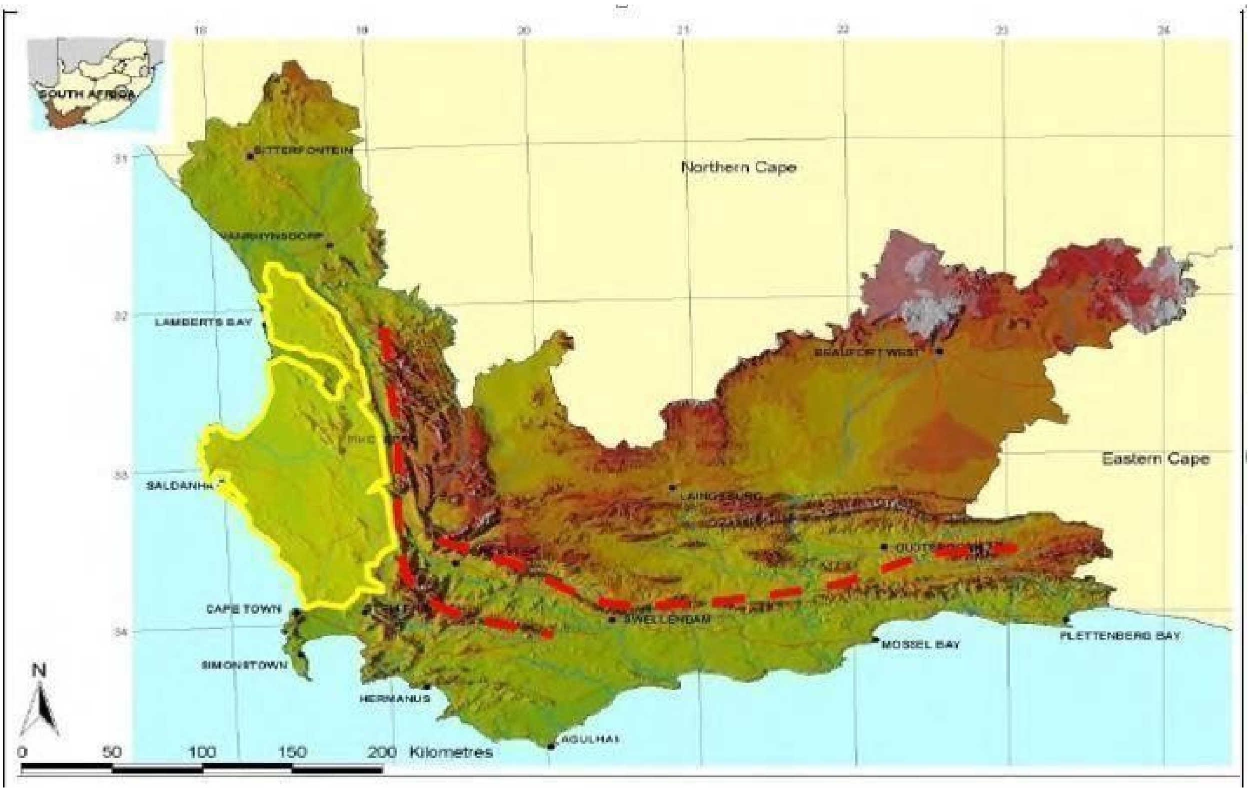


***Figure 1.2:*** *The Western Cape Province Map. The yellow shaded region represents the Swartland region, and the dashed red line signifies Cape Fold Mountain. Source: Department of Environmental Affairs and Tourism (DEAT) 2001.*

The Western Cape region where the Swartland is located has a Mediterranean climate, with warm dry summer and cool moist winter. The average annual rainfall (n = 68 years) is 398.2mm, with 80% of it falling between April and September (Crookes et al., 2017). Wheat cultivation is suitable for the Swartland due to the region's low humidity, mild temperature, and winter rainfall. Wheat sowing starts from April to early June and harvested from October to early December. Winter rainfall is crucial to wheat production in the region as wheat is cultivated on dryland, which makes it highly vulnerable to irregular variation in the winter rainfall (Kloppers, 2014).

Though there is literature on farm-level adaptation measures and the factors determining them globally (Piya et al., 2013), it is crucial to study country- and region-specific strategies for agriculture adaptation (Sarker et al., 2013). The reason is that farmers tend to use adaptation measures that are localized and region-specific, which differs owning to different environmental conditions and economic, political, and institutional influence(Brondizio and Moran, 2008; Hisali et al., 2011; Nguyen et al., 2016). Therefore, research that investigates the impacts of rainfall deficit and temperature increase on wheat yields in a region-specific will add to the literature on the impacts of drought on agricultural productivity and further provides insight into the factors affecting production of wheat in the Western Cape climate context.

Whilst the negative effects of drought on crop production have been well documented, its effects on wheat production in the Swartland region has not been well explored. The study aims to report the effects of drought on wheat yield and farmers' livelihoods in the Swartland region, access the coping strategies employed by farmers and suggest the adaptation measures that may be most effective in coping with the impacts of drought. The scope of this study will be limited to recruiting 10 highly experienced wheat farmers who will be engaged in a group discussion and a questionnaire will be sent to other 15 farmers in order to know their experiences on drought and their coping strategies. Also, wheat yield data from two districts (Malmesbury and Piketberg) between 1994 and 2018 will be correlated with rainfall and temperature data to establish the statistical relationship between them.

The findings of this study will benefit the South African economy, considering the vital contribution of agriculture to the economy. It will not only benefit the wheat farmers by employing the suggested the adaptation measures to cope with drought impacts, but crop production and agriculture at large. Thus, farmers that employ the recommended approaches derived from the result of this study may be able to adapt better to the impacts of drought. This could potentially provide useful insight into policy planning towards effective adaptation measures as policy makers will be guided on the right decisions towards measures that help farmers' adaptation and resilience towards improving agricultural productivity. The study will help the researcher uncover critical areas in the adaptation process which other researchers have not been able to explore.

## 1.2 Research Question, Aim and Objective

### 1.2.1 Research Question

What are the impacts of drought on wheat production and farmers' livelihoods in the Swartland region of the Western Cape?

### 1.2.2 Aim and Objectives

This study aims to examine what the impacts of drought on wheat yield have been in the past and how it has affected farmers' livelihoods in the Swartland region. Drought is not necessarily a shortage of rainfall over the whole season but could be rainfall at the wrong time. Delayed or insufficient rainfall prior to planting months could also constitute a drought because in the Western Cape, wheat farmers expect rainfall from April so that they can plant in May.

The specific objectives are to:

1. To investigate the impacts of drought on wheat yields through an analysis of the data. This will establish the relationship between rainfall, temperature and wheat yields in the Swartland region.

2. To identify the coping strategies adopted by farmers to cope with the impact of changing climate.
3. To suggest adaptation options that hold the potential of improving farmers' resilience to the impacts of drought.

### 1.3 Thesis Outline

This thesis has 5 chapters. Chapter 1 introduces the overall research and outlines the research aim and objectives and chapter 2 reviews the relevant literature. Chapter 3 explains the method and the data used in the study, chapter 4 presents and illustrates the result of the study. Chapter 5 discusses the results; the conclusions and the recommendations for further research.

# *CHAPTER TWO: LITERATURE REVIEW*

## 2.1 Impacts of Climate Change Induced Droughts on the South African Agriculture

Studies have shown that the climate change would negatively impact agriculture, which threatens world food security. The IPCC (2007) indicated that Southern Africa would be highly at risk of climate change which would have a critical consequence on a lot of people's livelihoods. The report also pointed out that climate change will lead to increased severity and frequency of droughts, which would lead to a decline in agricultural productivity of about 21% to 9% by 2080 in Sub-Saharan Africa and there are indications of a future reduction in the production of staple foods by up to 50% due to increasing temperature in precipitation (IPCC, 2007; Masipa, 2017). Climate change may adversely affect wheat production which accounts for 21% of food and 200 million hectares of farmland globally. Although future climate scenarios suggest that global warming may have positive effects on wheat productivity in some regions but could cause a reduction in yields in the zones that are already experiencing high temperature (Ortiz et al., 2008).

The South Africa agricultural sector has experienced recurrent droughts (Mare et al., 2018). Regular and recurrent prolonged droughts are features affecting farmers in the Southern part of Africa which includes South Africa (Mare et al., 2018; Rouault and Richard, 2005). Davis-Reddy and Vincent (2017) argued that climate change-induced droughts could lead to serious reductions of up to 50% in South African agricultural productivity. South Africa as a semi-arid and water-scarce country is vulnerable to the negative impacts of climate change (Botai et al., 2018; Talanow et al., 2021) and it is projected that increasing temperature trend would continue along with increased rainfall variability, reduces rainfall, drier winter, extreme weather events and severe droughts in Southwestern part of Africa (Niang et al., 2014; Talanow et al., 2021; Davis-Reddy and Vincent, 2017). These projected changes in weather events are expected to negatively impact South African agriculture, ecosystem, food security, water and the economy at large (Hannah et al., 2013; Ziervogel et al., 2014; Archer et al., 2019; Talanow et al., 2021). Benhin (2006, 2008) studied the impacts of climate change on South African agriculture using the Ricardian modelling method. His assessment on three climate scenarios shows that there may be an increase in temperature by between 2.3$^{o}$C and 6$^{o}$C by 2100 while there may be a decrease in precipitation by between 2 and 8%. An estimation based on this study predicts that crop net revenue may fall by 90% by 2100 if adequate measures are not implemented to reduce climate change impacts. The 2015 drought led to 8.4% decline in agricultural production and estimated 15% reduction in South African livestock herd (Agri SA, 2016; Mare et al., 2018), this led to increase in depression among agricultural producers as many of them were admitted to psychiatric hospital during the drought

(Mare et al., 2018). Tyson and Preston-Whyte (2000) pointed out that droughts are caused in South Africa by high temperature and rainfall variability. Therefore, drought occurs when there is high temperature with an associated low rainfall and the drought's severity depends on the magnitude of anomalous changes in either variable (Araujo et al., 2016). Some of the rainfall variability in South Africa can be linked to the El Niño Southern Oscillation (ENSO) (Meque and Abiodun, 2014). ENSO is the interconnectivity between the global atmosphere and the Pacific Ocean, which lead to variability in various climate and ocean patterns (Holloway et al., 2012). The events in the South Pacific Ocean affect the rainfall temperature and wind pressure over South Africa and El Niño events account for up to 30 % of rainfall variability (Tyson and Preston-Whyte, 2000; Araujo et al., 2016). Two phases that are connected with ENSO are the cold (La Niña) and warm (El Niño) phases and these ENSO eventssignificantly influence the winter rainfall over the western South Africa, as they influence the decrease or increase in rainfall (Philippon et al., 2011; Araujo et al., 2016). Therefore, ENSO- influenced drought may have negative impacts on the Western Cape agriculture, as drought couldlead to insufficient soil water for crop growth and development. This implies that drought may negatively impact wheat production in the Western Cape.

Studies have suggested that variation in the western Mediterranean region's temperature and precipitation will increase drought events' severity and duration in decades ahead (Peña-Gallardo et al., 2019; Spinoni et al., 2018; Vicente-Serrano et al. 2014; Forzieri et al., 2016; Dai, 2011; Giorgi and Lionello, 2008) and this may have negative implications on crop production. South Africa is the second biggest wheat producer in Africa with 1.9MT average annual wheat production, on an average of 524,000ha during 2010-2014 (Tadesse et al., 2019). Despite being the second highest wheat producer, the country has been unable to meet the local demand for wheat which makes the country a net importer of wheat. The Southwestern Cape (Swartland and Rûens) remains the highest wheat producer in South Africa producing over 50% of the country's total on dryland farming during winter rainfall season. Meanwhile, the Western Cape is vulnerable to droughts as projected by scientists that the region may experience drier conditions and moderate to strong warming over the next century (Pienaar and Boonzaaier, 2018) Thus, knowing the impacts of drought on wheat production in a regional context is very important for a region- specific adaptation and that is why this study will look to examine the impacts of drought on the Swartland wheat production and suggest the options that help the farmers' resilience to the impacts of drought.

## 2.2 Climate Projection and the Western Cape Wheat Production

There have been projections that adverse climatic events such as prolonged dry spells and rainfall irregularity could reduce wheat productivity in the Western Cape. For instance, a segment in South Africa's Second National Communication under the United Nations Framework Convention on Climate Change (UNFCCC) on the Western Cape winter wheat production states that there could be a reduction between 5 and 70% in wheat yield by the mid-21st century based on climate projections and the expected impacts on each sector of the economy (DEA, 2011; Wallace, 2013). The underlying uncertainties of climate predictions are not broadly considered, and this has caused a general belief that there will be a future reduction in the Western Cape dryland wheat production as the climate changes in the future (DEA, 2011; Wallace, 2013).

In the Mediterranean climate, wheat production has been revealed to be seriously influenced by rainfall and the quantity of soil moisture before and throughout the wheat growing period (Schillinger et al., 2008; Basso et al., 2012; Kloppers, 2014). In the Swartland region of the Western Cape, which has a Mediterranean climate, wheat production is carried out under dryland conditions. Consequently, any irregularity in winter rainfall always have a significant effect on crop yield and quantity produced, making the crop vulnerable to unusually drier years (Basso et al., 2012; Kloppers, 2014; López-Bellido et al.,1996). For example, the country recorded a huge decline in wheat yield from 1.1 million tons in 2016/2017 to 586,000 tons in the 2017/2018 season as reported by the Western Cape Department of Agriculture (Pienaar and Bonzaaier, 2018; Archer et al., 2019). The wheat yield decrease of 2017/2018 can be linked to rainfall deficit and lack of sufficient soil moisture in the Western Cape region (Archer et al., 2019). Thus, there is a general concern among the dryland wheat farmers about what the expected yield stresses could be, due to the changes in climate (Wallace, 2013). The Swartland region in the Western Cape is a major wheat-producing region that is affected by drought events. Therefore, a study that examines the detail sand intricacies of the relationship between drought and wheat production in the Swartland region is necessary towards suggesting adaptation options that help farmers' resilience to the impacts of drought based on the existing measures employed by farmers and what the scientists are suggesting.

## 2.3 Wheat Production and Management in the Swartland Region

The Swartland is one of the regions in the Western Cape, located 50 kilometers north of Cape Town. It is bordered in the south by Malmesbury, in the west by Darling, in the north by Piketberg and in the east by Riebeek Kasteel, Riebeek West and up to Elandsberg mountains (Voëlvlei Dam).

The South African government policy in 1930 announced the Wheat Importation Restriction Act, which effectively blocked wheat importation which accounted for 30% of the country's demand at that time (Meadows, 2003; Kloppers, 2014). This gave rise to an instantaneous increase in wheat production to meet the country's demand. The Swartland region for instance had an increase of 40% in the total area cultivated between 1930 and 1934 (Kloppers, 2014; Talbot, 1947). All the cropland in the Swartland region is covered by about 60% of grain production (Western Cape Agristats Dataset, 2018; Talanow et al., 2020). Wheat is the main crop cultivated in the Swartland and the larger percentage of the wheat production is rain-fed relying on winter rainfall, therefore, in the Swartland, wheat and grain production are generally sensitive to climate events such as higher temperature, reduced rainfall, heat waves, extended dry spell and persistent intense rainfall events(Talanow et al., 2020).

Since wheat farming is done under dryland (rain-fed) condition in the Swartland region; the winter rainfall anomalies have huge effects on the quality and quantity of yields and the crop produced (López-Bellido et al., 1996; Basso et al., 2012; Kloppers, 2014), exposing the wheat crop to unusual drier years. Most of the Swartland region has adequate resource potential for wheat cultivation (Kloppers, 2014; Hardy, 1998). This potential combined with government support in form of drought relief, price-fixing and subsidies led to decades of mono-cropping wheat production and spread out into marginal regions in the Swartland (Kloppers, 2014; Hardy, 1998). The South African wheat market was deregulated on the 1st of November 1997 under the African National Congress (ANC). This threw out the Reconstruction and Development Plan (RDP), which was based on the basis of redistribution first and then growth and encouraged macroeconomic plan of free market (Liebenberg and De Wet, 2018). The Marketing Act 59 of 1968 was replaced by the Marketing of Agricultural Products Bill of 1996 and wheat became freely traded in South Africa since 1997(Liebenberg and De Wet, 2018). The wheat market deregulation led to the decline in the profit of wheat from 30.4% to 13.3% in the Swartland despitethe increase in the average yield per hectare from 1.1 per hectare to 2.5 per hectare (Liebenberg and De Wet, 2018). The adjustment made farmers change their farming practices resulting in farmers embracing alternative crops and cropping systems. Alternative cropping systems such as crop rotation is broadly used over the Swartland region and it has led to a significant reduction in input costs, increased soil fertility and natural control of pests, weeds, and diseases (Kloppers, 2014). Some of the crops that have been proven to be good crop rotation with wheat include nitrogen fixing legumes like medics, clover, lupines, and oilseed crops like canola (Kloppers, 2014;Hardy, 1998). Canola has commercial value, steady yield potential and a good break-crop in wheat farming systems because it reduces weeds, pests, and diseases in the next wheat production. It also improves soil structure with its deep root system (Kloppers, 2014; Hardy, 1998; Hardy et al., 2011). Legumes are ideal for the Swartland's

Mediterranean climate, they improve the soil mineral nitrogen as they are nitrogen-fixing plants. The root structures also boosts soil stability and lowersoil density thereby boosting the next wheat crops yield (Kloppers, 2014; Hardy, 1998).

Crop rotation on its own is considered a highly risky farming practice in the drier northern part of the Swartland. Therefore, many wheat farmers use the mixed farming system to mitigate crop farming risk and provides alternative income source (Kloppers, 2014). Sheep are the commonly used livestock by the Swartland farmers as they can cope well under drier climate. For the livestock sustenance, the crop-pasture rotation farming method is generally carried out with hard-seeded, self-renewal annual pastures (medics and clovers) (Kloppers, 2014; Hardy, 1998). The legume pastures give sheep good quality fodder in the winter and if properly managed, the residue allows grazing in summer also.

The availability of several wheat cultivars has added to the complexity of decision making with each cultivar having its benefit and cost. Sixty-five different dryland cultivars were available in the country in 2010 and 12 of these were specifically developed to be suitable for the Western Cape Mediterranean climate (Smit et al., 2010; Kloppers, 2014). Risk is well managed and optimal grain yield is achieved when farmers make the right choice of cultivars in a particular situation (Kloppers, 2014; ARC-SGI 2013; DAFF 2010).

### 2.4 Importance of Wheat Production in South Africa

Baiyegunhi and Sikhosana (2012) and Kloppers (2014) maintained that South Africa like many developing countries has undergone a speedy urbanization rate in the past decades and this has caused changes in consumer behaviour to shift in diets. This has seen foods like bread being preferred over maize meal as a staple food in many households in South Africa. The larger percentage of the South African-produced wheat is bread wheat, with a small amount of durum wheat used for pasta production being planted in a certain region (DAFF, 2006; Kloppers, 2014). Wheat importance in the country is reflected in the national Coat of Arms with the insertion of two ears of wheat. This is a sign of fertility which symbolizes the conceptualisation of germination, growth and development of potential, the world’s agricultural aspects, and the nourishment of the people (Department of Government Communication and Information System (GCIS), 2005; Kloppers, 2014). However, wheat production has been on the decline in South Africa in recent years in contrast wheat consumption which is on the increase as shown in figure 2.1.

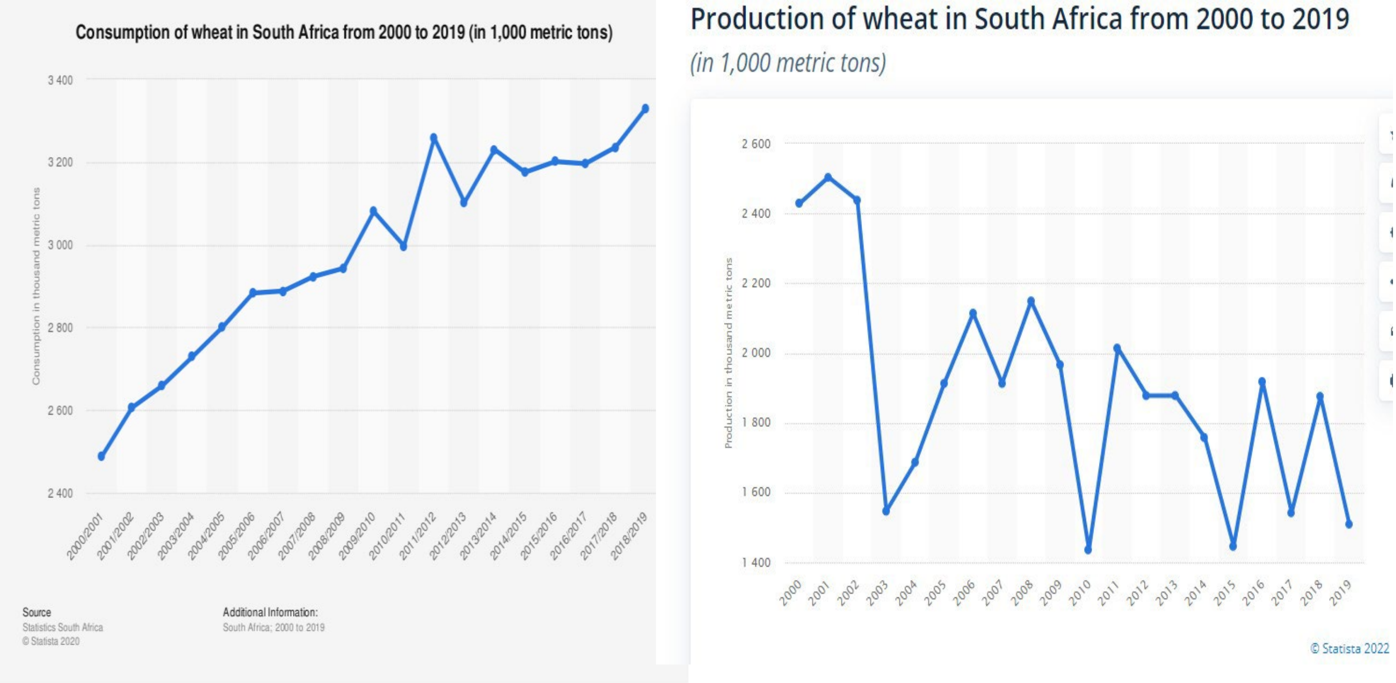


***Figure 2.1:*** *South African wheat consumption and production trend from 2000 and 2019. Source: (Statista, 2022).*

### 2.4.1 Importance of Wheat Production in the Western Cape

The Western Cape farmers produced about 55% of total South African wheat production between 1986 and 1996. The importance of the wheat sector in the region is highlighted in its contribution to field crop and land use (Mahlanza et al., 2003). Wheat production plays a key role in some parts of the province as it has relatively large multiplier effect on the economy of the Western Cape in term of income and output (Mahlanza et al., 2003). "The multiplier effect are the additional sales, value added, income, and jobs that stem from the direct effects" (Nadreau and Fortenberry, 2016). Wheat production expansion also leads to increased employment especially for grain processing activities (Vink et al., 1998; Mahlanza et al., 2003). For example, the wheat sector employed 26% of the 150,000 farmworkers in the province during 2000 (Mahlanza et al., 2003).

## 2.5 Impacts of Droughts on Wheat Production

Drought manifests through four main stages. Firstly, a meteorological drought occurs when there is below average precipitation for a long time, usually 1-3 months. When drought conditions linger and lead to insufficient soil and subsoil moisture to support crop growth, then its agricultural drought (Botai et al., 2017). Hydrological drought occurs when the persistent drought conditions lead to reduced water level in streams, groundwater and reservoirs (Wilhite, 2016; Botai et al., 2017; Tallaksen and Van Lanen, 2004). Lastly, the socio-economic drought occurs when drought conditions lead to water supply shortfall and human activities are being hindered (Botai et al., 2017). The drought impacts on wheat production are documented in the literature.

For instance, Farooq et al (2014) pointed out that “Drought is a major environmental stress threatening wheat productivity worldwide”. Though wheat growth performance is negatively impacted at all stages during drought, it is most pronounced during the stages of flowering and grain-filling, which causes significant yield losses and the extent of the yield loss is determined by the duration and severity of drought stress (Farooq et al., 2014). Ray et al. (2018) examined the impacts of the 2011 to 2013 drought period in Texas USA on four major crops. The result found that the winter wheat yield declined in 2011 and 2014 as a result of the severe drought. They concluded that drought could cause a decline in crop yields and planting area due to water deficit and low soil moisture level during the growing season.

Similarly, Giunta et al. (1993) carried out a field investigation in a Mediterranean climate to examine the impact of drought on wheat yield under different moisture levels. The result shows that wheat yields were significantly reduced due to drought stress on dryland farming compared to irrigation-controlled farming that shows an insignificant decrease. Trnka et al. (2014) also investigated a range of adverse weather events which might have significant impacts on wheat yields in Europe by analyzing how frequently some extreme weather events occur. The result showed that adverse weather conditions such as drought and extreme temperatures might increase significantly in 2060 in the main wheat-producing areas in Europe and may likely result in persistent crop failure over Europe. Drought can harm plants during their life cycle, high temperatures cause heat damage which negatively affects wheat during growth stages and pre-harvest sprouting which has negative impacts on wheat quality (Smit et al., 2010; Kloppers, 2014).

Southern Africa’s relatively low wheat production is primarily due to both abiotic (drought and heat) and biotic factors which are on the increase both in frequency and intensity due to climate change (Tadesse et al., 2019; Shew et al., 2020). Previous studies argued that the projected dry conditions in South Africa may lead to an annual reduction in wheat yields between 1.8% and 4.3% (Asseng et al., 2015; Cullis et al., 2015; Shew et al., 2020). Shew et al. (2020) analyzed the impact of temperature increase (heat) on 71 wheat cultivars in 17 locations across South Africa and found that extreme heat leads to reduction in wheat yields.

The negative impacts of drought on wheat yield globally are documented in the literature and some studies have modelled the impact of future changes in climate on wheat production but no specific study has investigated the impact of drought on the production of wheat in the Swartland region. Thus this study will fill that gap by investigating the impacts of drought on wheat yield in the Swartland and suggests the most effective adaptation options.

### 2.5.1 Rainfall and Wheat Production and the Link to Drought

Past studies have stressed the significance of seasonal variability of rainfall in influencing crop growth (Feng et al., 2018; Meinke and Stone, 2005). Cornish (1950) indicated that rainfall is more useful to high wheat yield production during the winter months than any other periods of the year in Australia. Precisely, winter rainfall remains an important factor for wheat growth in the dryland environment of the NSW wheat belt (Feng et al., 2018).

In the research carried out by Basso et al. (2012) to understand how fallow (pre-planting) and seasonal rainfall influence the spatial and temporal wheat yield variability in the Mediterranean climate, it was found that pre-planting rainfall is a key factor that affects the spatial and temporal wheat yield variability and concluded that the spatiotemporal variability of wheat yield is being influenced by the variability of soil contents and rainfall distribution. These show that the lack of adequate rainfall distribution and soil moisture due to drought have negative impacts on dryland wheat production. This finding is corroborated by other studies such as Boyer (1982) and Unger et al. (2006) who also believe that rainfall and the quantity of soil moisture before and throughout the growing period could greatly affect wheat production in a Mediterranean climate. Since Mediterranean conditions exhibit a high rainfall variability pattern, the quantity of soil, and farming methods can be as vital as the rainfall during the wheat growing season, for ensuring a reasonable quantity of yield (Basso et al., 2012; Sadras, 2002; Angus et al., 1980).

Sufficient rainfall before planting ensures the needed moisture for seed sprouting and provides an adequate water supply for post-germination growth. Insufficient amount of rainfall and soil moisture during planting reduce or halt the germination process leading to reduced germination percentage and consequently reduced planting density (Passioura, 2006; Basso et al., 2012). Summer rainfall also adds to the water stored in the soil that is useful for water absorption of wheat over the growing season (Feng et al., 2018; Angus et al., 1980). Therefore, some amount of rainfall in late summer (February) and in early autumn (March) add to the stored soil water and give the required moisture for sowing, which starts from April.

In wheat farming, what constitutes drought is not only seasonal rainfall deficit but could also be seasonal rainfall distribution. At every stage of wheat production, there is a minimum rainfall requirement to maintain the needed moisture for wheat growth and development. An uneven rainfall distribution that constrains the specific growth stage by too little moisture during the growing season leads to a decline in yield.

### 2.5.2 Temperature and Wheat Production

While wheat cultivars vary in their tolerance to extreme temperature, it is generally considered that wheat enjoys an optimal temperature range of 17-23°C throughout the growing season (Paldi et al., 1996; Porter and Gawith, 1999; Pomeroy and Fowler, 1973; Blum and Sinmena, 1994). Nevertheless, the most significant environmental perturbation in agriculture is the rising global temperature (Akter and Islam, 2017). Global temperature rise may have significant negative effect on agricultural productivity based on the intensity of drought, high temperature, mineral toxin, salinity and waterlogging (Akter and Islam, 2017; Teixeira et al., 2013). The heat stress condition is aggravated when there is a rise in soil temperature due to the increase in air temperature related to reduce soil moisture. Therefore, heat stress has been identified as a threat to global sustainable crop production (Akter and Islam, 2017; Lobell and Gourdji, 2012).

A number of studies have highlighted the negative effects of extreme temperatures (above 30°C) on crop development. Modarresi et al. (2010); Stone (2001); Wahid et al (2007); Ayeneh et al (2002)and Mitra and Bhatia (2008) all indicated that high temperatures have effects on all stages of crop growth, shorten the duration of spike development, hasten floral initiation, causing shorter spike with a reduced number of spikelet and negatively affect pollen development. High temperature is a key factor determining the development and growth of wheat and leads to a loss in yield in many areas globally (Modarresi et al., 2010). The temperature range of 15-18$^0$C is ideal for wheat during the stage of grain filling (Modarresi et al., 2010; Stone, 2001; Wardlaw and Wrigley, 1994) but the high daily temperature of 25-35$^0$C or more is common over several wheat-cultivated regions globally such as the Western Cape (Porch and Jahn, 2001; Modarresi etal., 2010). Heat stress occurs when the daily mean temperature is over 17.5$^0$C during the coolest month in a growing season and more than 50 countries (that import over 20 million tons of wheat yearly) face this same heat stress during the wheat growing season (Reynolds, 2001; Modarresi et al., 2010). This shows that the increasing temperature trend is evident across many regions and this calls for farmers' readiness in adopting strategies to coping with the changing climate.

When wheat is exposed to temperatures higher than optimal at all phases of crop growth, it causes reduced yield and reduction in the quality of grain (Modarresi et al., 2010; Gibson et al., 1998). During post-anthesis phases, heat stress mostly affects the availability of assimilates, the transfer of photosynthates to the grain and also affects starch build-up and synthesis in the growing grain (Modarresi et al., 2010; Gibson and Paulsen, 1999). Post-anthesis heat stress is the main limiting factor of grain yield in winter wheat genotypes in Mediterranean climates (Modarresi et al., 2010). The result of this is a declined grain yield owing to the lower weight of grain (Modarresi et al., 2010; Gibson and Paulsen, 1999). This claim is supported in a study by Akter and Islam (2017) who found in their review that heat stress enhances leaf senescence in wheat, reduces photosynthesis, deactivates photosynthetic enzymes, and generates oxidative harm to the chloroplasts. Also, heat stress cut down the size and number of grain by altering grain setting, assimilates transfer and grain growth rate. Rising temperatures and subsequent climate changes have negative impacts on the development and growth of a plant, causing a disastrous decline in wheat productivity (Akter and Islam, 2017). The suitable climate for winter wheat in the winter rainfall region of South Africa are cool temperatures (5 °C to 25°C) as cool and moist climate are idea for planting wheat, while warm dry season is ideal for harvesting (DAFF, 2016).

The increasing temperature is one of the major stresses facing wheat production in South Africa as temperatures above 30ºC could lead to yield decline (Shew et al., 2020). In the literature, suitable soil moisture is needed to aid sustainable wheat production. Even when there is good rainfall distribution, the increasing temperature has been a major concern to wheat farmers as it affects the soil structure by altering organic materials decomposition rate and the nutrients supply to plant (Davidson and Janssens, 2006). Foley et al. (2011) proposed many management options which include conservation agriculture, cropping efficiencies and embracing yield gap strategies. These could effectively reduce environmental impacts and aid sustainable crop production.

### 2.6 Wheat and Production Reforms in South Africa

In South Africa, wheat is grown in all the nine provinces but the two major contributors (dryland figures) for 2016/2017 and 2017/2018 production seasons are; the Western Cape (1,055,700 tons and 562,800 tons) and Free State (184,000 tons and 74,000 tons) (DAFF, 2018). In the Western Cape Mediterranean climate, dryland spring wheat is usually planted between mid-April and mid-June. In recent decades, the wheat sector in South Africa has undergone major structural reforms (Breitenbach and Fényes, 2000). These reforms include the dissolution of agricultural marketing boards, the elimination of some import and export regulations and the institution of different import duties (World Wildlife Fund [WWF] 2010; Kloppers, 2014). The Agricultural Marketing Act 59 of 1968 was established to control the marketing activities of the South African wheat via the Wheat Board who was the only buyer and seller of wheat crop in the country. The board used the farming cooperatives as agent for acquiring, storing and distributing wheat crop (Smit et al., 2010; Kloppers, 2014). The government set prices of grain, bread and flour-based on the recommendation by the Wheat Board and wheat cultivars for commercial production had to be approved by the Advisory Winter Cereal Grading Committee to ensure equal quality valuation

(Smit et al., 2010; Kloppers, 2014). This changed when the Marketing of Agricultural Products Act 47 of 1996 established the implementation of new regulations guiding the marketing of agricultural products and led to the effective deregulation of wheat marketing from the single marketing channel to a market economy where demand and supply determine prices (Vink et al., 1998; Smit et al., 2010; Kloppers, 2014). However, the transformation has had both positive and negative effects on wheat farmers. The state support removal and the low import tariffs implementation reduces wheat farmers' income as the locally produced wheat could not compete with state-subsidized imported foreign wheat (Vink et al., 1998; (Breitenbach and Fényes, 2000; Kloppers, 2014). This caused farmers to prefer the production of high-value products like deciduous fruits and game, where possible resources and conditions are available, that are considered for international markets over low-valued high-volume products such as wheat that are considered for local markets (Breitenbach and Fényes, 2000; Kloppers, 2014).

Before the effects of the reforms mentioned above, wheat produced in South Africa between 1970 and 1974 averaged 1,656 million tons per annum on 1,969 million hectares of land. Before the wheat market was deregulated, average of 1.4 million hectares of land was used for wheat production. The average size declined to 761,000 hectares after deregulation (Liebenberg and De Wet, 2018). The South African wheat import trend between 1960 and 2020 is shown in figure 2.2.

***Figure 2.2:*** *The South Africa wheat import by year from 1960 to 2020. Source: (United State Department of Agriculture).*

In the 1970s and 1980s, the country's wheat sector produced enough to meet the local demand for wheat. But the increasing demand has outgrown the domestic production of wheat since 1989. This has led to the importation of wheat to augment local production in meeting the country's demand for wheat, and the country has since remained a net wheat importer (Baiyegunhi and

Zikhosana, 2012; Kloppers, 2014).

## 2.7 Conclusion

The literature has shown the importance of the wheat crop to the South African economy as it contributes to food production and job creation. Also, it has been pointed out that drought remains of the major factors affecting the Western Cape wheat production, where over 50% of the total wheat in the country is produced. Studies have projected based on climate models that Mediterranean climate such as the Western Cape which is a winter rainfall region are likely to face higher rainfall variability and reduced rainfall leading to drier conditions in the future (Mahlalela et al., 2019; Tamarin and Kaspi, 2017; Barnes and Polvani, 2013; Chang et al., 2012). Also, there are projections with higher confidence over southern Africa of the expected change in rainfall and expected reduction in soil moisture towards the end of 2100 due to increasing temperature (Engelbrecht and Engelbrecht, 2016; IPCC, 2014; Landman et al., 2018). Based on the IPCC's fifth assessment report, long time climate models' projection suggests that a notable drying trend will persists across the western part of South Africa and could result in 40% reduction in annual rainfall (DEA, 2020). The same IPCC report projected that the Western Cape and some part of Southern Africa may experience mild to moderate drought by 2050 (Gizaw and Gan, 2017). Also, the already measured 1°C average temperature increase in the Western Cape no doubt added to the severe impacts of the drought (DEA, 2020). Figures 2.3 and 2.4 show the increasing trend of mean annual temperature anomaly in South Africa and the decreasing rainfall trend in a station in the Western Cape respectively.

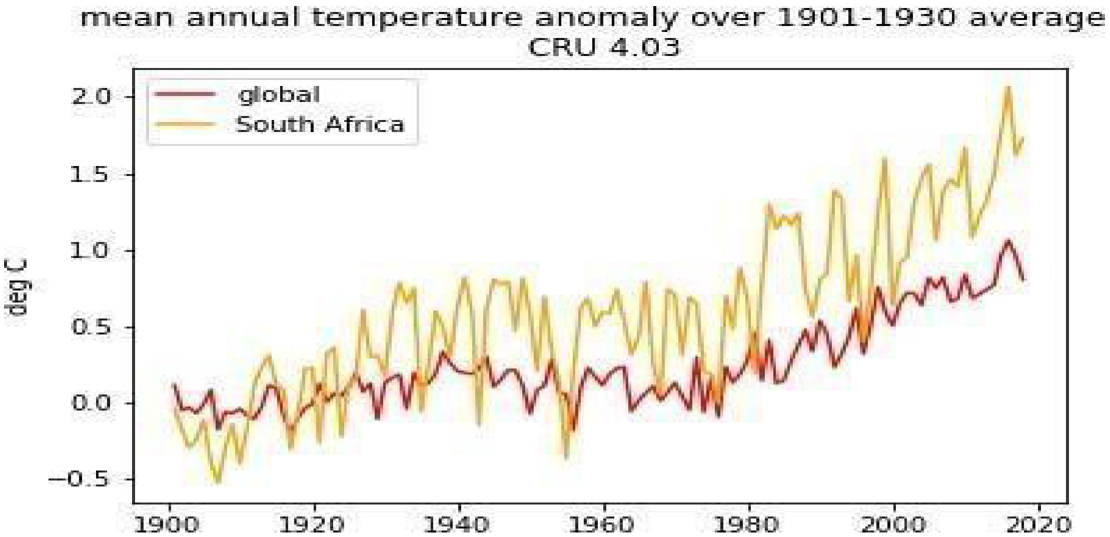


***Figure 2.3:*** *The increasing trend of South African mean annual temperature. Source: (CSAG), UCT.*

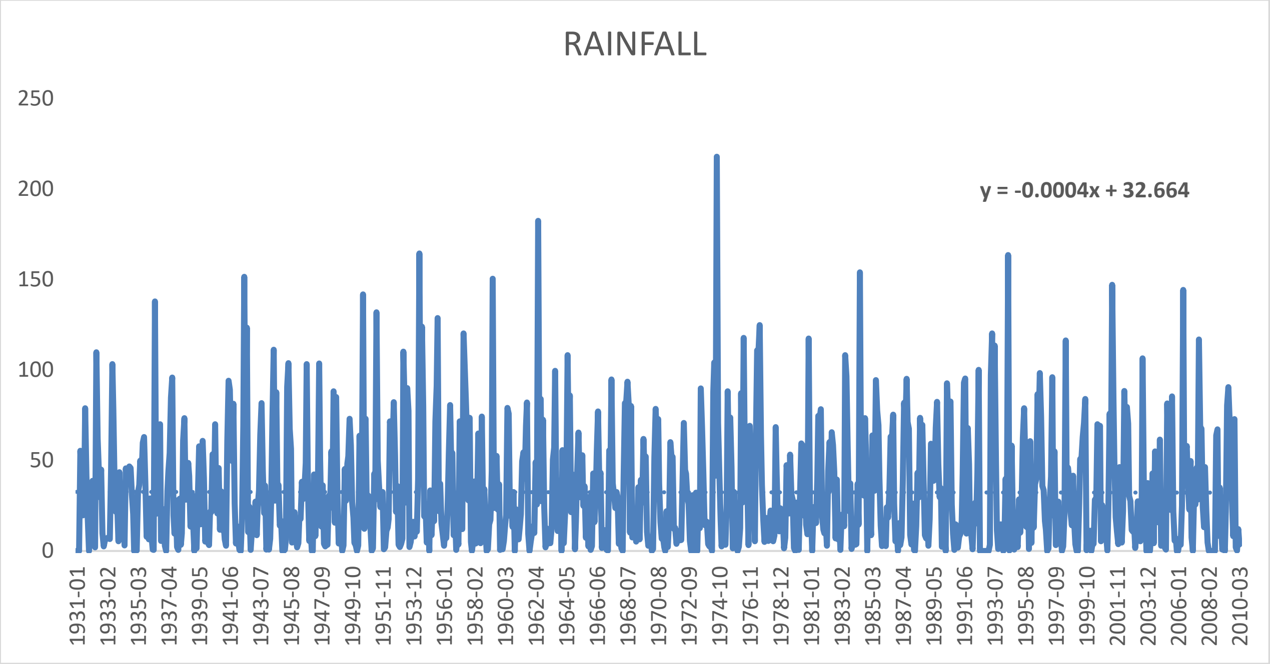


***Figure 2.4:*** *Annual rainfall showing statistically insignificant decreasing trend at Langgewens station in the Swartland region (1931–2010).*

Therefore, there is a need to explore the measures that help farmers cope with the impacts of the changing climate in form of reduced seasonal rainfall and its variability and the rising temperature. This study will establish the relationship between wheat yield, rainfall, and temperature, especially in the context of drought, in the Swartland and also assess the adaptation options that are most effective in drought risk management and improving sustainable wheat production in the Swartland region.

# *CHAPTER THREE: METHODOLOGY*

This chapter describes the methodology and the analytical approaches used to achieve the study's aims and objectives. This research makes use of both quantitative and qualitative approaches. The different datasets used will be explained and the analytical procedures used will be discussed.

## 3.1 Statistical Methods

In this study, the statistical approaches and analysis were achieved using EViews and Excel. EViews is a statistical package mainly used to analyse time-series data while Excel is an analysis tool typically used for data organisation and other statistical analysis.

### 3.1.1 Correlation

Correlation is a statistical method that measures the strength of direct association between two variables (Speed, 2011). Pearson's Correlation coefficient (r) was used to determine the strength of association between the dependent and independent variables in this study. Pearson's correlation coefficient (r) is stated below.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Pearson's correlation coefficient (r) scale ranges between -1 and +1. The positive coefficient signifies a positive linear relationship between two variables whilst the negative coefficient signifies a negative linear relationship. This indicates that as one variable increases (decreases), so does the other, either directly or inversely. A zero or approximately zero, coefficient means thatno direct association exists between the two variables. The "cor" function in "stat" package EViews was used to calculate the Pearson's correlation coefficients in this study. A hypothesis test was used to evaluate the significance of Pearson's correlation coefficients. A null hypothesis ($H_0$) that states that no relationship (zero correlation) between two variables was evaluated againstthe alternative hypothesis ($H_A$) that states that there is a relationship ($H_0$: $\rho=0$; $H_A$: $\rho\neq0$). The significance of correlation coefficients was established by using the critical values obtained from the probability density function to decide if the null hypothesis would either be accepted or rejected ($H_0$: $\rho=0$) and to accept or reject the alternative hypothesis ($H_A$: $\rho\neq0$). Correlation coefficients that shows significance at a 5% ($p<0.05$) level or higher are considered to be statistically significant for this study, but it is important to keep in mind that a significant correlation betweentwo variables does not prove a cause-effect relationship.

### 3.1.2 Linear Detrending

Linear detrending is the process of removing a linear trend from a time-series dataset to minimize spurious relationships in research findings. If two time-series of data are showing a trend, the measure of overall fit would give a misleading significance, if not detrended. The linear detrending in this study was achieved by calculating the linear least squares regression of each time-series using the "HP" function within the "stats" package in Excel. Then the deviations from the least-squares fit line were deducted from the actual time-series data and thereafter the residual values (the differences) were used as the time series data for the correlation analysis.

## 3.2 Datasets

### 3.2.1 Weather Station Data

Rainfall and temperature data are essential to this study; hence, it is crucial to use the most appropriate data. Due to the topography of the study area, station data was preferred to gridded data because it captures the different responses of local climate to large scale forcing in relatively small study areas (Kloppers, 2014).

Weather station data were obtained from the South African Weather Service (SAWS) and the Agricultural Research Council (ARC). The weather stations data met two criteria before they were considered suitable to be used for this study. The first is that the stations is located within the study area, whilst the second is that the weather stations have been in operation during the period used in this study (1st January 1994 – 31st December 2018) and have fewer than 10% of missing records during the period. Seasonal rainfall and temperature data (April – September) were extracted from the weather station dataset for each district and the monthly data were used for this study.

### 3.2.2 Wheat Yield Data

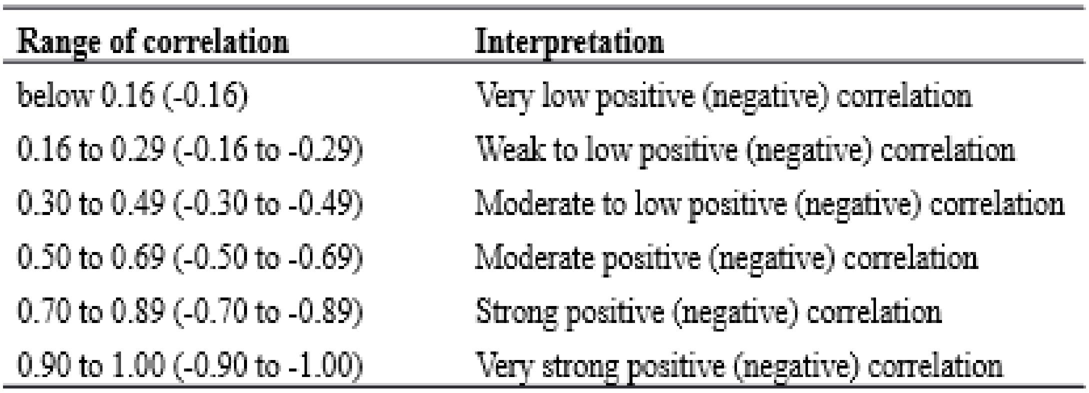
District wheat yield data used in this study were obtained from Overberg Agri, a farming cooperative (co-op) in the study area. The wheat produced by farmers in the Swartland area is bought by this co-op and sold to the wheat mills in the region. The co-op meets both the criteria of having been in operation during the period used in this study (1st January 1994 – 31st December 2018) and having fewer than 10% of missing records during the period. The wheat yield data used is measured in tons per hectare. Over the past four decades, the productivity of wheat farmlands (yield) has increased in South Africa, most likely as a result of technological advancement and improved farm management practices (DAFF 2013; Kloppers, 2014). Also, Troskie (2001) pointed out that the decline in profitability in the marginal wheat growing regions of the Swartland, leading to a reduction in area planted and hence an increase in yields. This skewed the yield records and made it necessary for the yield data to be detrended before using it for analysis (Kloppers, 2014). The district wheat yield data were detrended using the Hodrick-Prescott Filter in Excel to smoothen the long-term trend component in the data. The detrended values were deducted from the actual wheat yield data and the residual value (the difference) were used for the analysis.

## 3.3 Data Analysis

### 3.3.1 Correlation Analysis

This section examines the relationships between wheat yield and climate variables (rainfall and temperature) in the Swartland region, achieving the study’s first objective. This will determine the importance of these climate variables on wheat production. Therefore, correlation analysis was performed to determine the relationship between wheat yields and the climate variables. The rainfall, temperature and wheat yield data (1994-2018) in two districts (Malmesbury and Piketberg) were used for the analysis. Correlation coefficients range from -1 to 1, and the closer to 1(-1) a correlation coefficient is, the stronger the positive (negative) relationship and the closer a coefficient is to 0, the weaker the relationship.

***Table 3.1:*** *An interpretation rule for magnitude and sign of the correlation coefficient. Source: (Mukaka, 2012).*



| Range of correlation | Interpretation |
|---|---|
| below 0.16 (-0.16) | Very low positive (negative) correlation |
| 0.16 to 0.29 (-0.16 to -0.29) | Weak to low positive (negative) correlation |
| 0.30 to 0.49 (-0.30 to -0.49) | Moderate to low positive (negative) correlation |
| 0.50 to 0.69 (-0.50 to -0.69) | Moderate positive (negative) correlation |
| 0.70 to 0.89 (-0.70 to -0.89) | Strong positive (negative) correlation |
| 0.90 to 1.00 (-0.90 to -1.00) | Very strong positive (negative) correlation |

#### 3.3.1.1 Correlation Analysis (Wheat yield and climate variables)

The correlation analysis used the seasonal rainfall and temperature (April-September) and the detrended wheat yields of the two districts. Wheat yields of each district were correlated against the aggregated seasonal climate variables of each district using the Pearson Correlation Coefficient. The climate variables (rainfall and temperature) of the full wheat growth season (April-September), individual months, paired months, 3-month periods and 4-month periods were correlated with yields. The correlation coefficients for the two districts were obtained and recorded in one representative table and those that are significant at 10% level ($p<0.1$) and 5% level

($p<0.05$) are highlighted. For this study, a 5% level of significance was used because it confirms stronger evidence that the observed relationship between two variables does not occur by chance. A lower level of significance requires a stronger proof before the null hypothesis could be rejected. The chart of the respective correlation results was generated using Excel.

### 3.3.2 Drought Index SPEI

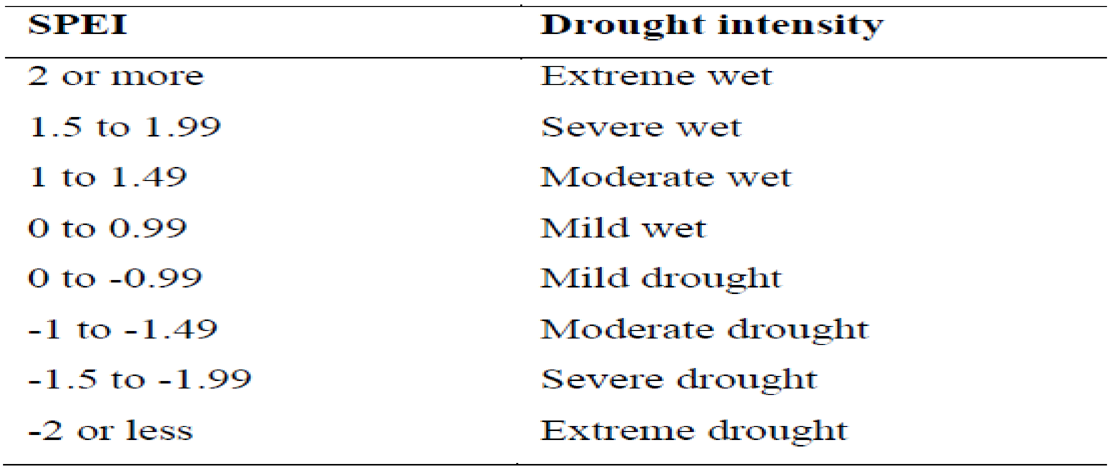
The Standard Precipitation Evapotranspiration Index (SPEI) is a standard meteorological index used for drought characterisation. SPEI is the most suitable drought index in Southern Africa, according to Ujeneza and Abiodun (2015). This is because SPEI provides spatial similarity of drought intensity without climatology, and it measures drought at various timescale (Lawal Et al., 2021; Gazol et al., 2018; Vicente-Serrano et al., 2013). The SPEI was computed from the observed dataset of the Climatic Research Unit (CRU) and that of the Community Earth System Model (CESM) simulations datasets at time scales of 1, 3, 6, 9, 12, 15 and 18 months. The calculation of SPEI was done based on the difference between precipitation (P) and potential evapotranspiration (PET) as follows: (Lawal Et al., 2021; Gazol et al., 2018; Vicente-Serrano et al., 2013).

$$D = Pi - PETi$$

Where
D = The difference.
P = Precipitation.
PET = Potential Evapotranspiration.
"$i$" = the month

PET was calculated using the mean temperature, the maximum temperature and the minimum temperature. The values of 'D' are aggregated to obtain different SPEI timescales, ranging between 1and 18 months (Lawal Et al., 2021; Gazol et al., 2018; Vicente-Serrano et al., 2010).

*Table 3.2:* *Rule of thumb for interpreting SPEI. Source: (Wang et al., 2014).*



| SPEI | Drought intensity |
|---|---|
| 2 or more | Extreme wet |
| 1.5 to 1.99 | Severe wet |
| 1 to 1.49 | Moderate wet |
| 0 to 0.99 | Mild wet |
| 0 to -0.99 | Mild drought |
| -1 to -1.49 | Moderate drought |
| -1.5 to -1.99 | Severe drought |
| -2 or less | Extreme drought |

#### 3.3.2.1 Correlation Analysis (Wheat Yield and SPEI)

An investigation of the relationship between wheat yields was also carried out to correlate the detrended wheat yield data and monthly SPEI-01, three-month SPEI-03 and six-month SPEI-06 for each district and the correlation coefficients obtained were tabulated. The chart of therespective correlation results was generated using Excel.

### 3.4 Semi-Structured Interview

Semi-structured interview was used in this study for a better understanding, exploration and explanation of the research subject's opinion, behaviour and experiences. The purpose of this is to hear directly from the respondents about their actual experiences and behaviour on drought andto confirm the statistical evidence. A group of wheat farmers in the Swartland region were contacted and asked if they are willingness to participate in a discussion about the study. Out of the group, 8 farmers indicated their willingness to participate. A group discussion was conductedwith the 8 dryland commercial wheat farmers and 2 agricultural experts from Overberg Agri. An array of pertinent questions was raised and discussed, which range from the farmers' perspectiveand experiences about drought and the changing climate, to their farm-level adaptation options and coping strategies, availability of information regarding impending drought, and support available towards climate adaptation. The strategies identified from the farmers' responses were interpreted as short-term coping strategies and medium and long-term adaptation strategies. The benefits of each strategy as stated by the farmers were evaluated for a better understanding of the reason a particular strategy is implemented and to rate if the practice could be classified as adaptation or a coping strategy (Talanow et al., 2021; Fischer, 2019).

### 3.5 Data limitation

For a study to be considered comprehensive and valid, some limitations that are imposed by several factors need to be acknowledged. There are some inherent variations and an element of error in the measured observational data and the measurement processes used (Kloppers, 2014). Due to this, the observed station rainfall and temperature data are expected to have both systematicand random errors, although they are usually considered little and insignificant (Kloppers, 2014). Weather station data is assumed to be a fairly accurate representation of the surrounding environmental conditions. But this assumption is not always accurate because anthropogenic influences may change the conditions of an environment over time, such as urban areas expansion, for example (Kloppers, 2014).

The assumption that agricultural production data are the exact measurement of values is not realistic. Although these estimations are meticulously calculated, they remain estimations which therefore may contain a certain amount of uncertainty (Kloppers, 2014). The wheat yield data used in the study are taken to be a fairly accurate representation of the yields record from the two districts. However, the exact locations and number of farms that supplied the yields to the co-operative are unknown. There are many factors (both known and unknown) that influence wheat yields such as mechanisation and improved farming techniques. Through detrending, influences that might have contributed to the decadal increases on yield record were effectively removed (Kloppers, 2014).

Correlation is an effective tool in measuring the linear relationship between two variables. However, some assumptions are made when using this technique. The assumption that two variables are isolated entities or non-dependent is not always accurate and may lead to inaccurate conclusions (Kloppers, 2014). There is possibility that two variables may correlate by coincidence, therefore the significance of correlation is evaluated. Only correlations at 5% significance level are considered in this study. Since correlation does not indicate causation, the values in this study were carefully evaluated for relevance and appropriateness.

A large sample size would have been ideal to gather sufficient information about this research. Due to the Covid-19 pandemic lockdown restrictions, it was difficult to access a larger number of farmers. Although efforts were made to reach out to more wheat farmers in the study area through email, phone calls and sending of a questionnaire via emails, they yielded no result. This prompted the group discussion with the highly experienced farmers and the agricultural experts from Overberg Agri. The limitation of getting a large sample size was partially mitigated by the fact that the minimum number of years of wheat farming experience among the participants is 22 years while some have over 40 years of experience.

### 3.6 Justification of the Methodology

The methods of analysis used in this study are quantitative (statistical) and qualitative (semi-structured interview) approaches. The combination of both methods was used to enhance the assessment and evaluation of the research by ensuring that the shortfalls of one method are balanced by the strength of the other. This may ensure improved understanding by integrating different approaches of analysis.

The Statistical method, also known as the quantitative method, enables us to analyse numerical data to detect trends, develop predictions, test casual relationships and generalise findings. Statistical analysis was used in this study to understand the association between climate variables and wheat production and the effects of the variability of the climate variables on yields over time. Understanding the long-term impact of drought on wheat yield is best achieved by using the statistical method of analysis to discover trends in the climate variables and how they impact yield records.

Qualitative research on the other hand provides the likelihood of obtaining more realistic observations of the world that can't be achieved in the quantitative research methods of numerical and statistical analysis. It provides flexibility in collecting, analysing, and interpreting data and information. Focus group discussion is often used to provide an in-depth explanation of social issues. It obtains information from a selected sample of people instead of a representative sample of the entire population. An in-depth understanding of farmer's perspective and farm-level experience of drought was gained through focus group discussion with highly experience participants.

In recent times, studies have used a combination of both qualitative and quantitative methods of analysis to successfully research the relationship between drought and agriculture. Such as (Ngaka, 2012; Maponya and Sylvester, 2012; Kloppers, 2014; Nembilwi et al., 2021 and Lottering et al., 2021).

# *CHAPTER FOUR: RESULT*

## 4.1 Rainfall and Temperature Relationship with Wheat Yield

The winter rainfall and temperature data and the detrended wheat yield data from two districts (Malmesbury and Piketberg) in the Swartland region were investigated to understand the association between each of the two climate variables and wheat yields in the region between 1994 and 2018. The table below shows the correlation coefficients obtained from the correlation results. The figures highlighted in blue and red are significant at 5% and 10% levels of confidence respectively. Significance at 5% and 10% confidence levels indicates that there is only 5% and 10% risk in concluding that the analysis is correct. This means that there is 95% and 90% confidence that the observed relationship between the two variables does not occur by chance. This study only considered the correlation coefficients that are significant at 5% ($p<0.05$) or higher to be significant. The cut off for the significance level used is the correlation results that probability figures are equal to or less than 0.05. In the result interpretation, the correlation coefficient is represented by($r$), probability value by ($p$), whilst $R^2$ represent the percentage of the total variation explained by the regression line.

***Table 4.1:*** *Pearson correlation coefficients(r) values of various monthly groupings of the rainfall and temperature relationship with wheat yield over the 1994-2018 period in Malmesbury and Piketberg. The correlation values that are significant at 5% level are shaded in Blue and those at 10% are shaded in Red.*

| | | **MALMESBURY** | | **PIKETBERG** | |
|---|---|---|---|---|---|
| S/N | MONTH | RAINFALL | MAXIMUM TEMPERATURE | RAINFALL | MAXIMUM TEMPERATURE |
| | **Individual month** | | | | |
| 1 | MARCH | -0.144 | 0.179 | 0.220 | 0.357 |
| 2 | APRIL | -0.214 | 0.174 | -0.282 | 0.394 |
| 3 | MAY | 0.009 | 0.093 | -0.082 | 0.105 |
| 4 | JUNE | 0.104 | -0.128 | 0.026 | -0.083 |
| 5 | JULY | 0.167 | -0.264 | 0.083 | -0.349 |
| 6 | AUGUST | 0.169 | -0.175 | 0.245 | -0.002 |
| 7 | SEPTEMBER | -0.018 | -0.029 | 0.001 | 0.012 |
| | **Paired months** | | | | |
| 8 | MA | -0.249 | -0.021 | -0.110 | 0.425 |
| 9 | AM | -0.108 | -0.030 | -0.216 | 0.287 |
| 10 | MJ | 0.102 | -0.000 | -0.036 | 0.017 |
| 11 | JJ | 0.197 | -0.250 | 0.076 | -0.270 |
| 12 | JA | 0.223 | -0.295 | 0.243 | -0.267 |
| 13 | AS | 0.099 | -0.103 | 0.149 | 0.006 |

| | | | | | |
|---|---|---|---|---|---|
| | **3-month periods** | | | | |
| 14 | MAM | -0.148 | 0.005 | -0.145 | 0.406 |
| 15 | AMJ | 0.006 | -0.050 | -0.117 | 0.183 |
| 16 | MJJ | 0.188 | -0.116 | 0.019 | -0.213 |
| 17 | JJA | 0.256 | -0.280 | 0.215 | -0.228 |
| 18 | JAS | 0.159 | -0.196 | 0.167 | -0.191 |
| | **4-month periods** | | | | |
| 19 | MAMJ | -0.016 | -0.017 | -0.070 | 0.316 |
| 20 | AMJJ | 0.105 | -0.094 | -0.061 | -0.079 |
| 21 | MJJA | 0.251 | -0.160 | 0.164 | -0.182 |
| 22 | JJAS | 0.195 | -0.212 | 0.177 | -0.186 |
| | **Full rainfall season** | | | | |
| 23 | AMJJAS | 0.134 | -0.118 | 0.054 | -0.055 |

### 4.1.1 Winter Rainfall and Temperature (Malmesbury).

The Malmesbury winter rainfall and temperature (April-September) were correlated with wheat yields between 1994 and 2018. All the correlation results obtained in Malmesbury are not statistically significant as all the probability values are greater than 0.05 (5% significance level). The results revealed that rainfall has a weak positive correlation ($r$ =0.134, $p$>0.05) with yields. This indicates that rainfall may have positive impacts on wheat yields. The result also revealed that temperature has a weak negative correlation ($r$ = -0.118, $p$> 0.05) with yields. This also indicates that temperature may have negative impacts on wheat yields. The seasonal rainfall and temperature correlation result in row 23 show positive and negative relationships with wheat yields respectively, and although they are not statistically significant, they indicate that adequate rainfall enhances good yields and that extreme temperature could alter soil structure, affect wheat growth negatively and lead to a decline in yield.

The non-significance of these results infers that the *amount* of winter rainfall and *the average* temperature may not be the paramount factors in determining the wheat yields, making it necessary for deeper investigation into rainfall and temperature-wheat yield relationship. Figures 4.1 and 4.2 below are the time series plots of the seasonal rainfall and temperature trend from 1994-2018 in Malmesbury. Rainfall and temperature time series were plotted to determine the seasonal trend during the period under consideration.

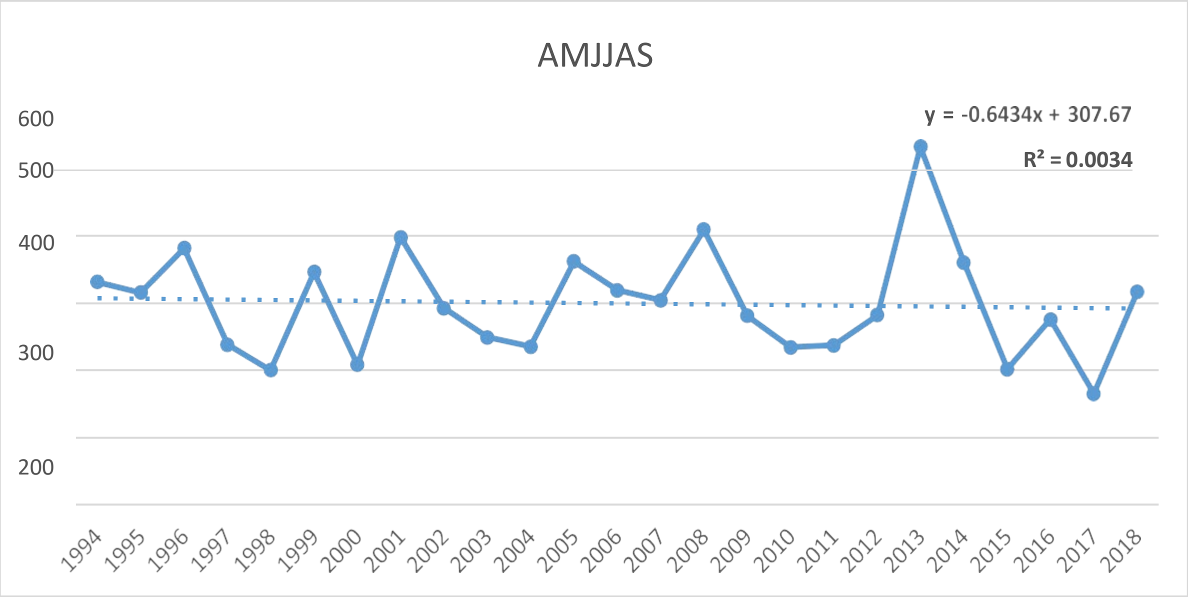


***Figure 4.1:*** *Annual seasonal rainfall (April- September) in Malmesbury between1994 and2018 showing a small declining trend (dotted line).*

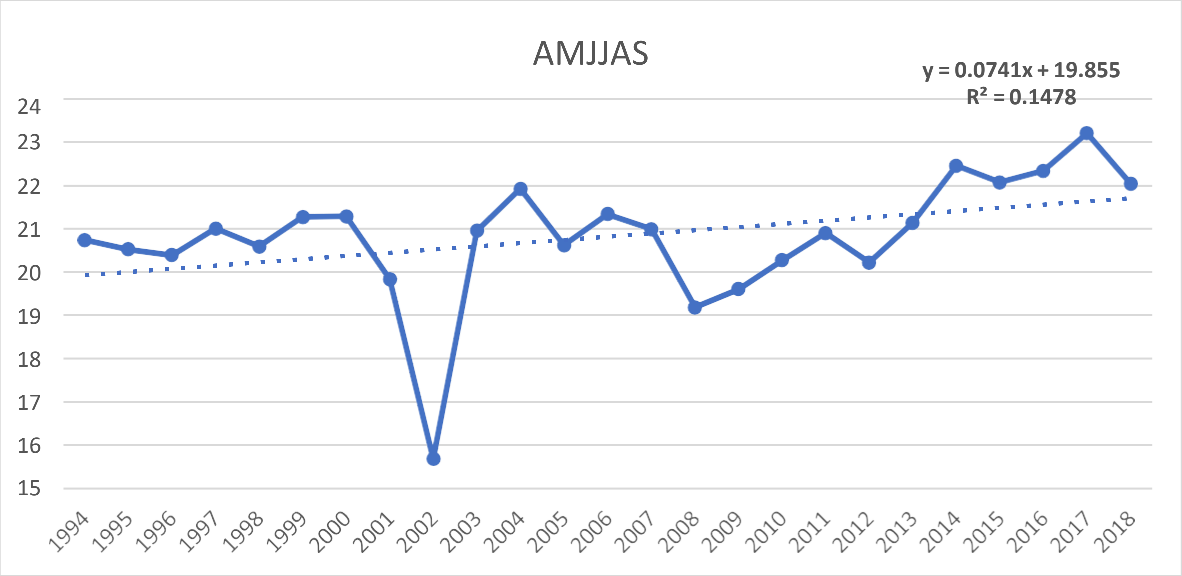


***Figure 4.2:*** *Annual seasonal temperature (April- September) in Malmesbury between 1994and 2018 showing an increasing trend (dotted line).*

The reported perceived declining rainfall trend has been a concern for wheat farmers who believe that an insufficient amount of seasonal rainfall (below 200mm) and high temperature will lead to a reduction in wheat yields especially if rainfall is not well distributed during the wheat-growing period. However, farmers pointed out that too much rainfall during the grain filling stage (usually August) could also adversely affect yields.

### 4.1.2 Monthly Rainfall and Temperature (Malmesbury)

The monthly rainfall and temperature data were also correlated with the wheat yield to investigate individual months' relationship with wheat yields within the period under investigation.

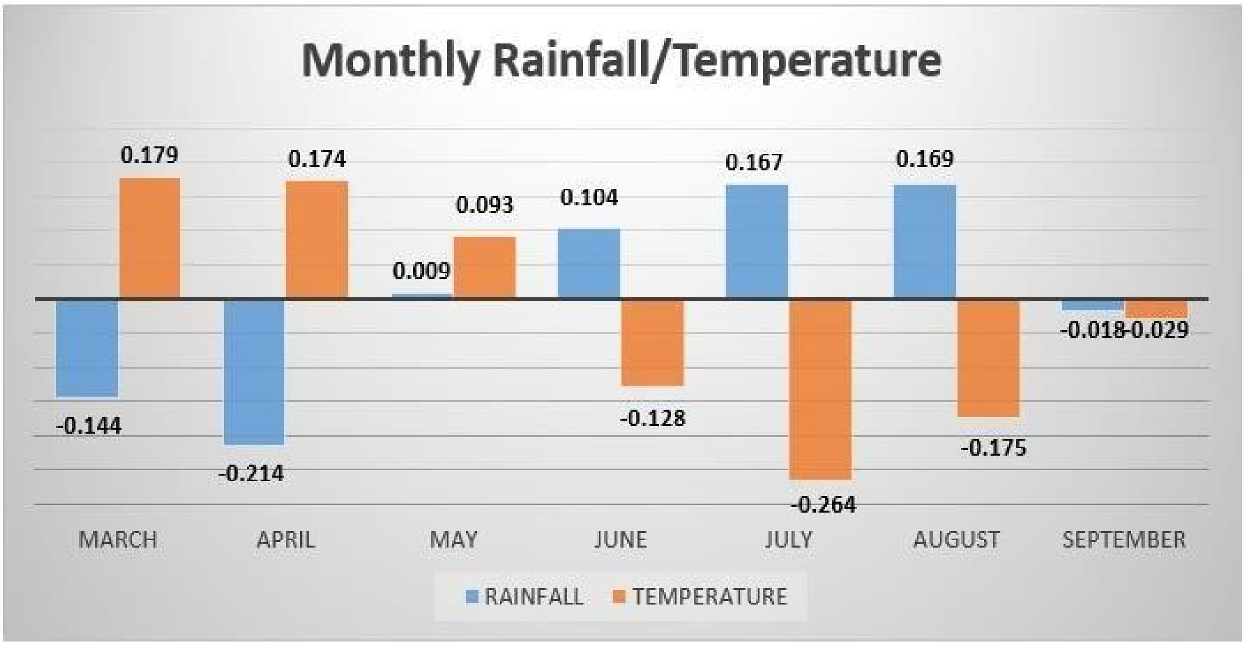


***Figure 4.3****: Monthly rainfall and temperature correlation with wheat yield in Malmesbury.*

The result of the correlation between monthly rainfall, temperature, and wheat yield in Malmesbury is presented in figure 4.3. The blue bars represent rainfall, while the orange bars represent temperature. The pre-season rainfall (March) reveals a negative correlation ($r$ = -0.144 p>0.05) and April rainfall also reveals a negative correlation ($r$ = -0.214, $p$>0.05) that suggests that an increase in rainfall in March and April could have negative effects on soil nutrients. However, the participants explained that some amounts of rainfall in March or April prepare the soil for planting. The May rainfall shows no correlation with wheat yields while June, July and August rainfall show weak but positive correlations ($r$ = 0.104, $r$ = 0.167, and $r$ =0.169) respectively all with $p$>0.05. This indicates that wheat growth during June, July and August requires moderate evenly distributed rainfall. Since we are not looking at the cause-and-effect relationship, the positive correlations of June, July and August likely indicate that wheat needs a sufficient amount of rainfall during the growing period. The negative correlations in March, April and zero correlation in May suggest that wheat may not require much rainfall (above 20mm) during the sowing period and the early stage of growth, as *sufficient* moisture is only required during these periods. September rainfall reveals zero correlation with yields, which indicates that wheat may not require much rainfall in September. Participants explained that when wheat is planted early, only a cool September is required but late planting needs rainfall in September.

Temperature shows a weak positive correlation with yields in March, (*r* = 0.179), April(*r* = 0.174) and May (*r* = 0.093). This would confirm that cool temperatures during these months would be suited for planting spring wheat. June, August and July temperatures show weak negative correlations (*r* = -0.128, *r* = - 0.264 and *r* = -0.175), while September temperatures show zero correlation. This indicates that an increase in temperature during June, July and August may cause harm to wheat growth, largely because these are the months where cooler temperatures are essential for wheat growth. The zero correlation of both rainfall and temperature in the month of September suggests that changes in both variables may have no significant effects on wheat production as the growth cycle is already completed and only awaiting harvest.

To further examine the relationship between wheat yields, rainfall and temperature, other time scales (three-month and four-month) average rainfall and temperature were examined.

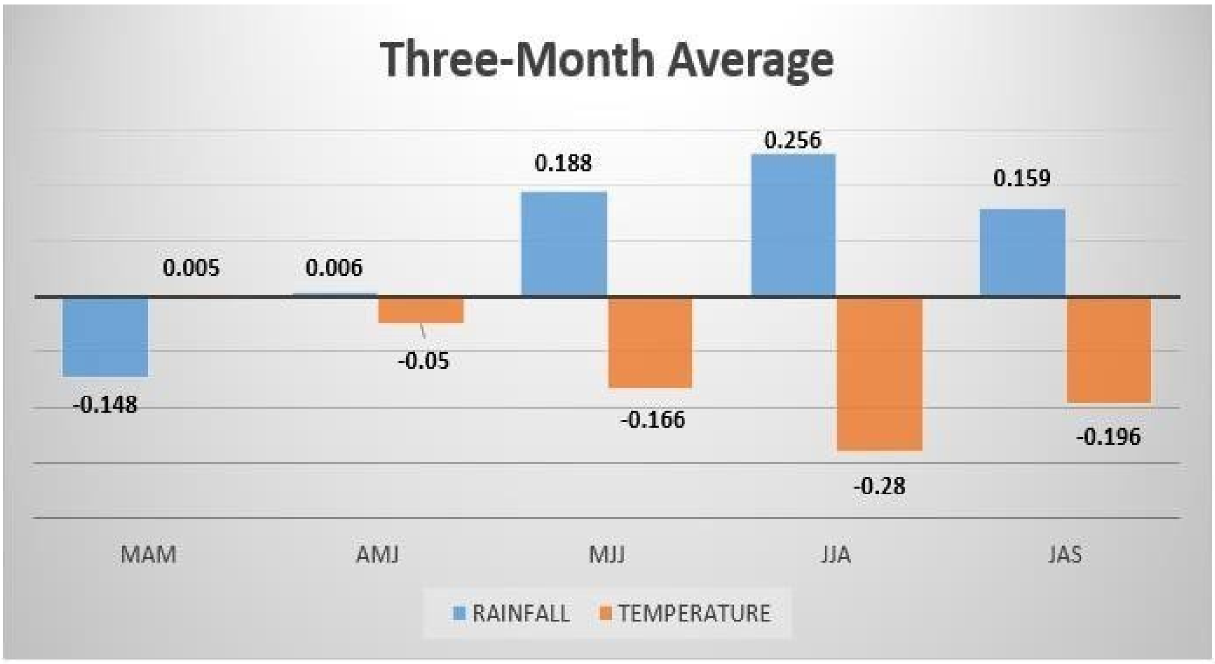


***Figure 4.4:*** *Correlation of three-month average rainfall and temperature with wheat yield in Malmesbury (1994-2018).*

The correlation results for three-month average rainfall and temperature with wheat yield is presented in figure 4.4. The combination of March, April and May (MAM) reveal a weak negative correlation (*r* = -0.148, *p*>0.05) with yields, which are aligned to those of the individual month correlation of March, April and May. The April, May and June (AMJ) rainfalls reveal zero correlation, May, June and July (MJJ) rainfalls reveal a positive weak correlation (*r* = 0.188, *p*>0.05), JJA reveals a weak positive correlation (r = 0.256, p>0.05). Lastly, the July, August and September (JAS) rainfalls reveal a weak positive correlation (*r* = 0.159, *p*>0.05). The resultsfor JJA are in line with and verify the individual monthly correlations of June, July and August in figure 4.3, indicating that these months are the main periods in which wheat growth requires adequate rainfall distribution. The weak positive correlation of JAS suggests within this period (July and August), wheat requires good rainfall distribution.

The results for the three-month average temperature correlation with yields on the other hand show that MAM has zero correlation with wheat yields, suggesting that temperature changes in these months may not significantly affect wheat production. The AMJ temperature reveal a low negative correlation ($r$ = -0.05), while MJJ, JJA and JAS temperatures reveal weak negative correlations ($r$ = -0.166, $r$ = -0.28 and $r$ = -0.196 with $p$>0.05). The negative correlations show that an increase in temperature during these periods could possibly have a negative effect on wheat yield and the non-significance of these correlations results indicates that other factors determine the variation in wheat yields.

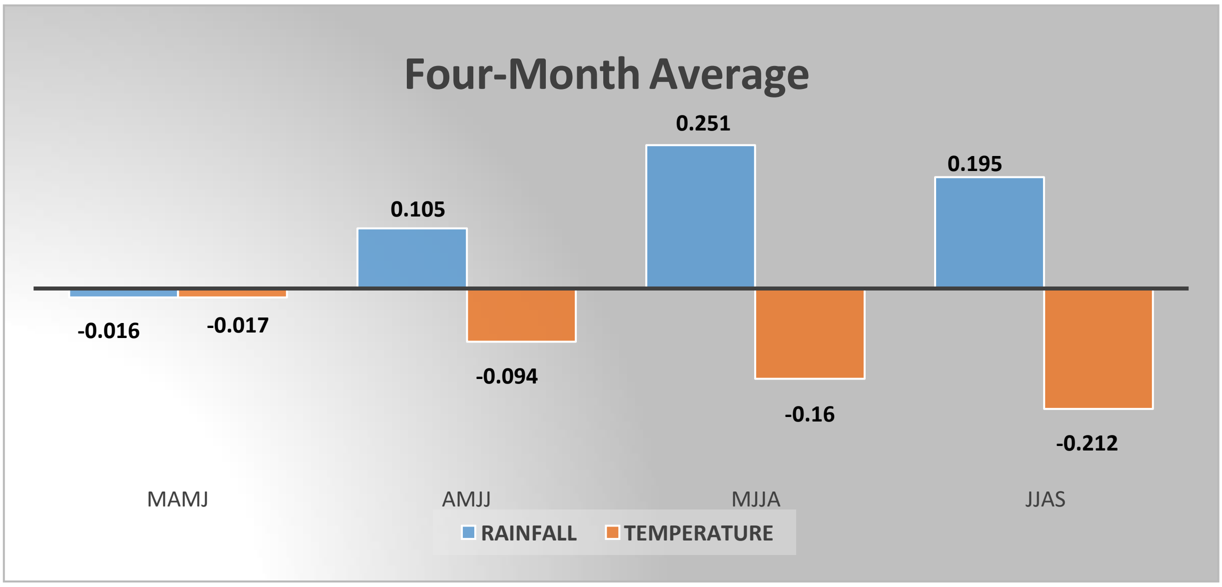


***Figure 4.5:*** *Correlation of four-month average rainfall and temperature with wheat yield in Malmesbury (1994-2018).*

The results of the four-month average rainfall and temperature correlation with wheat yield are presented in figure 4.5 above. The result reveals that there is no relationship between Marc, April, May and June (MAMJ) rainfall and yields. Whilst the April, May, June and July (AMJJ),May, June, July and August (MJJA), and June, July, August and September (JJAS) periods reveal weak but positive correlations ($r$= 0.105, $r$ = 0.251, $r$ = 0.195 with $p$>0.05). This indicatesthat rainfall has a positive impact on wheat yields during these periods. The highest correlation obtained in MJJA suggests that wheat requires a sufficient rainfall distribution during this period, which subsequently concurred with the evidence of the participants.

The four-month average temperature results reveal that MAMJ temperature has zero correlation with yield, AMJJ, MJJA and JJAS temperatures show weak negative correlations (*r* = -0.094, *r* = -0.16 and *r*= -0.212, with *p*>0.05). This suggests that temperature increase during these periods may have negative effect on wheat yield. It is important to keep in mind that these correlations are purely mathematical and based on statistics and at some points do not always tally with the evidence of the farmers.

### 4.1.3 Monthly Rainfall and Temperature (Piketberg)

Figure 4.6 presents the time series plot of annual variation of seasonal rainfall in the Piketberg district from 1994-2018.

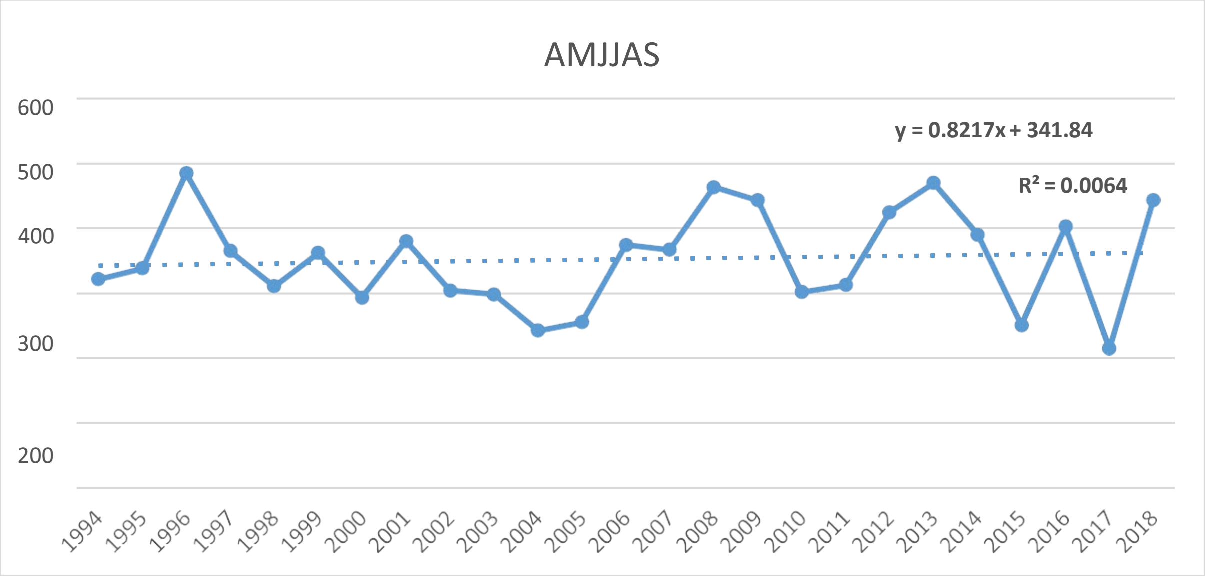


***Figure 4.6:*** *Annual seasonal rainfall (1994-2018) in Piketberg.*

The plot in figure 4.6 reveals an increasing trend, contrary to the declining trend seen in Malmesbury. This indicates that the amount of rainfall received in various locations varies and may have different relationships with crop development in each location.

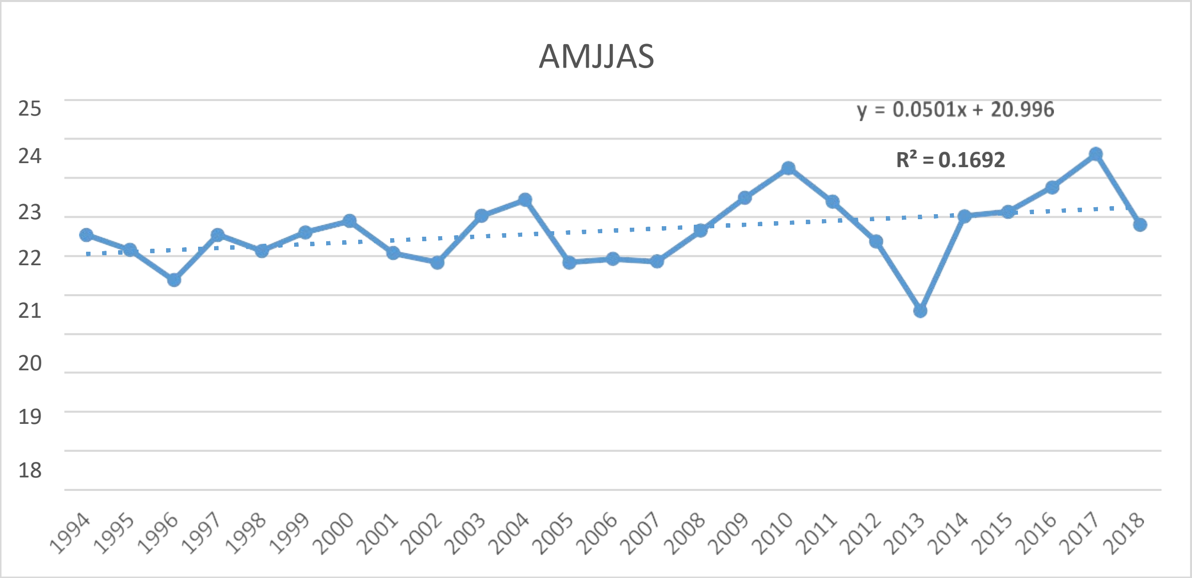


***Figure 4.7:** Annual seasonal temperature (1994-2018) in Piketberg.*

The time series plot of seasonal temperature in figure 4.7 reveals an increasing trend in the Piketberg district over 1994-2018. The interviewed wheat farmers stressed the threat posed by the increasing temperature on wheat growth especially at the early stages of wheat development. The increasing temperature trend is evident in both Malmesbury and Piketberg(see figures 4.2 and 4.7).

The winter rainfall and temperature (April-September) were correlated with wheat yields between 1994 and 2018 in the Piketberg district. The result reveals a very low positivecorrelation (*r*=0.05) between rainfall and yield, and it is not statistically significant as the *p*- value is greater than the 5% significance level. Temperature also shows a very low negative correlation (*r*= -0.05) with yields and is not statistically significant as the probability value also exceeds the 5% significance level. The low statistically non-significant correlations prompted a further investigation between these climate variables and wheat yield using different monthly scales.

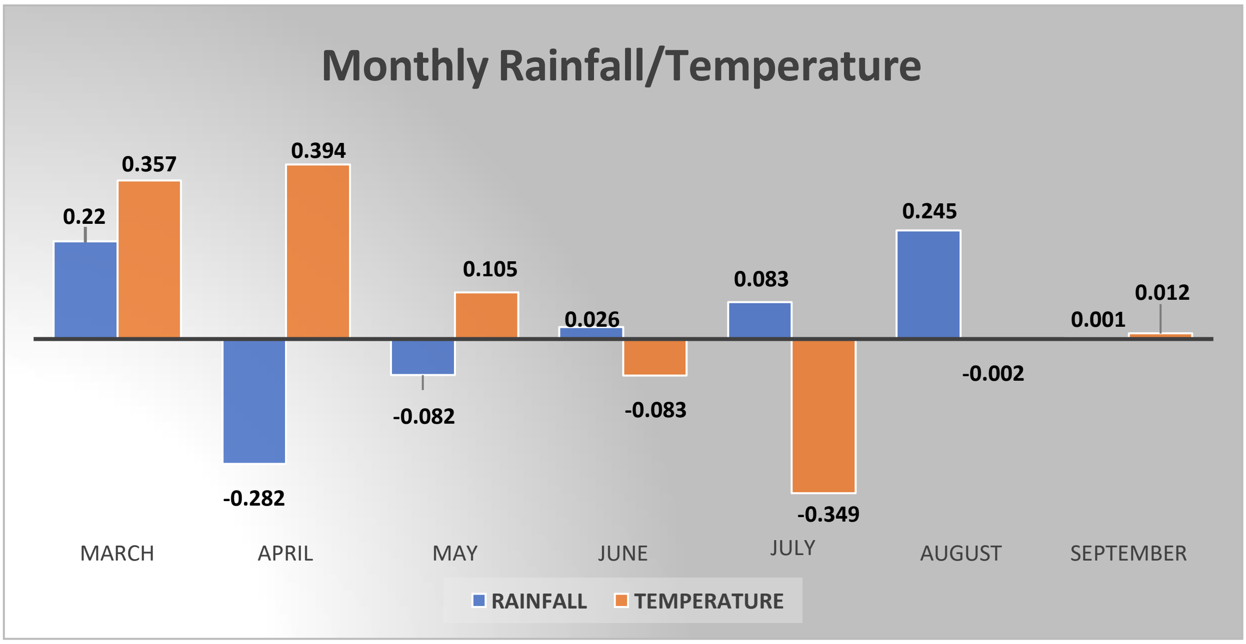


***Figure 4.8:*** *Monthly rainfall and temperature correlation with wheat yields in Piketberg.*

Figure 4.8 presents the correlation between monthly rainfall and temperature with yields in Piketberg. The pre-season rainfall (March) reveals a weak positive correlation ($r$= 0.22, $p$>0.05), this suggests that some amount of rainfall before planting may have a positive impact on wheat yield. Participants confirmed that some amounts of pre-season rainfall provide the soil with the needed moisture for sowing. April rainfall reveals a weak negative correlation ($r$= -0.282, $p$>0.05) with yields. This agrees with the April result in Malmesbury, and it suggests that increased rainfall in April could be detrimental to wheat production as excess moisture may impede germination due to limited oxygen supply (Grain SA, 2012). May rainfall reveals a very low negative correlation ($r$= -0.082), suggesting that rainfall increase in May could negatively affect wheat germination.
These results were confirmed by our participants who stated that wheat does not require too much moisture during the processes of planting and germination (April and May). June rainfall revealed no correlation, July and August rainfall revealed low and weak positive correlations ($r$= 0.083, $r$= 0.245) respectively, whilst September rainfall shows no correlation. The June, July and September results are contrary to expectations as these are the main winter months when wheat growth needs more rainfall. However, participants' accounts do not concur with the statistical evidence for the June, July and September periods, where participants explained that an adequate amount of rainfall (300-400mm) needs to be received during these months, as this is critical for a potential good yield. It is important to keep in mind that these correlations are purely mathematical and based on statistics and at some points do not always tally with the evidence of the participants.

The temperature correlations with yield reveal that there are moderate positive correlations ($r$=

0.357) in March, April (*r*= 0.394, *p*≤ 0.05) and a low positive correlation in May (r = 0.105). These results are similar to the positive correlations in March, April and May obtained in Malmesbury, and this indicates that temperature increase during these months may have a positive impact on wheat production. However, these results are contrary to the participants' accounts as they maintained that increased temperature (above 30ºC) would cause moisture deficits during the sowing and germination months (April and May). June shows a low negative correlation (*r*= - 0.083) and July shows a moderate negative correlation (r = 0.349) which also agrees with the result obtained in Malmesbury. This indicates that temperature increases during June and July may harm wheat growth. The result shows no correlation between temperature and yield in August and September.

Further investigation into the relationship between rainfall, temperature and wheat yield is done by using three-month and four-month time scales.

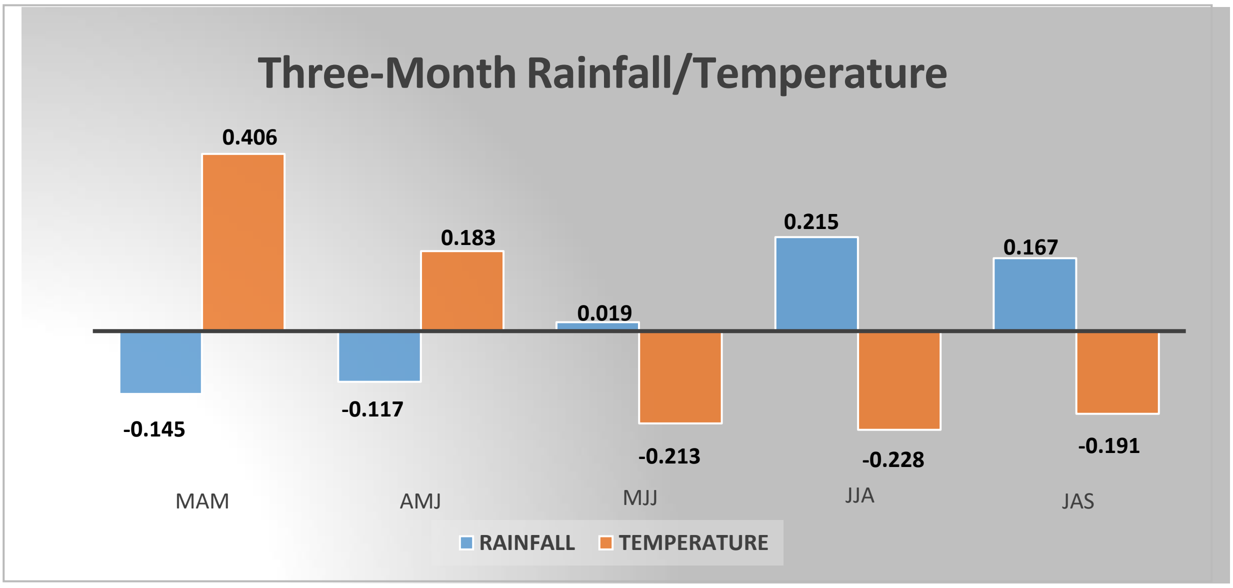


***Figure 4.9:*** *Correlation of three-month average rainfall and temperature with wheat yield in Piketberg (1994-2018).*

Figure 4.9 presents the correlation results of three-month scale rainfall/temperature and yield. The correlation results for the three-month average rainfall reveal that MAM and AMJ have low negative correlations (*r*= -0.145 and *r*=-0.117), this suggests that rainfall increase in those months may have a negative impact on yield, as it could cause excess moisture during sowing and germination. MJJ rainfall shows no correlation, JJA rainfall shows a weak but positive correlation (*r*= 0.215, *p*=>0.05) this indicates that an increase in rainfall during JJA would benefit wheat growth. The JAS period also reveals a low positive correlation (*r*= 0.167, *p*>0.05). The three-month average temperature on the other hand shows that MAM has a significant positive correlation (*r*= 406, *p*<0.05), this suggests that temperature increase during these months may have a positive impact on wheat. This is contrary to the participants' evidence, they believed that a temperature increase during this period could cause moisture deficit which would lead to a delay in sowing, as a sufficient level of soil moisture is required. AMJ temperature also reveals a low positive correlation (*r*= 0.183). Whilst temperatures for MJJ and JJA reveal weak negative correlations (*r*= -0.213, *r* = -0.228, *p*>0.05), this indicates that an increase in temperatures during these periods would have a negative effect on wheat yields. Lastly, the JAS period reveals a low negative correlation (*r* = -0.191), this also suggests that an increase in temperature during JAS could negatively affect yields.

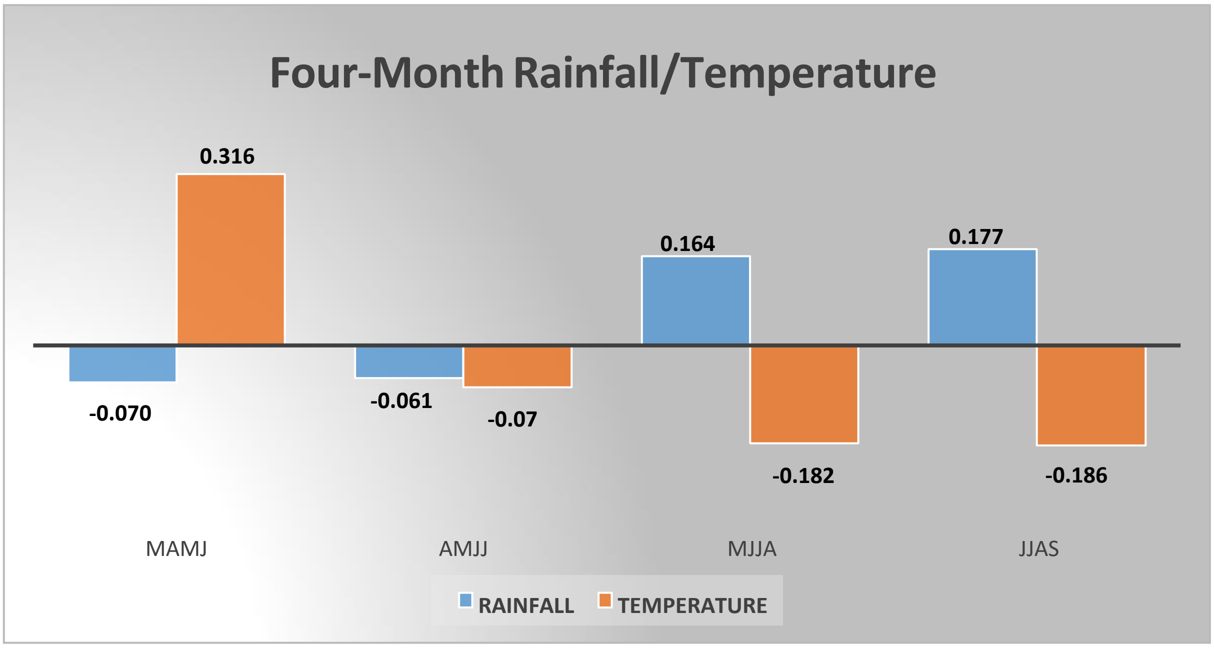


***Figure 4.10:*** *Correlation of four-month average rainfall and temperature with wheat yield in Piketberg (1994-2018).*

Figure 4.10 shows the four-month scale of average rainfall and temperature with wheat yield. The results of the four-month average rainfall reveal that MAMJ and AMJJ have low negative correlations with yields, suggesting that rainfall has a negative impact on wheat during these months. The periods of MJJA and JJAS reveal low positive correlations (*r* = 0.164, *r* = 0.177, with *p*>0.05), this indicates that rainfall increase during these months has a positive impact on yield.

The four-month average temperature results reveal that MAMJ temperature has a moderate positive correlation (*r* = 0.316, *p*>0.05) with yield. The AMJJ, MJJA and JJAS months reveal low negative correlations (*r* = -0.07, *r* = -0.182, r = -0.186 with *p*>0.05), which indicates that temperature increase during these periods would have a negative impact on yields.

## 4.2 Drought Index SPEI Relationship with Wheat Yield.

The Standardized Evapotranspiration Index (SPEI) was also correlated with the wheat yield to examine the impacts of drought events on wheat yield in both districts. SPEI shows information about drought conditions, with a 0.5 degree spatial resolution and a monthly time resolution (Dlamini, 2017). SPEI is used because it is a multi-scale index that comprises both rainfall and temperature to pick out drought conditions at different temporal scales (Dlamini, 2017). Only 01-, 03- and 06-month SPEI were used from each district to examine the relationship with wheat yield in the period 1994-2018.

***Table 4.2:*** *Pearson correlation coefficients values of SPEI relationship with wheat yield at 1month, 3month and 6month timescales over the 1994-2018 period in Malmesbury and Piketberg. The significance level of Blue shaded values is 5% and Red is 10%.*

| MONTH | MALMESBURY SPEI | PIKETBERG SPEI |
|---|---|---|
| APR | -0.338 | -0.319 |
| MAY | -0.043 | -0.154 |
| JUN | 0.243 | 0.316 |
| JUL | 0.216 | 0.200 |
| AUG | 0.140 | 0.227 |
| SEP | -0.070 | -0.085 |
| OCT | -0.111 | -0.144 |
| MAM | -0.070 | -0.092 |
| AMJ | 0.254 | 0.202 |
| MJJ | 0.339 | 0.430 |
| JJA | 0.132 | 0.153 |
| JAS | -0.026 | -0.017 |
| AMJJAS | 0.125 | 0.107 |

### 4.2.1 SPEI Correlation with Wheat Yield in Malmesbury.

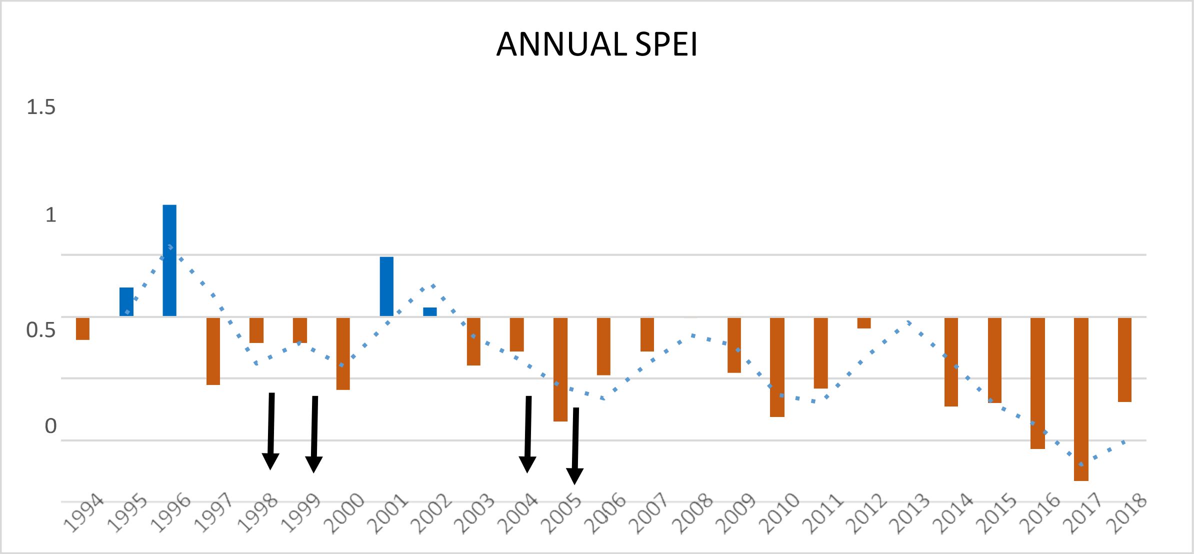


***Figure 4.11:*** *Temporal variation of annual SPEI in Malmesbury in 1994-2018 showing the persistent occurrence of drought conditions since early 2000. The orange colour indicates dry conditions, and the blue colour indicates wet conditions.*

Low yields were recorded in 1998, 1999, 2004 and 2005 (indicated by the black arrows). These years experienced light to moderate drought conditions as indicated by the orange bars in figure 4.11. The year 2005 was known as a drought year and recorded the lowest yield. This is indicated by the long orange bar in figure 4.11 indicating an extremely dry condition. The drought of 2015-2017 seems not to have caused decreases in yields in Malmesbury, as 2017 which was the driest year as indicated by the longest orange bar in figure 4.11 recorded the highest yield (3.9 tons/ha). But participants believe that there could be a mistake in the yield record as there was a general yield reduction in 2017. Also, 2015, which was a drought year, recorded a considerably above-average yield (3.45 tons/ha), while 2016 recorded a below-average yield (2.48 tons/ha). However, these records are not in line with the accounts of participants, who believe that these records are contestable as they claimed that the 2015-2017 drought caused huge decreases in yields for them. The majority of the participants (n = 6) confirmed that the drought caused yield reduction for them in 2015 and 2017 while the others (n = 2) maintained that they had yield reductions in 2015, 2016 and 2017. These yield (tons/ha) recorded by some of the participants in 2015-2018 revealed yield reduction in 2017 in comparative numbers; Famer 1 (2.4, 3.5, 1.2, 3.5), Gideon (1.0, 2.8, 0.87, 2.8), farmer 2 (2.24, 4.39, 1.97, 4.69), farmer 3 (3.0, 4.0, **2.7**, 4.0), farmer 4 (0.6, 0.9, **0.5**, 1.5) and farmer 5 (3.73, 4.13, **1.66**, 1.67). The participants recorded the lowest yield in 2017 (figures in bold) compared to the other 3 years.

The result of the 6-month (seasonal) correlation between SPEI-6 and wheat yield shows a low positive correlation (*r* = 0.12, *p*>0.05). This indicates a decrease in wheat yield as a result of decrease in SPEI, this means that as the weather conditions get drier, the lower the yields. The result is not statistically significant probably as there are other factors determining wheat yields aside from weather conditions.

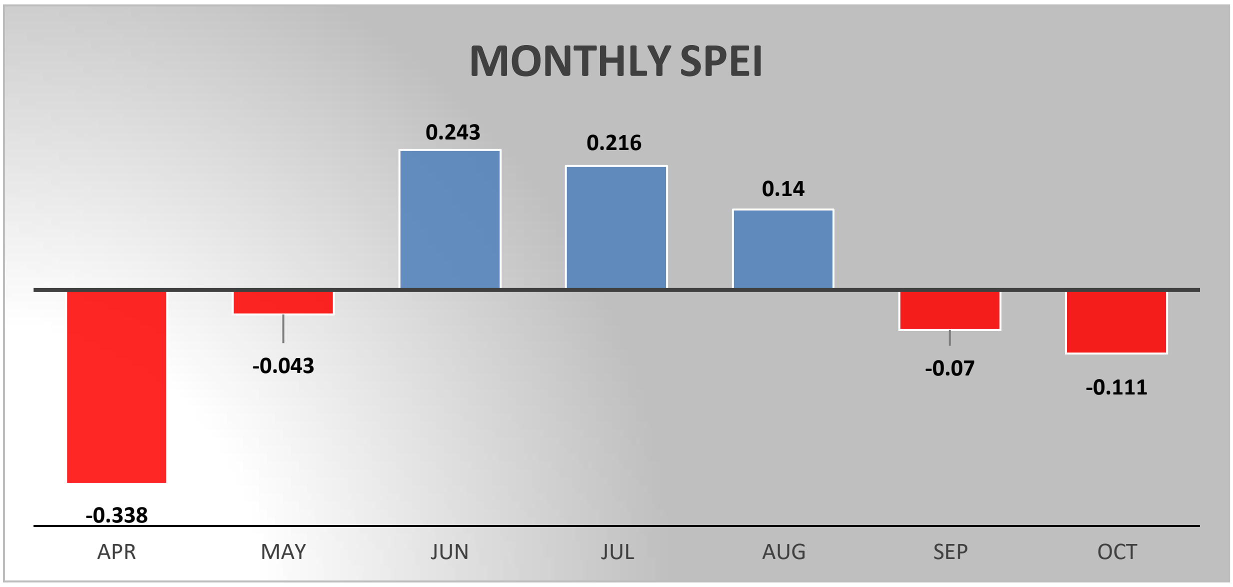


***Figure 4.12:*** *Correlation of monthly SPEI (March-September) in Malmesbury in 1994-2018.*

The correlation result between monthly SPEI-1 and wheat yield in Malmesbury reveal a moderate negative correlation (*r* = -0.338, *p*> 0.05) in April. This indicates that a moderate drier condition may have a positive impact on wheat during the planting period. However, participants believe that 10-20mmof rainfall is required for planting from mid-April to mid-May. SPEI reveals no correlation with yields in May, while it shows low negative correlations (*r*= - 0.070) in September, this indicates that an increase in SPEI in September would lead to an increase in wheat yields, that is, wheat needs wet conditions in September. The positive correlations between SPEI and yield in June, July and August (*r* = 0.243, *r* = 0.216 and *r* = 0.14) indicate that wet conditions are needed for wheat growth during these months.

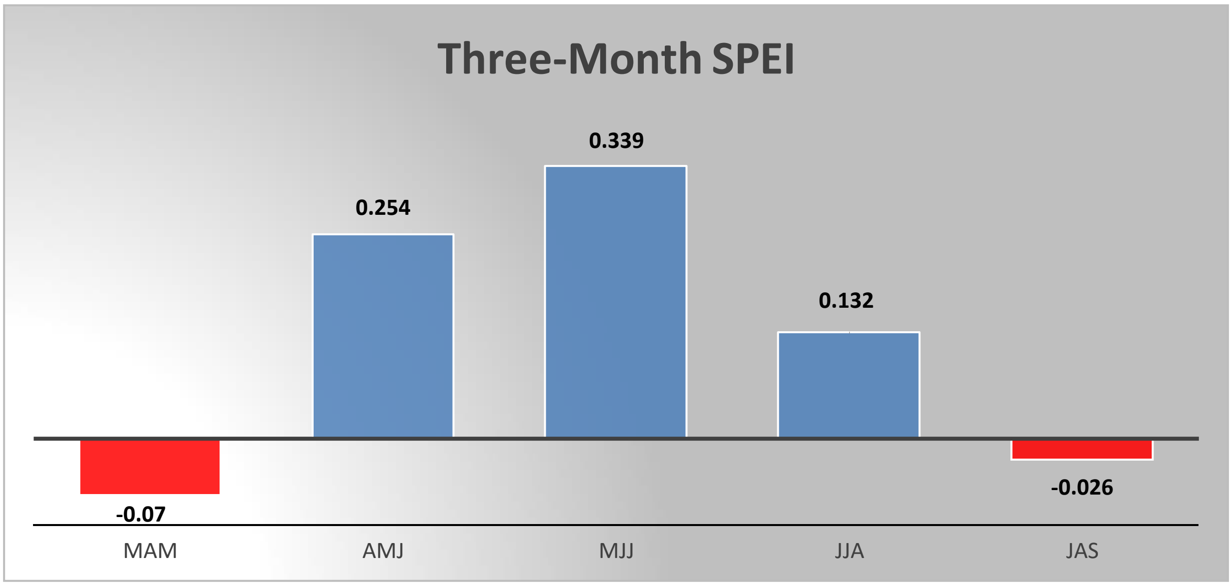


***Figure 4.13:*** *Correlation of three-month SPEI with wheat yield in Malmesbury (1994-2018).*

The three-month correlation results of SPEI-3 and wheat yields are presented in figure 4.13. There is a low negative correlation ($r = -0.07$) in MAM, which indicates that wheat may not require high rainfall during the planting and germination periods. There is a weak positive correlation in AMJ ($r = 0.254$), a significant moderate correlation in MJJ ($r = 0.339$, $p \leq 0.05$) and a low correlation in JJA($r = 0.132$). This indicates that a decrease in SPEI means there is drought which will lead to a decrease in yields, which means the drier the weather conditions in those periods, the lower the wheat yields. SPEI shows zero correlation with yields in JAS. The highest correlation is obtained in MJJ and it is statistically significant, indicating that wheat needs higher rainfall during these months as this is the main growing period for wheat.

### 4.2.2 SPEI Correlation with Wheat Yield in Piketberg District

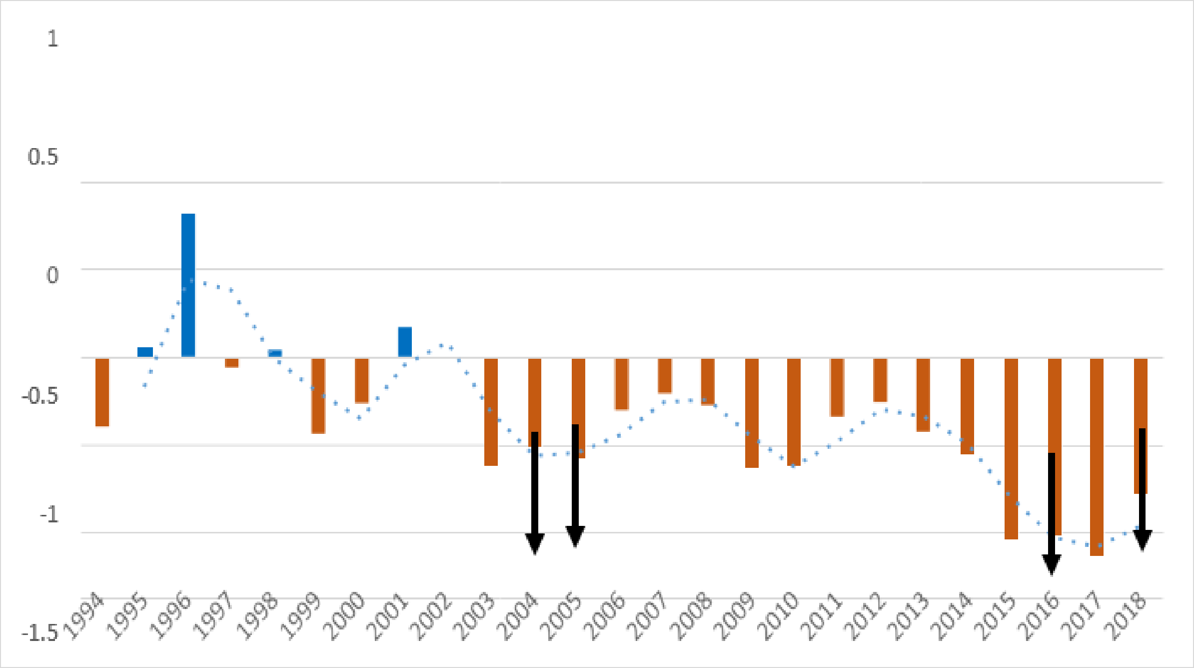


***Figure 4.14:*** *Temporal variation of annual SPEI in Pikerberg showing an increasing trend in dry conditions since early 2000. The orange colour indicates dry conditions while the blue colour indicates wetconditions.*

Most of the below-average yields were recorded during dry condition years such as 2004, 2005, 2016 and 2018 as indicated by the black arrows in figure 4.14. However, some years, like 2015 and 2017 which were drought years recorded above-average yields of 3.25tons/ha and 3.0tons/ha. This contradicts the accounts of the participants as they claimed that they recorded low yields during those years due to the drought. The 6-month correlation between SPEI and wheat yield in Piketberg shows a low positive correlation ($r = 0.10$). This indicates that a decrease in SPEI means there is a drought condition which would lead to a decrease in yields, this means, as the weather conditions get drier, the lower the yields.

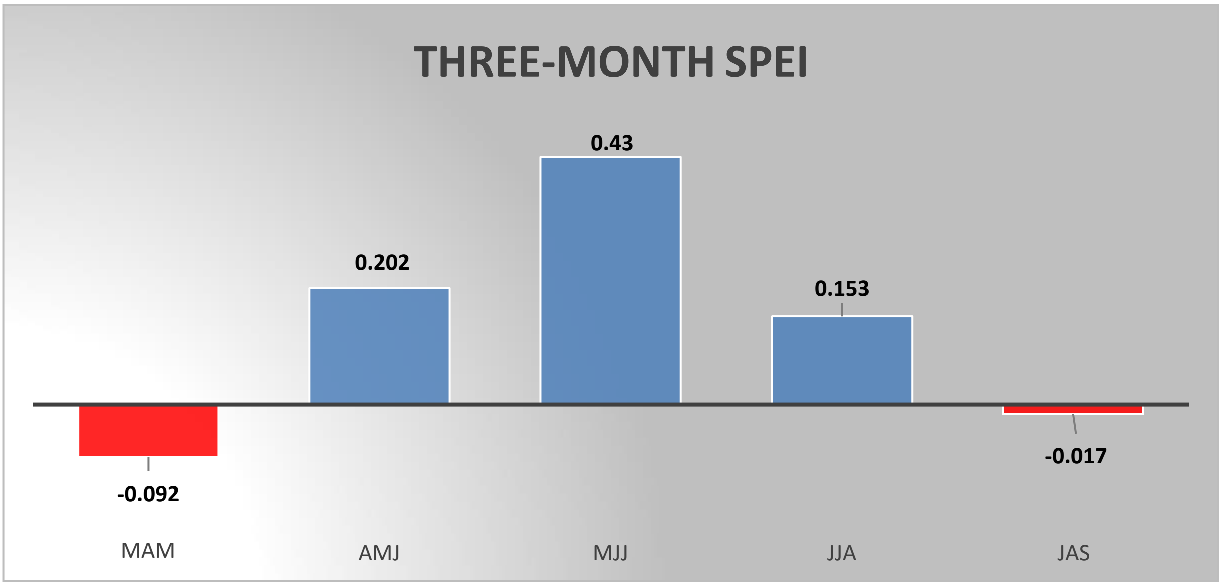


***Figure 4.15:*** *Correlation of three-month SPEI with wheat yield in Piketberg (1994-2018).*

The three-month SPEI-3 in Piketberg is presented in figure 4.15. It shows a low negative correlation between SPEI and yields in MAM. This agrees with the correlation result of MAM at Malmesbury, revealing that a few dry conditions would not harm wheat growth at this period. There is weak positive correlation in AMJ ($r = 0.202$) and JJA ($r = 0.153$), while MJJ reveals a significant strong positive correlation ($r = 0.43$, $p \leq 0.05$) with yield. JAS shows no correlation. The positive correlation with yields in AMJ, MJJ and JJA indicates that dry conditions during these periods may negatively affect yield. The highest correlation is obtained in MJJ revealing that dry conditions would have a significant negative impact on yield. The results of the SPEI-3 in Malmesbury and Piketberg are similar as drought conditions have the same influence on yields at both districts.

## 4.3 Non-Linear Relationship of Rainfall and Wheat Yield

Three low yields and three high yields years were picked randomly to further examine the association between wheat yield and rainfall in Malmesbury. Figure 4.16 below is the rainfall versus wheat yield chart that shows the indirect relationship between rainfall and wheat yield.

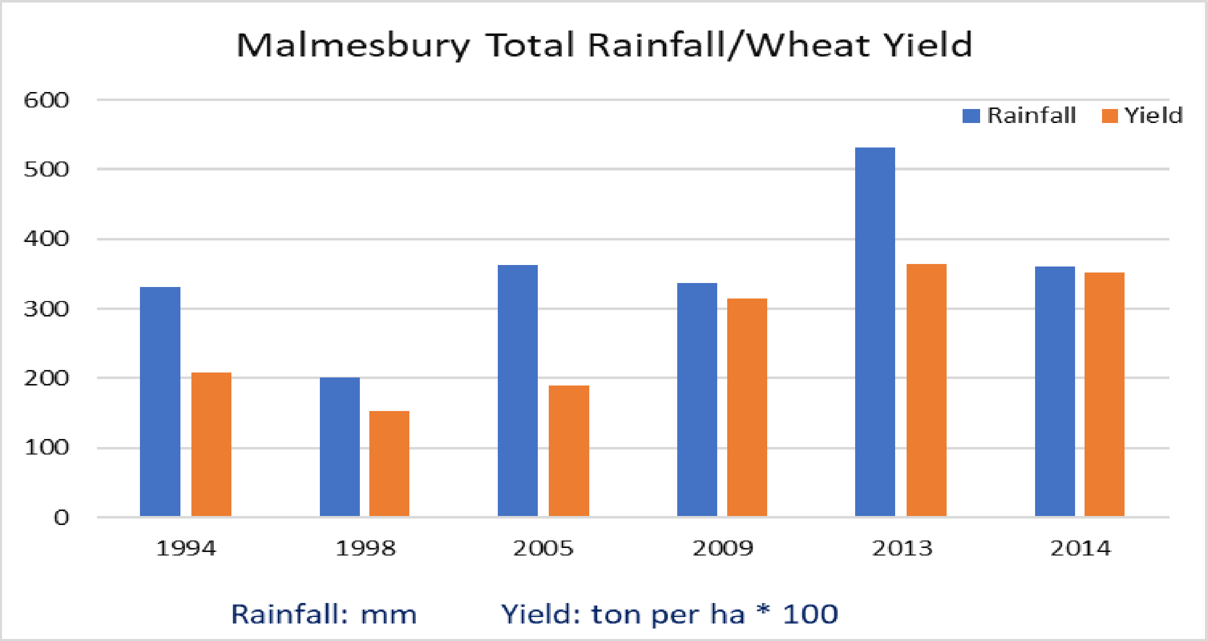


***Figure 4.16:*** *Rainfall and wheat yield chart in Malmesbury for selected years.*

It could be observed that the year with the highest rainfall (2013) recorded the highest yield and the year with the lowest rainfall (1998) recorded the lowest yield. But this does not mean that the amount of rainfall received in a particular year is directly proportional to the variation in yield. The selected six years wheat and rainfall data revealed a non-direct relationship between the amounts of seasonal rainfall received and wheat yield. For instance, the seasonal rainfall in 2005 (362.2mm) was higher than that of 1994 (331.4mm). However, the wheat yields (2.08 tons/ha) were greater than that of the year 2005 (1.9 tons/ha). This further suggests the importance of good rainfall distribution over the amount of rainfall received. Participants explained that 250mm of rain that is evenly distributed over the growing period (June-August) produces better yields than 400mm of rainfall that is not evenly distributed. This possibly explains why some drier years recorded better yields than wetter years.

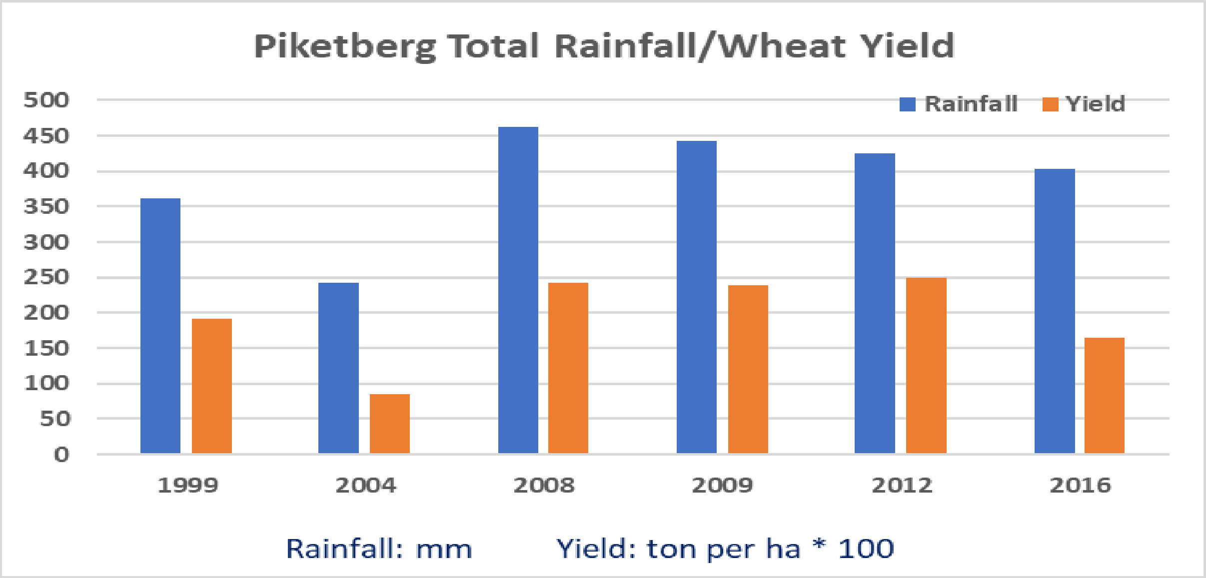


***Figure 4.17:*** *Rainfall and wheat yield chart in Piketberg for selected years.*

Figure 4.17 also shows that the selected six years wheat and rainfall data revealed positive but not direct relationship between seasonal rainfall and wheat yield. For instance, the 2004 season received the lowest rainfall and recorded a very low yield almost resulting in total yield failure for that year. But the amount of rainfall received in 1999 was 362.1mm and recorded a higher yield of 1.92 tons/ha than in 2016 which received a higher rainfall of 402.6mm and recorded yield of 1.64 tons/ha. Additionally, 2008 received seasonal rainfalls of 462.9mm and recorded a yield of 2.43 tons/ha which is lower than 2.5 tons/ha recorded in 2012 that received a higher rainfall of 424.8mm. This shows that good rainfall distribution that is evenly spread across each growth stage of wheat is more important than the total amount of rainfall received in a particular growing season.

## 4.4 Farmers' Perception of Climate Change

### 4.4.1 Participants' Observations on Drought

Participants were asked if they think that drought is becoming more frequent over the long term. All participants (*n*= 7) except one observed that drought has become more frequent in recent years. The only participant who did not agree with this observation believed that there have always been periodic droughts *"Rainfall records show dry years when I was a child, and in my father, grandfather and great-grandfather's time" (farmer 1)*. But all the participants reported that they are aware of the increasing intensity of recent droughts and they are struggling to adjust to the apparently changing climate. *"We always get dry years that are below our average rainfall, but the dry spells from 2015-2019 were the longest in our farm's history" (farmer 2). Drought has become more frequent, occurring every season for the last 6 years (farmer 3).* Some of the reported observations are late rainfall, reduced precipitation and shorter rainy periods. They pointed out that the late start of rainfall has shifted their planting period from mid-April to late May and the rainfall stops early, causing shorter growth seasons which have negative implications on yields. *"We now have shorter growing season due to the late start and early stop of rainfall" (farmer 4). "In recent years, we are experiencing shorter winters and uncertain September months" (farmer 5).* Participants believed that the observed reduced precipitation doesn't pose a big threat, as wheat can survive with as low as 30mm per month during the growth period, but the shortened rainy seasons and the temperature increase are the major concerns. *"The increase in temperature is the major problem, you don't need that much water if it's a cooler temperature. The hot weather causes evaporation and makes lots of moisture go up in the air" (farmer 3).*

### 4.4.2 Experienced Effects of Drought on Farming and Livelihood

Participants explained that crop failure, yields reduction and reduced crop quality are the main effects of droughts. When the drought is severe like that of 2015-2017, which could lead to a decline in the quantity and quality of wheat, we just have to save money by reducing any extra inputs. In the worst-case scenario, we cut it down and use it as feed (farmer 6). Participants reiterated that these factors result in financial losses and affect their livelihoods because they don't get the return on their investment in seedling and other inputs. Participants reported that low crop quality and reduced yield occur when rainfall starts late and stops early. Crop failure occurs when rainfall ceases for a longer period during the growing season and, in a worst-case scenario, they have to cut down the wheat before maturity and use it for animal feed. This enables them to cut down on further inputs expenses such as herbicides and nitrogen. When rainfall ceases for a longer period than usual during the wheat-growing period, we have to cut down our costs by cutting down the wheat and using it for animal feed to save the cost of nitrogen use (farmer 4). Additionally, participants reported that the recent drought did not only affect their livelihoods but also that of the farmworkers who lost their jobs as most farmers tried to cut the cost to enable them to recoverfrom the losses incurred during the drought years and some farmers even sold off their farms or parts of them.

## 4.5 Coping Strategies Employed and the Perceived Effectiveness

Participants believed that they cannot control nature and the changing climate but explained that proactive measures must be taken to reduce the negative impacts and minimize their losses. *"We cannot control nature because there have been drought occurrences before my dad's lifetime, so we need to find ways to reduce our losses" (farmer 1).*

Table 4.3 illustrates the coping measures employed by the wheat farmers in the Swartland region as reported by the participants.

***Table 4.3:*** *The coping measures adopted by wheat farmers in the Swartland region.*

| Implemented Coping strategy | Stated benefits | Number of farmers (N=8) | Used as Coping Measures (short-term) | Used as Adaptation Measures (medium to long-term) | Part of Conservation Agriculture Principles |
|---|---|---|---|---|---|
| **Crop Management** | | | | | |
| Crop Rotation | Improves soil quality and reduced nitrogen and herbicides inputs. | 8 | | X | X |
| Crop Diversification | Planting multiple crops helped financial losses in case of any failed crop. Improves soil health and the resistance to environmental hazards. Reduces the amount of fertilizer used. | 8 | | X | X |
| Reduction of fertilizer and herbicides input | This is done to reduce financial losses after planting. | 5 | X | X | X |
| Short growth season cultivars | This is better suited to the changing climate as the growing season gets shorter. | 5 | | X | |
| Less seed per hectare | Planting fewer seeds per hectare is effective when there is less moisture availability | 3 | X | | |
| Changing planting date | Adjusting planting date to make effective use of moisture base on rainfall variability. | 3 | X | X | |
| **Soil management** | | | | | |
| Minimal tilling | Increased soil moisture and increase yield | 2 | | X | X |
| Introduction of cover crops | Helps to reduce moisture loss and fertilizer usage | 2 | | X | X |

Participants identified eight measures as the coping strategies employed at the farm level to help their resilience against drought. Some of these measures are both coping and adaptation measures while some overlapped as conservation agriculture principles.

Some participants emphasised that knowing the appropriate time to plant is highly important and pointed out that the optimum time to plant is the first week in May if 10-20mm rainfall is received. One of the participants claimed, "*two of my highest yield years were not good rainfall years but I managed to get high yields because I made effective use of the moisture and planted early after some amount of rainfall was received*" *(farmer 3)* He stressed further *"Timing is crucial in wheat production because you can have a lot of rainfall in one year and almost half of the rainfall in the next year, but you can almost have the same yields because of good timing" (farmer 3).* Crop diversification is stated by farmers as the most effective adaptation measure which helps them to cope with the risk of drought and many wheat farmers also rear cattle.

## 4.6 Conclusion

Based on the correlation results obtained from the two districts and the qualitative accounts of the participants, the months of June, July and August rainfall is highly important for a good wheat yield. The participants explained that insufficient amounts of rainfall coupled with extreme temperature during these months have led to poor yield or total crop failure, as was evident during the 2015-2017 drought years in the south-western Cape. Participants also stressed the importance of early rainfall (April) and cooler temperatures in September. They explained that late start and early stop of rainfall coupled with hot September leads to poor yields. Also, the temporal variation of SPEI in both districts reveals that the years that experienced below-normal rainfall conditions recorded below-average yields. Overall, there was a low correlation between yields, rainfall and temperature in the two districts. This could be a result of the fact that other factors determine wheat yields apart from climate variables. Also, it is clear that farm management practices reduce the impacts of rainfall and temperature anomalies.

# *CHAPTER 5: DISCUSSION AND CONCLUSION*

There are four different sections in this chapter. In sections 5.1, 5.2 and 5.3 corresponding analyses designed and undertaken to achieve the objectives of this study are discussed. The key findings from the analysis are summarised and discussed and the suggestion of how these findings can be used to improve farm management decisions are presented. In the final section (5.4) the summary of the study is presented and the recommendation for future research that can address some of the limitations of the study is also suggested.

## 5.1 Rainfall and Temperature Relationship with Wheat Yields

The first objective of this study is addressed under this section, which was to examine the impact of drought on wheat yield in the Swartland region of the Western Cape by establishing the relationship between climate variables (Rainfall and Temperature) and wheat yields. The combination of abnormally low rainfall for a long period and high temperature constitutes drought which adversely affects wheat production. The analysis focused on Malmesbury and Piketberg for the 1994 to 2018 period and the relationship of rainfall and temperature with wheat yields were examined on different time scales listed below.

- Winter (April to September)
- Monthly
- Paired month
- Three-month
- Four-month

The winter rainfall in both districts revealed a low positive and not statistically significant correlation with wheat yields whilst the temperature in both districts revealed a low negative and non-statistically significant correlation as listed below.

Winter rainfall (Malmesbury) - ($r$ =0.13, $p$>0.05)

Winter rainfall (Piketberg) - ($r$=0.055, $p$>0.05)

Winter temperature (Malmesbury) - ($r$ = -0.11, $p$> 0.05)

Winter temperature (Piketberg) - ($r$= -0.055, $p$>0.05)

Although the effects are not statistically significant, the results support that adequate winter rainfall helps wheat production, while temperature increase is detrimental to wheat yield in the Swartland region. To further examine the relationship between rainfall, temperature and wheat yields, other temporal timescales were used to examine the correlations. The individual month timescales correlation results for Malmesbury revealed that both rainfall and temperature have weak correlations with wheat yields. Also in Piketberg, rainfall and temperature correlation with wheat yields revealed weak correlations. The weak correlation results from both districts prompted a further investigation using other time scales.

Other timescales were used to further examine the relationship between rainfall, temperature and wheat yields. The paired month timescales results for both districts only revealed statistically significant correlations for Piketberg in MA (March, April) and MAM (March, April, May). The rest of other time scales revealed weak correlations.

Finally, the monthly SPEI-1 result also revealed optimal correlations in the growing periods (June, July and August) at both districts. The correlation results revealed weak correlations ($r$ = 0.243, 0.216 and 0.140) in Malmesbury and weak correlations ($r$ = 0.316, 0.20 and 0.227) respectively in Piketberg. This indicates that wet conditions during these periods have a positive impact on wheat yields. Indicating that a decrease in SPEI would lead to a decrease in yields, this means, as the weather conditions get drier the, during the growing period, the lower the yields.

The correlation analysis revealed that rainfall and temperature influence wheat production mostly during the growing period (June - August). Based on the discussion with the farmers and the agricultural experts, it is clear that droughts negatively affect wheat yields, particularly during the growing period. Participants also confirmed that poor yields were recorded in the years that experienced abnormally low rainfall and high temperatures during the wheat-growing period. This confirms the main finding from this section of the analysis, that a good rainfall distribution (250-400mm) that is evenly spread across the months and a moderate daily maximum temperature (between 20 and 30$^{o}$C) are required during the wheat growing season. Particularly, this study found that wet seasons have become drier, shorter, and later starting. This corresponds with the evidence from the projected rainfall seasonality trend for the winter rainfall zone (Roffe et al., 2021), which have negative implications for rainfall-dependent activities. Consequently, the finding of this study could be useful to the development of water resource management strategies for the Western Cape region, which is already susceptible to seasonal rainfall changes. Therefore, if scientific evidence is taken into consideration for those strategies, then the future multi-year severe droughts impacts, that are predicted with a high degree of confidence (Roffe et al., 2021; Otto et al., 2018; Pascale et al., 2020) may be considerably mitigated.

## 5.2 Farmers’ on-farm coping Strategies

Based on the discussion with the participants, it was revealed that farmers who had experienced droughts are adopting coping strategies, confirming the theory that experience of risk determines response behaviour (Talanow et al., 2021; Grothmann and Patt, 2005; Clayton et al., 2015). Farmers utilized various coping/adaptation strategies to reduce vulnerability to drought. The most commonly used adaptation strategies by the Swartland wheat farmers are soil and crop management which are aimed at maintaining soil quality and crop productivity.

### 5.2.1 Crop Management

The crop management strategies mentioned are; Crop rotation, which helps to improve soil health and reduced nitrogen and herbicides inputs by reducing pests and weeds. Some of the crops used for rotation among the Swartland wheat farmers include canola, oats, barley, peas, medics and lupine. The use of nitrogen-rich fertilizers is another crop management strategy mentioned by farmers, which is used to improve wheat yields. However, knowing the appropriate time (when crop failure is perceived due to drought) to reduce or stop fertilizer and herbicides input is a coping strategy adopted by the Swartland wheat farmers to reduce financial losses during drought events. Crop diversification is another strategy used by the Swartland wheat farmers. Planting multiple crops is a measure employed by farmers to reduce financial losses in case of wheat crop failure. It improves soil health, helps resistance to environmental hazards and reduces the amount of fertilizer used. Pest and disease-resistant varieties can reduce the need for harmful pesticides and herbicides use can be reduced by more vigorous varieties that can compete with weeds. Farmers also mentioned the use of short-season wheat cultivars, which are better situated to a shorter growing season. The late start of seasonal rainfall in recent years has led to a shift of the historical wheat sowing period which was usually between mid-April to mid-May in the Western Cape to late May and early June. Farmers explained that the short-season cultivars have helped their adaptation to the changing climate by reducing the risk of yield decline and crop failure associated with short growing seasons. Changing planting dates is another coping strategy mentioned by farmers. Adjusting planting dates to make effective use of moisture based on rainfall variability is a smart strategy used by the Swartland wheat farmers. Based on the participants’ accounts, the optimal time to plant is between late April and early May. However, the sowing date can be smartly adjusted to early April without further delay if 10-20mm rainfall is received. This strategy also depends on the type of soil as some soils require more rainfall than others at the start of the season. A previous study has that sowing wheat crops immediately after the seasonal rainfall starts (in April) may reduce the negative impact of climate change whilst improving the yields of crop in the Mediterranean climate (Bassu et al., 2009). This practice could be very dangerous if wheat is planted early in April on enough moisture and the rain stopped for a month or two after crop germination, it could result in crop failure. Hence, the need for a near accurate weather forecast before this practice could be relied on. Less seed per hectare is mentioned as a coping strategy when there are perceived impending dry conditions. Farmers claimed that planting fewer seeds per hectare has been an effective adaptation measure when there is less moisture availability. They explained further that a suitable seed spacing has proven to produce optimum yields, under those conditions, as it enables each wheat plant to grow bigger and develop a better root system.

### 5.2.2 Soil Management

The soil management strategies mentioned by the Swartland wheat farmers include minimal tillage which helps to conserve soil structure, increase soil moisture and improve yields. Minimum tillage is a conservative cultivation practice where there is minimum amount of disturbance to soil structure, instead of turning the soil over to prepare it for the seeding. This falls under the medium to long-term adaptation strategies and conservation agriculture principles which help the farmers' current coping strategy and the long-run adaptation to drought. The introduction of cover crops is another soil management strategy implemented by farmers to reduce the impact of drought on wheat yields. Cover crops are the crops that are purposely planted to provide cover to the soil rather than to be harvested. They help to reduce moisture loss, fertilizer usage and combat weeds. It is important to plant cover crops early enough to provide the needed cover for the soil over the winter. Some of the crops used for crop rotation are also used for cover cropping. The difference between the two is that cover crops are planted along with the main crop while crop rotation are the alternative crops to the main crop. The introduction of cover crops is also an adaptation strategy based on conservative agriculture principles. Planting cover crops reduce sedimentation from cropland by capturing the kinetic energy of rainfall and decreasing runoff (Dabney et al., 2001). Cover crops improve the quality of soil by boosting the chemical, physical and biological properties such as cation exchange capacity, organic carbon content, water infiltration and aggregate stability (Dabney et al., 2001). In the Western Cape, a cover crop will have to be implemented as part of the current crop rotation plan for the winter production, due to the lack of summer rainfall (Grain SA, 2019).

## 5.3 Suggested Adaptation Options that can Potentially Reduce Drought Impacts

In regions with typical Mediterranean climates, water deficit and heat stress limit winter wheat yields production during the flowering and grain filling period and these unfavourable growing conditions are expected to worsen in future climates (Yang et al., 2019; Asseng et al., 2011; Páscoa et al., 2017; Wang et al., 2017). Farmers have implemented various on-farm coping and adaptation strategies to drought. Some of these strategies are short to long-term adaptation strategies and conservation agriculture principles which are part of the climate-smart agriculture approach. Based on the adaptation measures mentioned by farmers and those suggested by scientists, this study suggests some adaptation measures that have the potential of improving the Swartland wheat farmers' on-farm drought preparedness and resilience to the impacts of drought.

**5.3.1 Crop rotation:** Planting different crop sequentially increases farmers' profitability while avoiding any crop loss due to unpredictable environmental conditions that affect monoculture farming. Crop rotation is a medium to long-term adaptation strategy, as well as a conservative agriculture principle. It has been implemented by the Swartland wheat farmers and has proven to be an effective adaptation strategy.

**5.3.2 Crop Diversification:** Planting multiple crops helped to reduce financial losses in case of any failed crop. It also improves soil health and the resistance to environmental hazards. It also reduces the amount of fertilizer used. Diversifying crops can improve nutrient production and recycling, thereby lowering the need for fertilizer inputs, along with their associated social costs (Isbell et al., 2017). Crop diversification is a crucial component of an effective and resilient agricultural system (Hitayezu et al., 2016). Crop diversification is a medium to long-term adaptation strategy, as well as a conservation agriculture principle.

**5.3.3 Early/dry planting:** Planting on dry soil while waiting for rainfall at the beginning of the season is a strategy that helps farmers to cope with the risk of planting late and shorter growing seasons. Uncertainty and irregularity of the seasonal rainfall onset cause delay in planting as farmers usually wait for rainfall to start before they start planting. In semi-arid regions, a strategy to cope with climate uncertainty is to sow the crop before the rainy season begins. This way, when the rain starts, germination can start immediately as the seeds are already planted (Lana et al., 2018). Farmers need accurate information about the expected weather condition early in the season for a successful implementation of the strategy.

**5.3.4 Short-Growth-Season Cultivars:** This is better suited to a changing climate as the growing season gets shorter. Since the conventional weather system seems to have changed to a late start and early cessation of seasonal rainfall, using shorter growth period wheat cultivars is a potential climate change adaptation strategy. They can be planted later based on the late start of seasonal rainfall and still be harvested at the optimal time. When there is no delay to the start of seasonal rainfall, farmers prefer the long growing period cultivars as they give higher yields. Improved or accessible seasonal forecasting that accurately predicts the start of seasonal rainfall would help farmers to choose an appropriate cultivar.

**5.3.5 Reduced Tillage:** No-tillage conserves soil moisture and helps farmers to plant earlier in the season. Some wheat farmers have started using disc planters or knifepoint planters to sow seed directly into the soil without tilling the soil. By doing this, soil moisture is conserved, farmers cope better with mid-winter droughts, soil quality is improved and ultimately yield is increased. Minimum tillage should remain a robust conservation farming principle under increasing temperature and rainfall anomalies (dry climate). No-till is both a medium to long-term adaptation strategy and a conservation agriculture principle as it reduces soil degradation, erosion and weed growth.

**5.3.6 Introduction of Cover Crops:** Cover crops improves soil quality, reduce moisture loss, fertilizer usage and serve as both medium to long-term adaptation and mitigation measures. Cover crops are typically planted as a way of managing soil fertility, soil erosion, soil quality, water, weeds,diseases, pests, biodiversity, and wildlife in an agro-ecosystem (Grain SA, 2019). Some farmers may be reluctant to adopt this strategy due to the expertise required. Therefore, to promote cover crops as an adaptation and mitigation strategy to climate change, farmers' education or subsidies may be needed initially to encourage this practice (Kaye and Quemada, 2017). A cover crop is a profitable long-term investment alongside the main crop (wheat) that does not bring an immediatereturn on investment. However, cover crops can pay off in year one if used for grazing or tackling herbicide-resistant weeds.

**5.3.7 Crop Insurance:** Crop insurance protects farmers from income loss, caused by natural disasters such as droughts and floods or agricultural commodities prices decrease. Crop insurance is usually subsidized by the national government. Enrolling in crop insurance is an innovative method of risk management during severe weather events like drought. Swartland wheat farmers do not have insurance coverage on their crop since it is not available. They explained that insurance companies do not provide coverage for wheat because the financial impact of insuring wheat outweighs the risk profile. The proposed 25% Multi-Peril Crop Insurance (MPCI) premium subsidy (SAIA, 2013), which is formulated by insurers and the government for a 10-years state subsidy scheme, will greatly minimize commercial grain farmers' risk and help them cope with the impacts of drought. The proposed government subsidies may encourage both the insurance companies to provide coverage for wheat crops and farmers to take up wheat insurance.

**5.3.8 Seasonal Forecasts:** Improved seasonal forecasting could provide farmers with valuable insight into what the season will hold and how to plan their crops accordingly. Farmers want a seasonal forecast that will tell them, for example, if there will be early or late rain, cool September or not. Most forecasts give rainfall data as monthly and seasonal totals, which has limited usefulness for farmers because they can be ambiguous and often misinterpreted (Kloppers, 2014). There is a need for improved applied forecasting that will inform realistic and practical adaptive measures. Therefore, climate forecasts need to be presented in a clear and accessible manner that gives a clear insight into seasonal rainfall distribution across the months in specific regions.

## 5.4 Conclusion and Recommendations for Future Research

### 5.4.1 Summary of Key Findings

This study aimed to investigate the impact of drought on wheat yields in the Swartland region between 1994 and 2018. This was achieved by analysing the temporal variation of climate variables (rainfall and temperature) on wheat yields and using the correlation analysis to establish the relationship between these climate variables and wheat yields at different temporal scales. This study confirms that drought is one of the environmental stresses that negatively impact wheat yields in the Swartland region. It established that a negative relationship exists between dry conditions (increased temperature) and wheat yields, and a positive relationship between wet conditions (good rainfall distribution) and wheat yields, especially during the growing period (June-August).

For a potentially good yield, some rainfall must be received in April, and there must be an even distribution of adequate rainfall from June to August, with a cool September. These are the basic climatic requirements for above-average yields based on the data analysis and the participant's account. The region has experienced regular moderate to severe droughts, with the most recent severe drought recorded from 2015 to 2017. This severe drought caused a 12.6% decrease in wheat yields in 2017, due to a 32% decline in production (Grain SA, 2018). Winter rainfall in 2017 was significantly lower than the long-term average, and winter wheat production declined by 32% (Grain SA, 2018). However, some drier years recorded good yields while some wetter years recorded low yields. This is mostly due to the right amount of rainfall at the right time and perhaps the farm management practices adopted, which most often stem from the farmers' long time experience of drought anticipation and preparedness. It can be concluded that high temperature combined with low rainfall (drought) adversely affect wheat yields during every growth stage. All the temporal scales used in this study indicated that wheat requires sufficient amount of rainfall all through the growing season. However, high rainfall with cool temperatures particularly in the germination and harvest stages may cause waterlogging and disease prevalence respectively, which reduce wheat yields.

The study also identified the coping strategies adopted by farmers during drought events and suggests the adaptation options that provide the potential of improving farmers' resilience to drought. The suggested adaptation options are part of conservation and climate-smart agricultural practices, which are methods that increase productivity and improve resilience to climate change impacts. Evidence suggests that the Western Cape may face a warmer climate in the future, with a decreased rainfall expected on average (Engelbrecht et al., 2009; Otto et al., 2018; Archer et al., 2019). Therefore, adaptation measures will be more effective if there is an early warning system that allows for early detection of drought, which will improve farmers' response in a very proactive manner. Participants explained that they do not make use of seasonal climate forecasts because they are not always available or accurate and are sometimes misleading. Some of the participants explained that, based on their farming experience, they can sometimes predict if there will be a wetter winter when the temperature is above 40ºC between mid-January and mid-March. They do this by observing nature and comparing signs with the past (such as flowering) before the start of the season. An early warning system that disseminates agro-meteorological information to farmers in real-time will aid successful farming decisions during these times of climate change.

### 5.4.2 Future Research

This study did not include all the climatic factors that may affect wheat yields. Therefore, future research is recommended to broaden the scope of this study by including additional climatic factors that affect wheat production (such as soil moisture, atmospheric humidity, surface wind etc.). Investigating the impacts of these climatic factors on different types of soil is also important as soil types react differently to each climatic influence. This will improve the robustness of any future research and the information that arises from this type of analysis will be more reliable, accurate and useful and will be more beneficial to wheat farmers. Effective adaptation measures may improve wheat yield per hectare; nonetheless, wheat production may be declining due to other factors that are non-climatic such as economic factors and availability of alternative crops which influence wheat profitability in South Africa. These factors as well as climatic factors may cause wheat production to decline in the Swartland region of the Western Cape. Hence, other research could investigate the impact of economic forces of international trade and the availability of alternative crops on wheat production decline in the Swartland region. This information from the analysis could suggest further policy recommendations that will increase the financial returns of the Swartland wheat farmers without an increase in the wheat market price.

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## Appendix A

### Questionnaire

District/Town: …………………………………………………………………..

(1) How long have you been planting wheat? ............................. Years. What is your annual average yield ........................... ? (T/ha)

(2) How many hectares of wheat did you plant in the following years?

2015 …………………………………….. 2018 ……………………………….

2016 ……………………………………. 2019 ……………………………….

2017 ……………………………………. 2020 ……………………………….

(3) For the 6 years above, what is your yield (t/ha) in each year?

2015 ………………………… 2018 …………………………

2016 ………………………… 2019 …………………………

2017 …………………………. 2020 ………………………..

(4) In which of the 6 years above did drought affect your yield?

2015 ☐ 2016 ☐ 2017 ☐ 2018 ☐ 2019 ☐ 2020 ☐

(5) Have you noticed a change in rainfall pattern? If yes, can you describe it in a sentence?

……………………………………………………………………………………………

(6) Over the long term do you think drought is becoming more frequent?

……………………………………………………………………………………………

(7) Was there any indication that there would be drought in a particular year in the past 6 years? If yes, how did you know?

……………………………………………………………………………………………

(8) During a drought, what, if any, strategies did you employ?

(i) Before the drought
……………………………………………………………………………………

(ii) During the drought
……………………………………………………………………………………

(iii) After the drought
……………………………………………………………………………………

(9) Did the strategies in (8) above have any effect on your normal farming strategies on the long run? If yes, can you explain in a sentence?

………………………………………………………………………………………………

(10) What adaptation measures (responses) have been most effective to reduce the risk of drought? Kindly list all you can think of

………………………………………………………………………………………………

(11) Are there any further actions that you will take in the future to reduce your losses from the impacts of drought?

………………………………………………………………………………………………

(12) Do you carryout anyof the following activities to reduce the impacts of drought?

1. Diversification ☐ 2. Supplementary irrigation ☐ 3. Soil management ☐

4. Crop rotation ☐ 5. Changing planting date ☐ 6. Others? Please specify:

………………………………………………………………………………………………

(13) In a good year such as 2018/2019 or 2019/2020, did you recover from the losses you suffered (if any) during the drought years (2015-2017)? Kindly explain.

………………………………………………………………………………………………

(14) Can you list a few of the financial and social stresses experienced during the drought years?

………………………………………………………………………………………………

(15) Aside from climatic stresses what are the other major challenges facing wheat production?

………………………………………………………………………………………………

(16) Do you have drought insurance cover for your crop? If no, why not? If yes, did you receive an adequate pay-out covering your losses?

………………………………………………………………………………………………

(17) Do you think the government is taking necessary actions to assist wheat farmers to reduce the risk of drought? If no, what types of government assistance you think will help farmers to become more resilient to the impacts of drought?

………………………………………………………………………………………………

(18) Do you make use of seasonal climate forecasts before or during the growing season?

If yes, which forecast (s):

………………………………………………………………………………………………

If no, why not? Not sure where to access them ☐

Don't understand them ☐

Don't find them useful ☐

Other reason

……………………………………………………………………………………..

(19) What kind of information would you like a seasonal forecast to provide?

……………………………………………………………………………………………………