Drought Response Mechanisms and Adaptation: An Analysis of Strategies Adopted by Wine Grape Farmers in the Western Cape

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Abstract

This thesis examines the response mechanisms and adaptation strategies adopted by grapevine farmers to counteract the effects of the 2015-2018 Western Cape drought, which was characterised as particularly rare and severe. The challenges that emerged during the drought within the study area were exacerbated by the increasing competition over water resources between urban and agriculture users, as investment to supply water to urban users are expected to bring more economic and social value than investments in water supply for agriculture.

The study responds to the dearth of literature on climate change adaptation strategies by grapevine farmers in South Africa. Using information from 27 open-ended, face to face interviews conducted with grapevine farmers operating in the Berg River catchment area, as well as an analysis of existing economic and weather data, the research sought to understand the effects of the water stress on grapevine production, the main cause of yield loss and the key drivers of farmers' behaviour shifts.

Analysis of industry production performance from 2015 to 2018 and observed rainfall from 2015 to 2017 suggests that water stress remains the key factor influencing grapevine yields. The water stress was also found to have catalysed later ripening of red varieties, higher pH levels in the wine and the introduction of emergency pruning methods to reduce water use, which in turn led to uneven budding budding due to pruning methods, later ripening of red varieties, higher pH levels in the wine. It was also found that the depleting quality of the Berg River water led to reduced yield, as well as heightened financial and psychological stress.

The research identifies a portfolio of long-term and short-term adaptation options pursued by farmers in the study area, entailing reduced water consumption and increased water efficiency.

The research identified that the drought induced farmers to suspend or reduce plant replacement. However, this behavior cannot be explained simply as responses to climate change, but that this is linked to the low profitability of the local wine grape industry. Most farmers adopted incremental measures rather than transformative strategies, where the major barriers to transformative adaptation included uncertainty regarding climate trends, limited financial capacity for large investments, the belief in grapevine drought resilience and the cultural attachment to viticulture.

List of Acronyms

ARC: Agriculture Research Council of South Africa

BEE: Black Economic Empowerment

BFAP: Bureau for Food and Agricultural Policy

CMA: Catchment Management Area

CSA: Climate Smart Agriculture

CSAG: Climate System Analysis Group

DEA: Department of Environmental Affairs

DWA: Department of Water Affairs

DWS: Department of Water and Sanitation

ENSO: El Niño Southern Oscillation

FAO: Food and Agriculture Organisation

GCM: Global Climate Model

GDP: Gross Domestic Product

GHG: GreenHouse Gases

GVA: Gross Value Added

IPCC: The Intergovernmental Panel on Climate Change

MLD: Millions of Liters per Day

NDVI: Normalised Difference Vegetation Index

PRD: Partial Root Drying

RCP: Representative Concentration Pathways

RDI: Regulated Deficit Irrigation

SATI: South African Table Grape Institute

SAWIS: South African Wine Industry Information & Systems

SAWS: South African Weather Service

SDI: Sustained Deficit Irrigation

STATSA: Statistics South Africa

UCT: University of Cape Town

WCWSS: Western Cape Water Supply System

WMA: Water Management Area

WWA: World Weather Attribution

WWF: World Wildlife Fund

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Chapter 1: Background and Identification of Problem

Between 2015 and early 2018 the region of the South Western Cape experienced a drought characterised by chronic water shortages due to three successive below average rainfall seasons. A drought with these characteristics was defined as severe and rare for the region (Wolski, 2018; Otto et al. 2018). The city of Cape Town and the surrounding municipalities receive water from the Western Cape Water Supply System (WCWSS), which relies primarily on rainfall for its water. Hence, the drought led to a provincial water crisis that presented challenges for both urban and agricultural water consumption.

From February 2018, agricultural water allocations for irrigation were reduced drastically (DWS, 2018). Water scarcity led to a production drop in the agriculture sector, which corresponded to a consistent loss of R5,9 billion of Gross Value Added (GVA) and more than 30,000 jobs losses (Pienaar and Bonzaaier, 2018). An example of where this was most felt was the wine industry, which plays an important role in the regional economy, creating almost 200,000 jobs in the Western Cape (SAWIS, 2014). The drought revealed the sector's sensitivity to water stress, which exacerbated pre-existing challenges such as low investments and profitability in the industry.

This research documents wine grape farmers' responses to the drought and examines their strategic choices for long-term adaptation in the light of the forecasted increase of drought likelihood due to climate change (Otto et al. 2018).

This dissertation is structured as follows. Chapter 1 provides background information on the characteristics of the water crisis, its impact on the WCWSS, the agriculture sector and wine industry. Chapter 2 reviews the main literature, focusing on climate change and drought impact on wine grape farming, adaptation measures in agriculture and the wine sector and farmers' perception of climate change. Chapter 3 presents the methodology used for the research. It hence introduces the main research questions, the studied area and the questionnaire, which forms the basis of the interviews with the farmers. Chapter 4 examines the interview results. It studies the main drought impacts identified by the farmers; the implemented water-efficient farming practices; farmers' long-term adaptation strategies and the role of drought in triggering adaption behaviour. The research also explores the extent to which dependence on the Berg river for irrigation, the average rainfall during the drought and the farm size influenced farmers' responses. The final chapter provides a final analysis of the data in response to the research questions. It also provides the limitations of the study and suggestions for further research.

1.1 The Severity of the 2015-2017 Drought and the Rarity of Multi-year Droughts in the Western Cape

Drought is defined in various ways according to the sector or geographical area in which it is being examined. The South African Weather Service defines and classifies drought by comparing the dryness, severity and duration with the rainfall average in a specific area. According to Otto et al (2018) between 2015 and 2017, the area bounded by 31° and 35°S and 18° to 23°E, including the Western Cape and a part of the Northern Cape provinces, experienced a significant reduction in the rainfall level which ranged between 30 and 50 percent, confirming that there was indeed a drought.

In January 2018 the Climate System Analysis Group (CSAG) analysed the severity of the drought, using data from four rainfall stations (Vogel Vallij, Zacharashoek, Theewaterskloof, Kogel Baai) located in the WCWSS that tracked data from 1981 to 2017 (Wolski, 2018). The CSAG analysis revealed that the drought severity was not caused solely by the low rainfall level in 2017, but that it was also linked to the relative dryness of the previous two years (Fig.1). The study showed that the 2017 was the driest year since 1981.

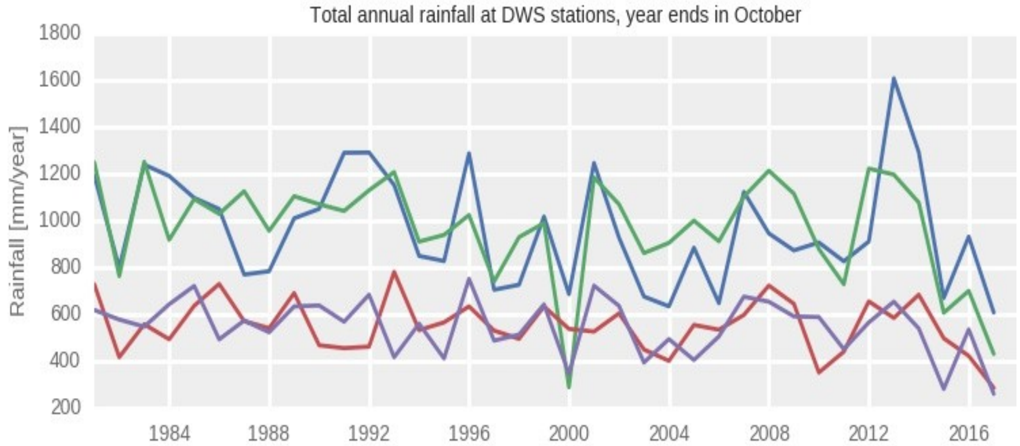


Figure 1: Total annual rainfall according to the Department of Water and Sanitation data with the year ends in October (Wolski, 2018). Unfortunately, the stations in this figure were not displayed in the source article.

The data from the South African Weather Service also confirmed these findings, showing that the 2017 rainfall level, and the average rainfall between the years 2015, 2016 and 2017 was the lowest recorded since 1933 (Wolski, 2018). The occurrence of three successive years characterised by such scarce rainfall level is very rare. In the more circumscribed area of the City of Cape Town this kind of event has a return period longer than 300 years, while in the wider area of the Western Cape a rainfall deficit of this magnitude has an occurrence of 1 over 150 years (Otto et al., 2018).

1.2 Relationship between the Drought and Climate Change.

Understanding the relationship between the drought and climate change is key to determining whether droughts will be recurrent phenomenon in South Africa's future. Drought periods may be associated with long-term climate variability phenomena such as the El Niño Southern Oscillation (ENSO). However, the University of Cape Town (UCT) Oceanography Department found a positive correlation between the 2015-2017 drought and the ENSO limited only to the areas with summer rainfall (Conradie, 2018). As El Niño large scale climate variability can only partially explain the 2015-2017 drought, climate change might be another of contributing cause of this phenomenon. The latest World Weather Attribution (WWA) study examined the correlation between anthropogenic climate change and the drought of 2015-2017 in the Western Cape. The results showed that the human influence on the climate has increased the likelihood of this occurrence approximately three-fold when compared to a scenario without climate change (Otto et al., 2018). Their analysis is based on a "standard risk" multi-method approach to extreme event attribution. These observations are based on the data collected by the eighteen weather stations that are part of the South African Weather Service which have collected data since 1930. According to the dataset analysis, the recurrence of 0.72mm/day annual mean precipitation over three years is about 150 years[1] (Otto et al., 2018). Observations were coupled with two atmosphere-lands models and two coupled climate models. The first atmosphere-land model is the UKMet Office attribution model HadGEM3-A (Christidis et al., 2013), which has a horizontal resolution close to 60km (N216), and the second one is the weather@home model (Guillod et.al, 2017). This model simulated three scenarios: first, the "actual" scenario, representing the current situation of anthropogenic Greenhouse gases (GHG) and aerosol dynamics. Second, the "natural" scenario, defining the world without anthropogenic climate change and third, reporting the characteristics of a world in which the global mean surface air temperature at the end of 2000s is 2°C above preindustrial levels. The other models are a coupled atmosphere-ocean model, which runs with a 125km resolution and a coupled Earth System Model (Otto et al., 2018).

The study also assessed how the probability of the occurrence of a drought like the 2015-2017 might change in a scenario where the global air surface temperature is 2°C higher than the pre-industrial level (Otto et al., 2018). These models predicted an increased risk by a further factor of three. Climate change increased and will further increase the likelihood of a drought event in the area as the temperature raises, along with the vulnerability and the exposure of the Western Cape Water Supply System, which mainly relies on rainfall.

Previous studies have highlighted the potential impact of climate change on Southern Africa rainfall variability. An analysis included in the 2008 IPCC assessment (IPCC, 2008) forecasted lower water capacity in South Africa as a result

[1] *This is the observed value obtained by the observational data set CRUTS 4.01 at 0.5degree horizontal resolution. The observed value is the result of the data averaged over an area included between 31-35 degree S and 18-21 degree E, over a period of three years. In this study the annual precipitation is expressed in mm/day amount, rather than the usual approach of mm/year.*

of decreasing precipitation and increasing evaporation.

The latest IPCC assessment on the impact of 1,5°C of global warming on natural and human systems reported that the western part of Southern Africa will experience the highest increase in temperature, along with dry conditions and continued drought (Engelbrecht et al., 2015; Mauré et al., 2018; Dosio, 2017). According to Mauré's analysis, precipitation changes in a scenario of 2.0°C are much more severe than those projected for the 1.5°C scenario in certain areas of Southern Africa, including the western coast of South Africa, where the precipitation reduction might reach 0.3mm per day. Mauré also found that the number of consecutive dry days are projected to increase, and the number of consecutive wet days would probably decrease (Mauré et al., 2018). The correlation between Climate Change and the drought of 2015-2017 increases the pressure on South African government to meet the Paris agreement requirements to reduce climate change risks to livelihoods, food security and development in many sectors of the South African economy.

1.3 Drought Impact on the Western Cape Water Supply.

As stated, these droughts are rare, and the South African system was unprepared. This explains why the drought became a water crisis and triggered risk management mechanisms in the Western Cape province. The WCWSS comprises fourteen dams and pipelines, which are managed by the municipality of Cape Town and the national Department of Water and Sanitation (City of Cape Town, 2018) (Fig.2). The system's water capacity mainly relies on six major dams that also serve the city of Cape Town (DWS, 2018b). Those dams are filled by rainfall run-off in the catchment area, but they also get water either from secondary streams flowing into the dams or from rainfall over the dams (DWS, 2018a).

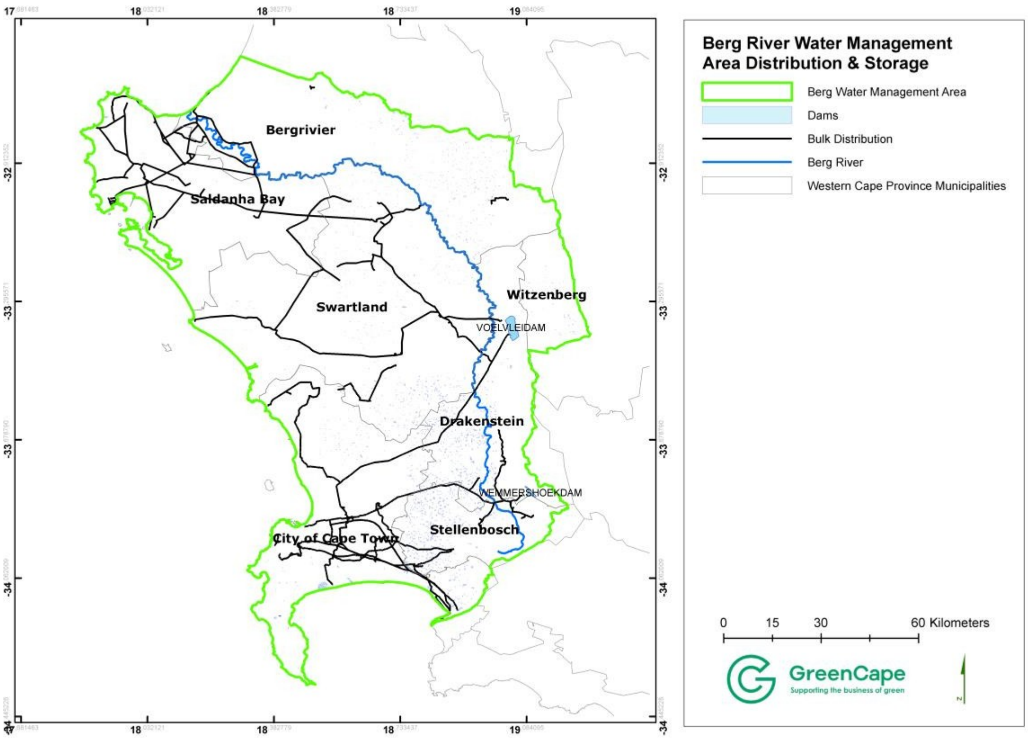


Figure 2: This map illustrates the section of the WCWSS within the study area, the Berg River Catchment Area (GreenCape, 2018).

The entire system, comprised of the City of Cape Town, farms and other urban centres, has a capacity of about 900 million m^3 and it usually meets a daily demand of about 1350 MLD. Water is supplied to domestic and industrial users via the municipality supply systems and to agricultural users via the Water Users Associations and several irrigation boards (GreenCape, 2018). Most of the water is allocated to the City of Cape Town, 29% is supplied to the agriculture sector and the remaining 7% goes to other municipalities (City of Cape Town, 2018b). The allocation data of 2014/2015 show that the water supplied by the WCWSS was already over-allocated before the 2015-2017 drought (GreenCape, 2018), thereby increasing the difficulties of dealing with eventual water shortages.

During the drought, water allocations to the City of Cape Town were prioritised and those destined for agriculture were reduced drastically. To reduce water demand, agricultural water use was restricted to 60% of its normal consumption before water supply was suspended entirely in February 2018, for those irrigation boards which had already reached their allocated quota (DWS, 2018a). As will be further discussed in the next sections, restrictions and drought had a significant impact on agriculture production and more on the agricultural economy of the Western Cape generally (Pionaar and Boonzaaier, 2018).

Scholars have attributed the lack of diversification of the Western Cape Water Supply System as one of the causes that transformed the drought into a water crisis and aggravated the challenges for water provisions in both urban and rural areas. Being based only on surface water storage, the WCWSS has a high level of exposure to climate change and variability. This is because as evaporation increases with warming temperature and rainfall are projected to be scarcer in the area (Garcia et al., 2014; Major et al., 2011; 2030 Water Resource Group, 2009; Mauré et al., 2018). Otto et al. (2018) confirmed that the recent scarcity of surface water was linked more to the rainfall scarcity than evaporation rate.

The problem has been exacerbated due to population increase, where the City of Cape Town with the partial support of the DWS, started several initiatives to augment the water-supply capacity of the area. The City responded by increased regulation of groundwater extraction and implementing water re-use strategies such as recharging processes of the Cape Flat Aquifer and treating water to drinking standards (DWS, 2018c). The national government has been criticised for its slow response to the water crisis and delayed imposition of urgent water restrictions on the agricultural sector (The Lancet Planetary Health, 2018). Thus, local government sought autonomous solutions, such as the construction of small-scale desalination plants. At the time of writing, a large-scale desalination option was still under consideration and faces difficulties related to high costs and the choice of optimal-scale (DWS c, 2018).

Besides the announced interventions to enhance the water supply capacity, the most effective measures consisted of reducing the water demand by increasing water tariffs and other conservation measures like fixing leakages, installing water management devices and tightly restricting individual water consumption. The municipality of Cape Town advanced its “Day Zero” campaign aimed at preparing the citizens for a worst-case scenario, when the taps would be turned off completely and all people would be required to fetch water from communal water sources. In the urban area, the highest level of restrictions limited the total water consumption to 50l per day per person (City of Cape Town, 2018).

While these measures were relatively successful in urban contexts (the City of Cape Town saved around 40% of the average demand and nearly 60% of the peak water usage during the summer season (DWS, 2018b)), the agriculture sector suffered.

1.4 The Agriculture Sector in the Western Cape: Importance and Sensitivity to Drought.

The agriculture sector plays an important role in both the national economy, and Western Cape province. It supported 842,000 jobs in the 3rd quarter of 2018, of which about 85% are unskilled workers (STATSA, 2018). Agriculture and agri-processing contribute to 2.5% of the value added to the country's economy and up to 3.9% of the value added to the Western Cape economy (Pienaar and Boonzaaier, 2018). Of the Western Cape's exports, 52% originates from these two sectors and agriculture remains the main employer in the region, comprising 22% of the total people employed (Pienaar and Boonzaaier, 2018).

1.4.1 Sensitivity to Meteorological Drought in South Africa.

Agricultural production is dependent on weather and climate variability, making it particularly sensitive to both drought and climate change. The 2014 IPCC assessment synthesised several findings on drought effects on Agriculture, confirming with a high level of confidence that climate change is projected to negatively affect crop yield (IPCC, 2014). Increased dry periods during the key reproductive phases, intensified winds and the increased likelihood of extreme weather events, such as drought, hail and frosts impact the sector significantly (Midgley et al., 2016). Hence, climate change will influence precipitation over South Africa, increasing thereby water demand and competition over water resources by different sectors. This will happen especially where irrigation demand is projected to increase. (GreenCape, 2017). South Africa is already a semi-arid country, with a rainfall average of around 464mm and high variety of soils and climates (GreenCape, 2017). The combination of soil and climate that is suitable for rain-fed crops is present only on the 12% of the South African territory; hence, water became the major constraint for many sectors' development (WWF, 2010).

Climate change also increases the stress on land and water resources, creating challenges for food production (Horlings and Marsdens, 2011). The latest 2018 IPCC assessment shows that communities dependent on livestock and agriculture may experience food scarcity even if the warming is limited to 1.5°C (IPCC, 2018). Thus, Walthall (2012) asserts that climate change will pose challenges to farmers' adaptive capacity as warming temperature and related dynamics influence crop distribution and production.

In 2017, a Geographical Information System analysis revealed that fruit trees in the Western Cape were under stress during crucial growing period, resulting in an estimated average production drop of 14% compared to 2015 (Pienaar and Boonzaaier, 2018). According to Pienaar and Bonzaaier (2018) this output drop might result in a reduction of R5.9 billion, in terms of Gross Value Added. Employment data from 2015, 2016 and 2017 show a drop of about 32,000 jobs, which have been linked to production decline (STATSA, 2018). The drought's impact has been amplified by other elements: economic - such as stronger national currency - and natural hazards like hail, sun burn and storms (Pienaar and Boonzaaier, 2018).

1.4.2 Hydrological Drought in the Berg River Catchment Area

The area considered for this study is the Berg River Catchment. It is one of the original nineteen Water Management areas.[1] The Berg area joined the Breede River area, which together form the Berg-Breede Catchment Management Area (CMA).

[1] The catchment areas gets its name from the Berg River that runs for 285km in the South West of the Western Cape Province (DWAF, 2004).

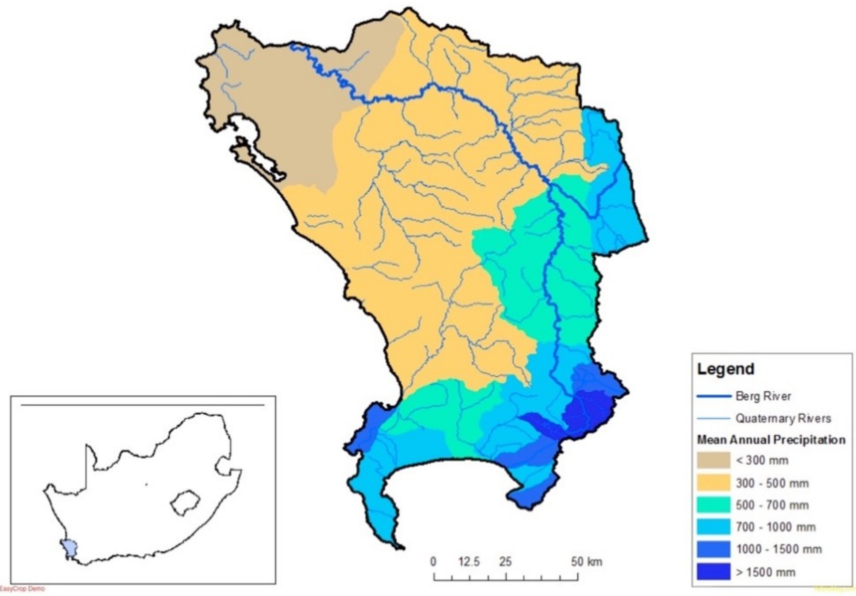


Figure 3: Mean annual precipitation in the Berg River Water Catchment Area (Cole et al., 2018).

Mean annual rainfall varies from 3000 mm in the South East area to the 300mm in the west and northwest (Cole et al., 2018) (Fig.3). The Berg WMA can be classified as a water scarce area according to the Falkenmark Indicator, which measures the flow of renewable surface and available groundwater per capita every year. This area has 193m^3 per person per year, while the national indicator is 921m^3 per person per year (Cole et al., 2018). Due to the good seasonal rainfall distribution and general annual rainfall average in the area the Berg River Water Management Area is highly utilised by competing sectors. The local supply system includes the six dams, which are part of the WCWSS. However, from 2019 the supply requirements will outstrip the system provisions and the area will require an additional 45% of water by 2040 (GreenCape, 2018)[2]. Even if the Voelvlei dam augmentation scheme is expected to be fully operational in 2021, the system will remain over-allocated. This future water constraint is expected to cost to the region R146 billion and almost R650 millions of jobs per year by 2040 (GreenCape, 2018)[2].

The same report calculated that the value added by the city of Cape Town and the opportunity cost of the water-supply deficit in the city will exceed those of any other municipalities. Therefore, many of the water supply enhancement works will focus on expanding the provisions for the city of Cape Town. It predicts that

[2] The projection of the future water demand used in the Green cape study considered the results of several climate change models and population growth projections

urban water users will be prioritised over agriculture users. The same study calculated that “1m^3 of agricultural water will add significantly less economic and social value than the non-agriculture water” for the region. This focus on city supply water will be detrimental to local economies that rely on agriculture, such as Drakenstein, Swartland, Bergriver and Stellenbosch, where instead agricultural water has significant economic and social impacts. For Cole et al. (2018), creating jobs with low dependence on water could become an important adaptation measure, considered the increased likelihood of drought in the future. The issue is that agriculture uses the highest proportion of water from the Berg WMA and is also the sector that employs a significant portion of the population in the rural areas (Cole et al, 2018). For this reason, adaptation strategies that consider all working people are necessary.

Irrigation in agriculture in the Berg WMA accounts for 387,650,971 m^3 of water per year (Cole et al.2018). The irrigation demand is projected to increase between 2025 and 2040 (GreenCape, 2018). Approximately 6653 large-scale commercial producers, 9480 emerging farmers and 50,000 poorer families are dependent on irrigated backyard gardening for their subsistence and will be exposed to food insecurity if the water demand gap is not filled (Pienaar and Boonzaaier, 2018). As water in the region is scarce and demand is expected to rise, improving water efficiency will be crucial for agriculture.

1.4.3 The Wine Industry in the Western Cape: Significance and Sensitivity to Climate Change and Droughts Events.

Wine grape production in South Africa is characterised by high level of variability in terms of soils, rainfall average and seasonal distribution. The map below depicts the wine grape production areas in the Western Cape, highlighting the hectares on vineyards in 2018 for each of the districts (Fig.4).

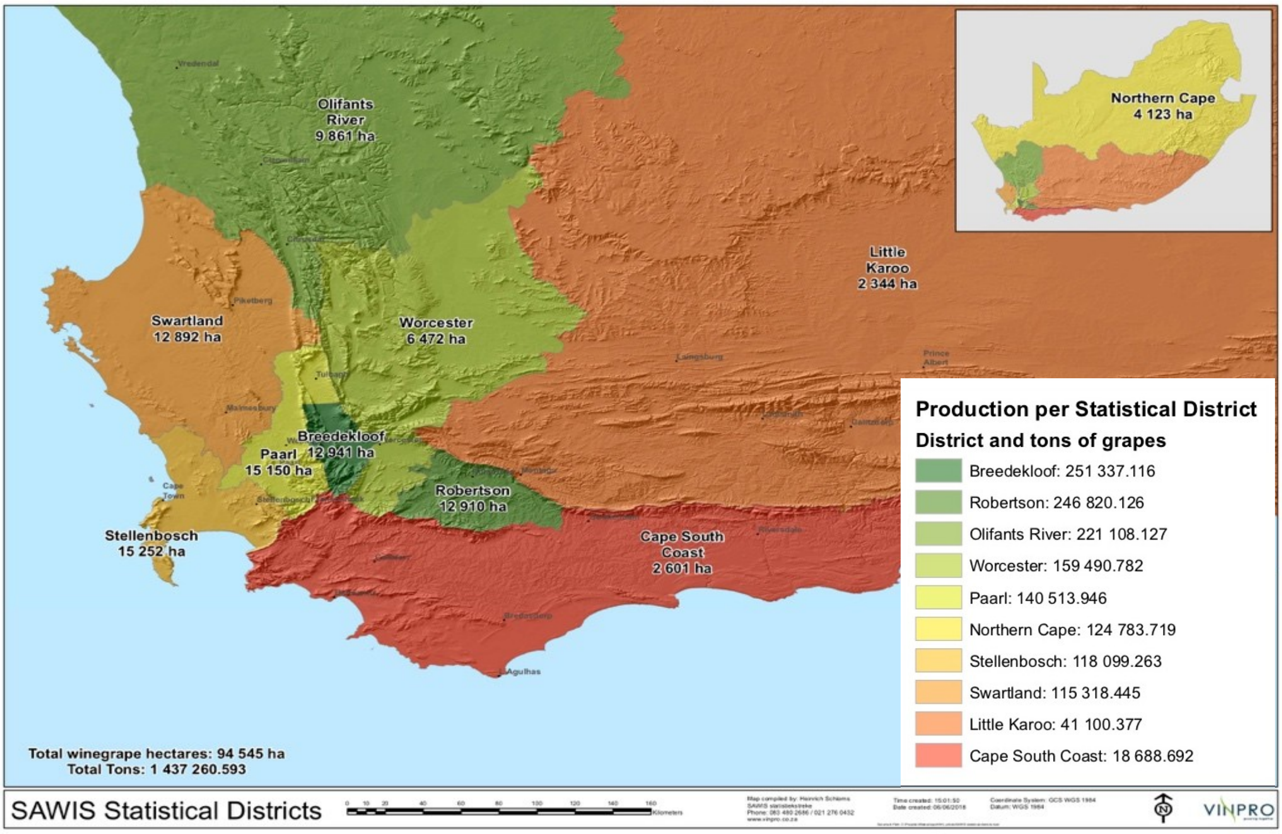


Figure 4: This map shows the districts used in SAWIS statistics, Winegrape hectares and production for each district in 2018 (SAWIS, 2018).

Wine grapes are sensitive to drought and prolonged water stress. Water deficit leads grapevines to close their stomates to minimise evapotranspiration and water loss. Plants can also decrease the process of photosynthesis, thereby reducing carbohydrate production and thus roots, shoots and fruit growth. Considering that the suggested optimal rainfall average required for growing vineyards is at 500mm of rain per year (Johnson and Robinson, 2001); most of the producing areas of the Berg River require supplementary irrigation for wine grape production (see Fig.3).

Determining grapevines' water requirements and the right amount of irrigation is complex, as it depends on many factors, such as soil characteristics, climate, the age of the grapevines, grapevine density, rootstock types, roots depth and the presence of cover crops. Water requirements also change according to the desired fruit quality and wine style. This makes it difficult to identify a standard requirement. Nonetheless, one of the most used methods to estimate grapevine water requirements is based on the calculation of the grapevine evapotranspiration through the Penman-Montheith equation (Allen et al. 1998; GreenCape, 2018). The equation relates evapotranspiration of the grapevines (ETc) with the quantity of grass water loss in a specific period (ETo) and a coefficient specific for each crop (Kc):

$$ETc = Kc \times ETo$$

The specific coefficient for wine grape (Kc) depends on the seasonal growth stage, the trellis system and partially from soil evaporation (Bueno-Delgado, 2017; GreenCape, 2018). The difference between the evapotranspiration and the effective rainfall over the same period is the amount of moisture deficit that should be compensated for via irrigation.

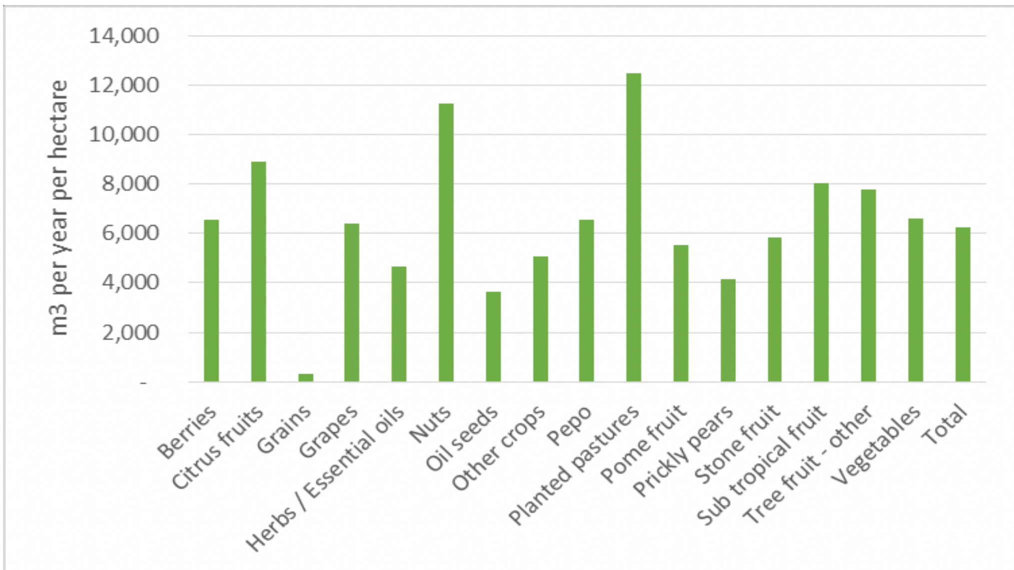


Figure 5: This chart shows different crop water requirement per hectare per year. The water requirement is calculated based on the crop evapotranspiration (GreenCape, 2018).

The GreenCape association reported that grape farms consume around 79% of the irrigation water in the Berg River catchment and will require an additional 34% of water by 2025 (GreenCape, 2018). However, the average water requirement per hectare (Fig.5) shows that grapevines have an average water requirement which varies according to the different climates across the region. The map below (Fig.6) shows that in certain municipalities, such as Bergriver, Swartland, and Witzenberg, a switch towards more water efficient crops would be desirable.

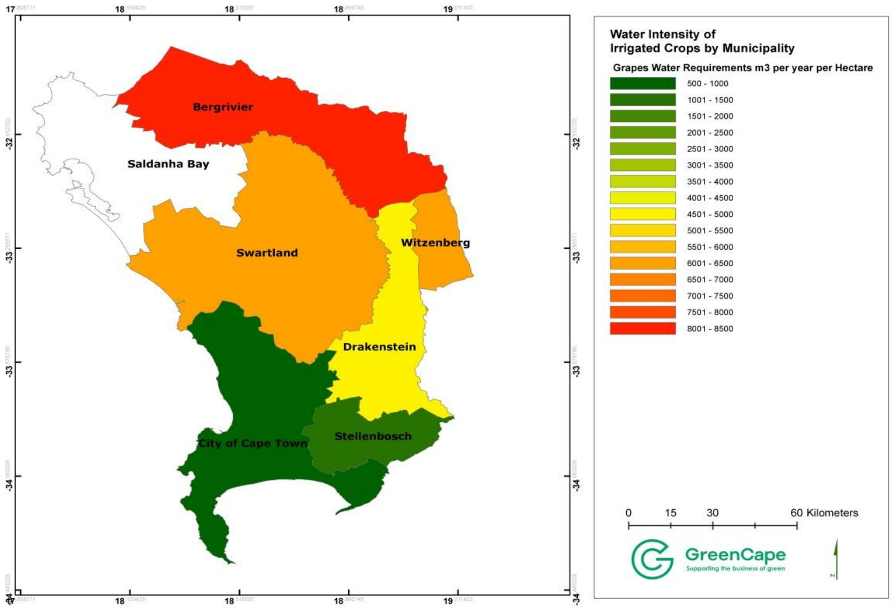


Figure 6: The map shows the grape water intensity in each of the municipalities of the Berg WMA (GreenCape, 2018)

It should be noted that the data provided by GreenCape refers to grape farms in general and does not distinguish between wine grape and table grape. The distinction is important as the wine grape industry can better tolerate smaller grape berries with less water content, as the fruits are not subject to export standards and the quality of the wine might benefit from a reduced dimension of the berries (Bonfante et al., 2014).

Wine grape has been found to be a drought-resistant high-value crop. Charrier et al. (2018) conducted long-term observations in two of the most important wine producing areas: the Napa region in California and the Bordeaux region in France. Their research concluded that wine grape never passed the lethal threshold defined on the basis of plants' water-potential, during seasonal drought.

The authors observed that different varieties of *Vitis Vitifera* did not show significant differences in hydraulic vulnerabilities and the plants were able to maintain an important hydraulic safety margin during seasonal stress. The authors concluded that even though plants have a high rate of leaf mortality and crop loss during extreme drought, “severe drought induced embolism seems to be uncommon for grapevine” (Charrier et al., 2018, p. 5).

Therefore, wine grape is sensitive to very high temperature, severe water scarcity (especially during flowering and berry-set), heavy rainfall, frost, hail sun-burn and CO_2 levels (SmartAgri, 2018). Climate variations might alter the characteristics of the terroirs from which the identity of the wine originates (SmartAgri, 2018). However, wine grapevines can benefit from mild drought periods in terms of quality (Bonfante et al., 2014) and are resistant to seasonal drought (Charrier et al., 2018). As mentioned, research shows that the optimal area for viticulture in the Cape region might decrease in the future and climate change could lead to an increase in water and irrigation demand, due to the higher evapotranspiration, higher rainfall variability and scarcity (SmartAgri, 2018).

1.4.4 Socioeconomic Trends in Wine Grape Industry: Pre-and Post- Drought

The wine industry contributed to R36.145 million to the South African GDP in 2013, amounting to 1.2% of the annual GDP (SAWIS, 2014). About 53% of the GDP produced by the wine industry remained in the Western Cape province. Moreover, wine industry is estimated to create around 289,151 employment opportunities at the national level, of which 55.6% unskilled jobs, 29.3% semi-skilled and 15% skilled jobs. In the Western Cape, the wine industry employs 167,494 people (SAWIS, 2014). Grapes also have the highest rate of jobs per hectare, compared to other crops in the region (GreenCape, 2018).

However, the 2018 Bureau for Food and Agriculture Policy report states that the wine industry is facing numerous challenges, both in the short and the long term. Some of the events that have a negative influence in the short term are the 2015-2017 drought and the increase in indirect taxes, while on the positive side a lower production in other wine producing countries might have facilitated the SA export in the short term (BFAP, 2018). The 2015-2017 drought had a clear negative effect on wine grape production. The Normalised Difference Vegetation Index (NDVI[3]) calculated by Pienaar and Boonzaaier reveals that the average NDVI for wine grape declined by 13.7% from 2015. In 2017, the tons of grape crushed were about 30,000 less than 2015 and in 2018 the tons of grapes harvested decreased by 14% compared to 2017 (SAWIS, 2017). However, if we look at the wine grape production in the medium term, the output level of 2017 is still higher than the average. The industry scored three years of production peaks from 2013 to 2015, which makes the 2017 level higher than all prior levels to 2013 (Fig.7). These effects of the drought are evident from the 2018 harvest affected by prolonged water scarcity from the three previous years and water restrictions applied at the beginning of 2018, which limited water availability for irrigation.

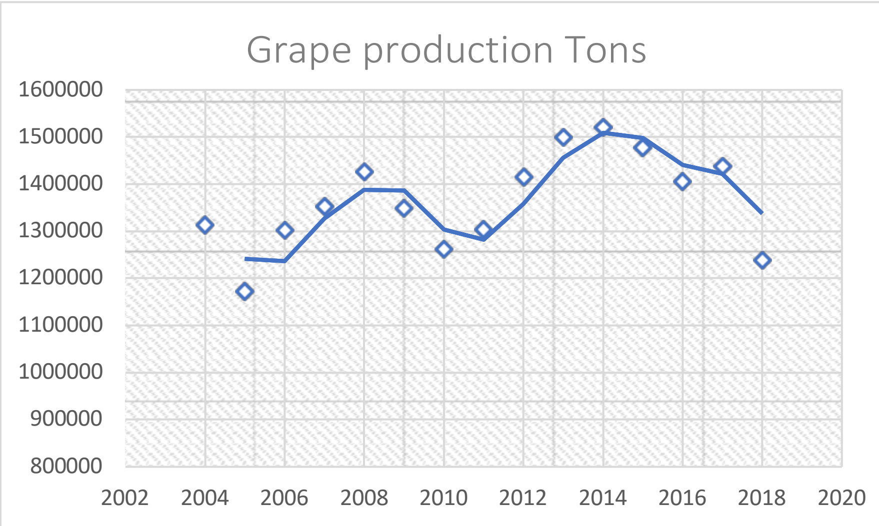


Figure 7: Grape production expressed in Tons from 2004 to 2017 (SAWIS, 2017).

Besides the immediate effects of the drought, the industry in South Africa is showing several signs of long-term structural decline, such as the reduction in primary grape producers, the decline in number of hectares dedicated to wine grapevines and number of grapevines planted.

The number of primary grape producers has been in decline for some time. In 2005, there were 4360 producers and in 2017 they were down to 3029 (SAWIS, 2017). Hectares dedicated to grapevines also constantly declined from 101,957

[3] *NDVI is Normalized Vegetation Index and it is a measure of vegetation greenness. Reduced greenness means lower leaf area or greenness and in this case is might be a signal of grapevine growth struggle due to the drought.*

hectares in 2007 to 94,545 hectares in 2017, with a reduction of 7.3%. In addition, uprooted grapevines outweigh those planted, at least since 2007, with a peak in 2016, when uprooted grapevines were 3414 more than those planted, compared to an average difference of about 1050 in the previous five years (SAWIS, 2017) (Fig. 8). As a result, grapevines are progressively ageing and becoming more vulnerable to extreme climate events such as drought. Most white wine grapevines have more than twenty years of ageing and most of the red varieties have between sixteen and twenty years. Both red and white have the smallest number of grapevines having less than four years of ageing (SAWIS, 2017). This structural decline of the wine industry is more evident when compared to the table grape industry: the number of hectares dedicated to table grape farming grew during the three years of drought. They increased from 18,212 hectares in 2015 to 21,067 hectares in 2017 (SATI, 2018).

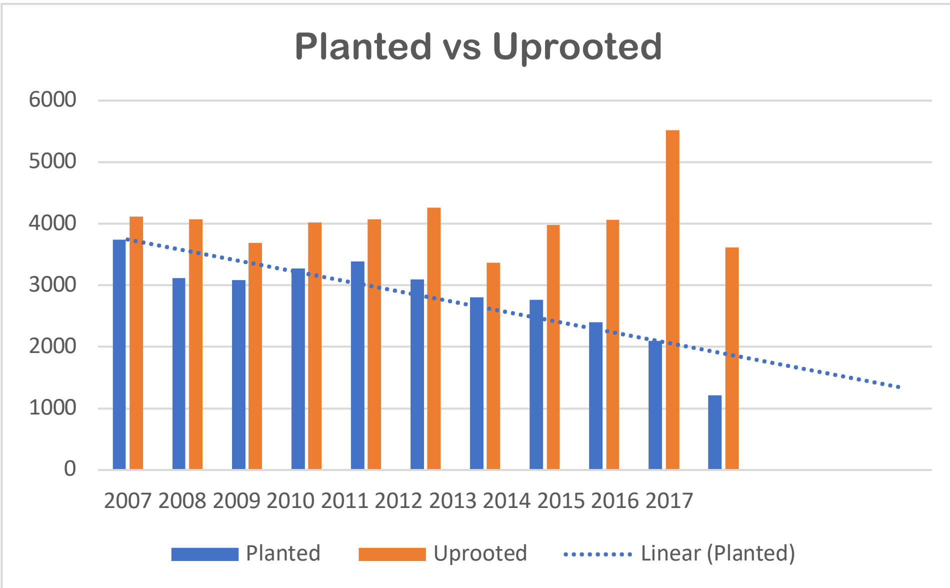


Figure 8: Comparison of the number of grapevines uprooted and those planted from 2007 to 2017 (SAWIS, 2017)

The same picture emerges when looking at the producers' income (Fig.9). Even if the export value, the domestic sales and the average producers' income increased from 2015, so did average production costs (SAWIS, 2017). The SAWIS analysis of 2017 shows that the index of the average producers' income is increasing less than the index of average producers' costs. According to Rico Basson from Vinpro, the price of South African wines has to change to make the industry economically and financially sustainable.

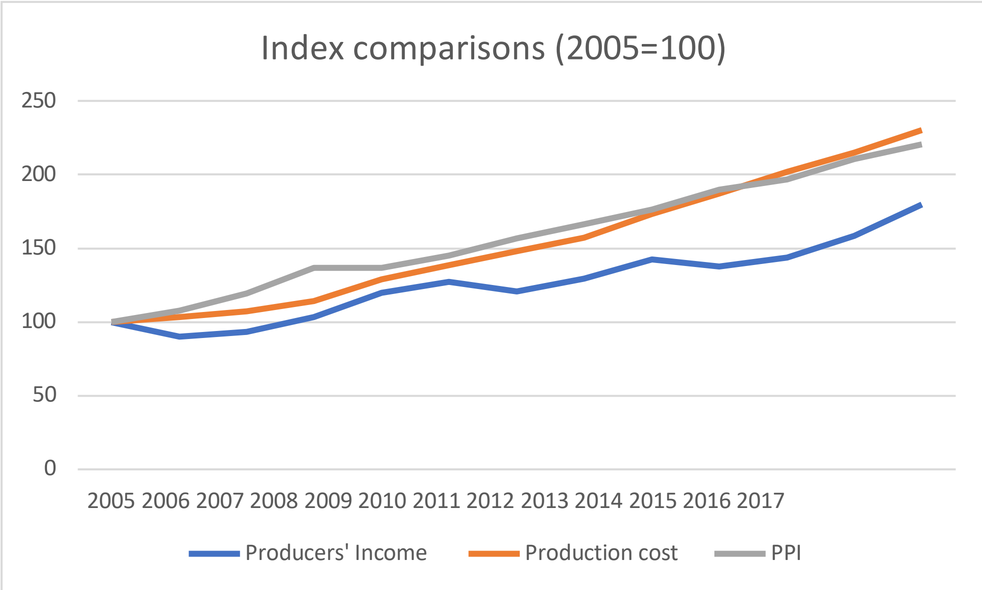


Figure 9: Comparisons of the Producers' income Index, the Production cost Index and the Producer Price Index. The Index calculation is based on the 2005 value: 2005=100 (SAWIS, 2017).

Currently only 14% of the wine grape farmers are sustainable and the price should increase by about 30% in order to ensure the industry sustainability (DGB, 2018). The wine industry has a return on investment of only 1% and more than a third of the producers operate at a loss (VinPro (a), 2018). The sector's low profitability might be an important factor at the origin of the industry structural decline (DGB, 2018). According to the Provincial Government, investments are now directed to crops with higher market value, such as citrus, berries, sub-tropical and nuts (Provincial Treasury, 2018; Pienaar and Boonzaaier, 2018).

Therefore, the production drop of wine grape experienced during the drought of 2015-2017 enhanced pre-existing structural challenges of the industry, thereby highlighting its sensitivity to this climate extreme event.

Chapter 2: Literature Review

To provide the context for this study, previous work on impacts and adaptation to climate variability in the wine sector is reviewed. The review covers four main topics: climate change and drought impact on the wine grape sector; climate change and drought adaptation strategies in agriculture; climate change and drought adaptation strategies in the wine sector; and farmers' perceptions of climate change.

Literature concerning climate change effects on the wine sector only recently received scholarly attention, and adaptation measures implemented in wine grape farming are yet to be properly investigated (Mozell and Thach, 2014; Palliotti et al. 2014; Pickering et al.2015; Neethling, 2016; Sacchelli et al. 2016;). Studies looking at climate change impact on the wine sector tend to be focused on winemaking production and on general sustainability issues (Sacchelli et al., 2016).

2.1 Climate Change and Drought Impact on the Wine Grape Sector

2.1.1 Climate Variability Impact: Heat and Water Stress

Climate variability can cause a considerable impact on wine production, from floods and frost to heat and water stress. The literature shows that the climate impact on wine grape cultivation is highly complex (Hunter and Myburgh, 2001; Hunter and Bonnardot, 2002; Deloire et al. 2005; Hunter et al. 2010; Hunter and Bonnardot, 2011a, 2012; Lecamus and Sova, 2018). Wine farming involves climate and soil variations at a very small scale, while climate and crop models are still inadequate to correctly capture microclimates (Bonnardot et al. 2011a, 2012; Lecamus and Sova, 2018).

In fact, wine style and grape quality are influenced by terroir, a term that includes all the elements that constitute the vineyard environment such as climate, type of soil, grapevine training and location, pruning, planting density and even traditions and cultural environment (Van Leeuwen et al. 2004; Deloire et al., 2005; Carey et al., 2008). Soil is a key element of terroir as it shapes the grape through its chemical and physical contents (Van Leeuwen et al. 2004; Carey et al., 2008; Poni et al.2017). The relationship between the type of soil and the fruit is still debated; however, Van Leeuwen et al. (2004) observed that the soil type can affect berry weight, sugar and the colour of grape berries. This and other studies (Pomerol, 1989; Gladstones, 1992; Poni et al. 2017) show that the soil's physical characteristics have a stronger influence in grape quality than chemicals.

Furthermore, anthropogenic climate change impact is narrowly context-specific, and, in some cases, it might bring to the industry more benefits than risks (Mozell and Thach, 2014; De Salvo et al., 2015). For this reason, the literature examined below focuses on the main climate variables aggravated by climate change in climates similar to the Berg river area: heat stress and water stress. The impacts of these climate variabilities on wine grape production are summarised in Table 1.

Table 1 Impact of Heat and Water Stress on Wine Grape according to literature.

CLIMATE/WEATHER VARIABLE	IMPACT	REFERENCES
Heat stress	Earlier bloom	Paliotti et al., 2014; Kelller, 2010
	Earlier veraison	Paliotti et al., 2014; Keller, 2010
	Faster grape ripening	Paliotti et al., 2014; Webb et al., 2012; Keller, 2010; Carey et al., 2008; Fürer 2006;
	Higher sugar and alcohol concentration	Paliotti et al., 2014; Keller, 2010; Mira de Orduña, 2010; Webb et al., 2012; Hunter and Bonnardot, 2011.
	Higher level of pH and subsequent higher instability in the fermentation process	Paliotti et al., 2014; Keller, 2010.
	Possible negative effect on wine aroma	Jones 2005; Fisher and Noble, 1994; Paliotti et al., 2014; Keller, 2010; Schultz, 2010; Mira de Orduña, 2010; Hunter et al., 2010; Webb et al., 2012
	Sun burnt berries	Paliotti et al., 2014
	Higher likelihood of pests/diseases	Mozell and Thach, 2014
Water stress	Earlier bloom	Ramos, 2017; Castex et al., 2015; Carey, 2005.
	Earlier veraison	Ramos, 2017; Castex et al., 2015; Carey, 2005.
	Reduced berries size	Ojeda et al. 2001; Van Leeuwen, 2009; Myburgh, 2011; Charrier et al., 2014
	Reduced shoot grows	Deloire et al., 2005; Van Leeuwen, 2009; Charrier et al., 2014
	Faster ripening, for mild water stress	Castex et al., 2015; Ramos, 2017; Van Leeuwen, 2009; Webb et al., 2012
	Reduced shoot development and unripen fruit, for severe water stress	Pickering et al., 2015
	Enhanced grape quality when water stress is mild	Van Leeuwen, 2009; Myburgh, 2015; Bonfante, 2014
	Yield reduction	Myburgh 2011, 2015; Hunter and Bonnardot 2011; Lereboullet et al., 2014; Webb et al., 2012; Ziergovel et al., 2014

The most common impact of these two stresses is the alteration of wine grape phenology. This is because warming temperatures (Fürer, 2006; Carey et al., 2008; Keller, 2010; Webb et al., 2012; Paliotti et al., 2014; Southey, 2017) and low moisture in the soil (Carey, 2005; Van Leeuwen, 2009; Webb et al., 2012; Castex et al., 2015; Ramos, 2017) modify the timing of growth stages, like earlier flowering, earlier ripening onset (known as "veraison" phase) and faster grape ripening process.

Heat stress and fast ripening are also associated with a higher concentration of sugar and a subsequent higher degree of alcohol production during fermentation (Keller, 2010; Mira de Orduña, 2010; Hunter and Bonnardot, 2011; Webb et al., 2012; Paliotti et al., 2014). Higher levels of alcohol can be problematic for the industry as national laws provide specific standards for the range of alcoholic content in table wine and consumers seem to prefer wines with lower alcoholic content (Paliotti et al., 2014). Higher temperatures also affect the berries' acid and pH balance: acid decreases and pH is found to be excessively high, requiring intervention during the winemaking phase, such as adding tartaric acid to limit microbiological unpredictability during fermentation (Keller, 2010; Paliotti et al., 2014).

All these elements influence the final wine style and aroma (Jones, 2005; Hunter et al. 2010; Keller, 2010; Schultz, 2010; Mira de Orduña, 2010; Webb et al., 2012; Paliotti et al., 2014), as the temperature and the timing of the growth phases influence the berries' biochemical composition (Jones, 2005). For example, the presence of ethanol might accentuate the sweet and bitter flavours and decrease the salty, acidic and sour notes of the aroma (Fisher and Noble, 1994). Another element connected to warmer temperature and increased humidity is the proliferation of new pests and insects (Mozell and Thach, 2014).

Water stress and drought are generally less examined in the literature. However, South African academics, for example Hunter and Myburgh, produced many researches on water management, as local climate is characterized by low average rainfall and the sector is subsequently dependent on irrigation. In these studies, it is found that a typical effect of limited water availability is the reduced size of grape berries (Van Leeuwen, 2009; Myburgh 2011; Charrier et al., 2014). Ojeda et al. (2001) found that water stress might irreversibly affects berries' cell enlargement, if it occurs between the flowering and veraison. On the contrary any effects linked to water stress in the post-veraison period might be reversible as berries' cells have more plasticity. According to Van Leeuwen (2009) Bonfante (2014) and Myburgh (2015), reduced size of berries can be positive for wine quality, especially for red varieties.

Similarly, a study conducted in the Aglianico producing region in Italy shows that grape quality is highly correlated with the Crop Water Stress Index, for levels of mild water stress (Bonfante, 2014). However, drought and low levels of soil moisture are generally associated with negative effects on grape yield, both due to reduced berry size and difficulties in photosynthetic process (Hunter and Bonnardot 2011; Myburgh, 2011, 2015; Webb et al., 2012; Lereboullet et al., 2014; Ziergovel et al., 2014; Pickering et al., 2015). Water stress can also negatively affect the level of pH, leading to an eccessive pH increase, especially during ripening phases (Hunter and Myburgh, 2001). Nonetheless, wine grapevines are suitable for dry climates. Charrier et al. (2018) found that the drought-induced mortality threshold in stems and leaves is never reached during seasonal droughts in the Napa (California) and Bordeaux (France) areas, affirming that wine grapevines are generally drought-resistant.

2.1.2 Climate Change Impact on Wine Grape Production

As stated above, Mediterranean climate is ideal for wine production, as it is characterised by warm and dry summers with cool and wet winters (Jones, 2005; SmartAgri, 2017). However, climate change-induced heat and water stress might challenge wine production in these areas (Carey, 2005; Jones, 2005; Van Leeuwen, 2009; Keller et al., 2010; Mira de Orduña, 2010; Bonnardot et al. 2011b; Moriondo et al., 2011; Lallanilla, 2011; Webb et al., 2012; Hannah et al., 2013; Lereboullet et al., 2014; Mozell and Thatch, 2014; Paliotti et al., 2014; Castex et al., 2015). Webb et al. (2012) highlighted the importance of attribution studies, linking biological system to anthropogenic climate changes to develop targeted and effective adaptation strategies.

The literature mainly identifies the following climate change impacts: shifting of the wine grape production areas, alteration in wine phenology and quality, potential yield reduction, increase in pest and diseases and changes in cultivar distribution. These impacts are summarised in the table below (Table 2)

Table 2 Climate change impacts on wine grape production according to literature.

CLIMATE CHANGE IMPACT	REASONS OF THE IMPACT	REFERENCES
Shifting of the wine grape production areas	Alteration in rainfall variability; global circulation cyclones shifted northpoles; warming temperature.	Carey 2005; Jones, 2005; Bonnardot et al., 2011b; Moriondo et al., 2011; Lallanilla, 2011; Hannah et al., 2013; Mozell and Thatch, 2014
Alteration in wine phenology phases	Warming temperature; decrease in glaciers volume and subsequent lower water availability;	Paliotti et al., 2014; Keller, 2010; Castex et al., 2015; Webb et al., 2012;
Alteration in wine quality	Higher CO_2 level, warming temperature, decrease in acidity, higher level of alcohol	Paliotti et al., 2014; Schultz, 2010; Mira de Orduna, 2010
Yield reduction	Lower soil moisture. Decrease in rainfall in Mediterranean climate.	Fraga et al., 2014; Lereboullet et al., 2014; Van Leeuwen, 2009; Webb et al., 2012
Increase in pest diseases	Higher temperature will push insects' upper temperature thresholds towards the pole, making them survive in some producing areas, where they are generally unusual.	Mozell and Thatch, 2014
Changes in cultivar distribution	Because of heat and water stress linked to climate change.	Mozell and Thatch, 2014; Moriondo et al., 2011
Increased demand for irrigation	Rainfall variabilities; warming temperatures	Carter, 2006; Hannah et al., 2013; Ramos et al., 2008; GreenCape, 2018; Castex et al., 2015

Climate change might cause a shift in the wine grape growing region and lead to increased challenges for farmers who are operating close to the upper temperature threshold but may open opportunities for unusual growing regions (Carey, 2005; Jones, 2005; Bonnardot et al. 2011; Jones 2012; Mozell and Thatch, 2014; Moriondo et al., 2011; Lallanilla, 2011; Hannah et al., 2013). Jones (2006) observed that the ideal surface temperature for viticulture falls within a range of 12° and 20°C in the critical phase of plant growing. He also examined temperature changes in 27 of the main wine producing areas in the world, observing that temperatures warmed by 1.3°C between 1950 and 2000, leading to a poleward shift of the optimal temperature condition for growing grapevine (Jones, 2012).

Hunter and Bonnardot (2011) examined some climatic parameters in order to better establish the suitability of grapevine cultivation in South Africa. They selected three grapevine production areas: the Stellenbosch district for the Coastal Region; the Robertson district for the Breede River Valley and the Upington district for the Central Orange River production region. They observed hourly weather data during two key periods of grapevine cultivation: pre veraison, from November to

December, and post veraison, from January to February. They were investigating for how long each region falls in and out a series of climatic parameters required for "optimum photosynthetic activity". This optimum climatic range is defined by temperature between 25°C and 30°C, windspeed below 4m/s and a relative humidity between 60% and 70%. Besides the conditions for an "optimum photosynthetic activity" they also investigated the presence of the requirements for sugar content and organic acid levels, which are a diurnal temperature range between 25°C and 30°C, and the optimum parameter for colour and flavour, which corresponds to maximum day/night temperature difference of 15°C and 25°C. Considered all these physiological requirements, the region with the best climatic profile resulted the Coastal Region, that is the Stellenbosch district.

Bonnardot et al. (2011b) further observed climatic trends in Stellenbosch. The results showed a temperature increase of 0.02°C per year from 1967 to 2010, based on the data from the Nietvoorbij weather station. This temperature increase determined that the Stellenbosch area falls in a different region of the Winkler index, which is used to identify the most suitable cultivars and wine styles for a specific grapevine production area. Stellenbosch theoretically shifted from Region III, coinciding with red and white table wine and port, to Region IV, coinciding with dessert wine and standard quality table wine. According to Bonnardot et al. (2011b) the Winkler index should be revised because it does not consider microclimates features and climatic peculiarities of the different production regions. However, the authors stated that because of temperature increase, "a change in wine style and/or altered viticultural and oenological practices to be associated with such a shift" are certainly expected (Bonnardot et al. 2011, p. 3).

Ideal precipitation conditions for viticulture are linked to slightly dry conditions for veraison (start of the ripening) and mildly wet conditions at the beginning of the growing phase (Hunter and Myburgh, 2001; van Leeuwen et al., 2009; Myburgh 2011; Fraga et al., 2014; Myburgh, 2015). In particularly dry area such as Western Cape, irrigation plays an essential role in supplement rainfall deficit in the first part of the growing season, maintaining the necessary level of moisture and avoiding thereby excessive stress on grapevines. However, several climate models confirm that climate change will lead to subtropical regions experiencing drier climates as the Hadley circulation seems moving more poleward, resulting in more intense rainfall at northern latitudes (Hu and Fu 2007; IPCC, 2014; Reason, 2017).

Consequently, climate change may increase the likelihood of severe drought in the Western Cape (Otto el al. 2018), placing risk on the suitability of wine grape farming in some of the current producing areas, like the Olifants and the Swartland regions (GreenCape, 2018).

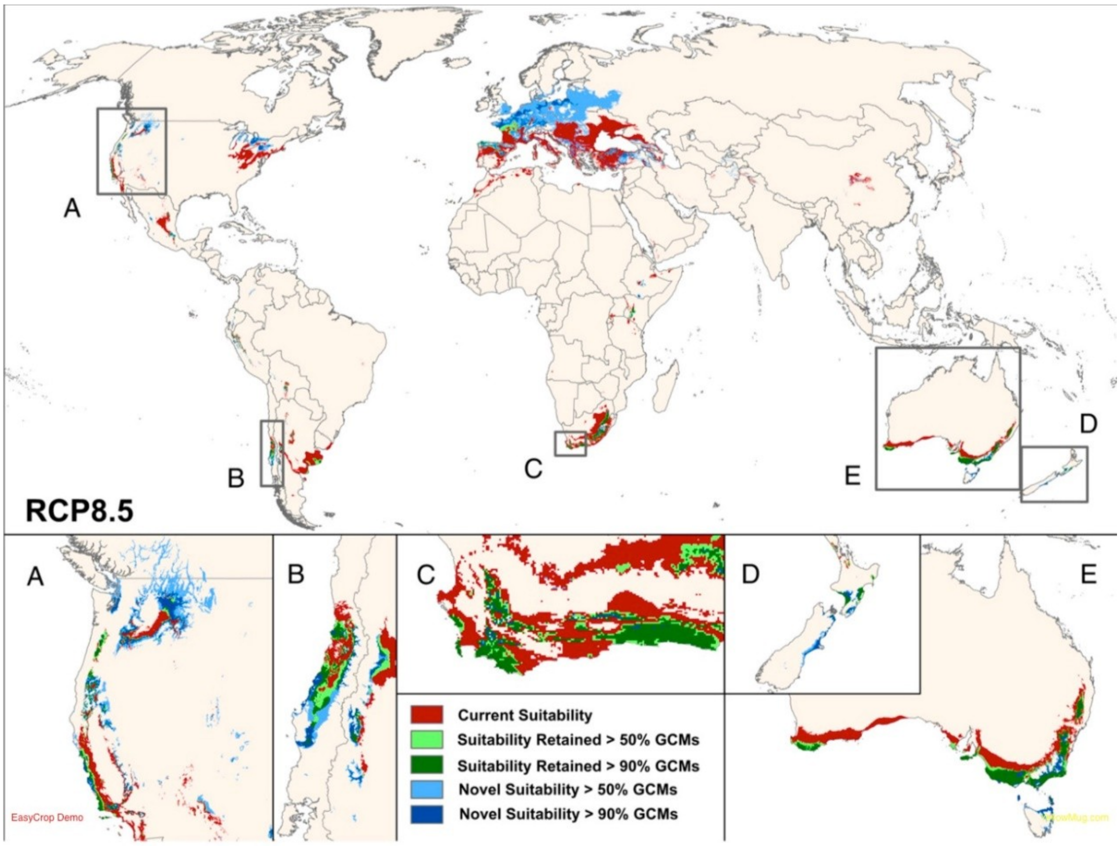


Figure 10: Global change in viticulture suitability under the Representative Concentration Pathways 8.5 (RCP) The Red areas (Fig.10) are expected to lose their current suitability by midcentury, with an agreement among GCM models higher than 50%. Light green areas are expected to retain their suitability, with an agreement higher than 50%. Dark green areas are expected to retain their suitability, with an agreement higher than 90%. Light blue areas are currently not suitable but are expected to gain suitability in the future, with an agreement among GCM models higher than 50%. Dark blue areas are expected to gain suitability, with an agreement higher than 90%. (Hannah et al., 2013)

Fig10 shows the global change in viticulture suitability under the Representative Concentration Pathways (RCP) 8.5. RCPs are projections of possible greenhouse gases concentration associated with different scenarios of GHGs emissions. These pathways were used by the IPCC in the 5th Assessment Report. Hannah et al. (2013), modelled potential global change in wine grape climatic suitability. They used the consensus of several wine grape suitability model driven by 17 Global Climate Models (GCM) under two RCPs, RCPs 4.5 and RCPs 8.5.

Hannah et al. (2013) observed that following the RCP 8.5 concentration scenario, the areas suitable for viticulture may decrease between 23% and 75% in the principal wine producing area by 2050. Following a low concentration scenario (RCP 4.5) the area may decrease between 19% and 62%. The map (Fig.10), suggests that wine grape suitability in the South African Cape will decrease in the Central Big Bay area, the internal area of the Swartland district, the Stellenbosch area and partially in the Paarl area. In brief, viticulture suitability in the Berg river region seems to decrease under a high CO_2 concentration scenario.

Hannah et al., 2013 also found that the South African Western Cape production area will experience an increase in irrigation demand and a severe impact on freshwater availability, as it has a high incidence of warming temperature, lower precipitation and pre-existing water stress. The increased demand on irrigation for wine grape production is explored by Ramos et al. (2008), who identified the relation between warming temperature and increased water demand in wine grapevines in North east Spain. Through the calculation of crop evapotranspiration, they found that a 1°C increase in temperature might correspond to an increase in water demand in the region of between 6% to 14%.

However, the results of Hannah et al.'s research were highly criticized by Van Leeuwen et al. (2013). The authors agree that new areas might become suitable for grapevine cultivation due to climate change and that global warming will entail important consequences for conservation and water availability. However, they strongly disagree on the fact that a large number of the present wine-growing regions will become unsuitable for viticulture. The suitability projections are not adequate as they are built on empirical observation collected in some of the premium wine-growing areas and they do not rely on grapevine physiological modelling. Hannah et al. (2013) did not adequately consider adaptation capacities of wine growers and grapevines, therefore they underestimated the upper limits for the cultivation of specific varieties and the production of high-quality wine.

This dispute evidenced that modelling local climate variability is utterly important for viticulture. Hannah et al. (2013) carried out a suitability assessment on a global scale, missing important details and circumstances that are only evident considering a local scale.

Even if it is not possible to affirm that the study area will become unsuitable for viticulture, important signs of changing climate have already been observed (see Introduction chapter). Research conducted in main South African grapevine production areas showed that temperature increased in the last ten years of a range between 0.5°C and 1.7°C and warming was particularly relevant during the growing season (Bonnardot and Carey, 2007; Vink et al. 2010). Frequency of extreme weather events was also observed, together with a delayed occurrence of winter rainfall (Bonnardot and Carey, 2007; Otto et al. 2018). Carter also projected a decrease in winter rainfall over Stellenbosch, Franschoek and Paarl of around 20%.

Increased temperature, less rainfall and limited water availability will characterize viticulture in the study area, requiring thereby important measures of adaptation in order to maintain grapevine cultivation suitability and the possibility to produce high quality wines.

As mentioned, heat stress and water stress can also lead to phenology and quality alteration. Thus, if the Western Cape region experiences warming temperatures and reduced precipitation this will probably change the growth timing and wine aroma (Jones, 2006, 2012; Hannah et al., 2013; Soltanzadeh et al., 2017; Otto et al., 2018). As mentioned in the previous section, grapes are altered by higher temperatures leading to different pH and acidic balance or different ethanol concentration. The aroma might be influenced by the increased level in CO_2, which is the major greenhouse gas responsible for anthropogenic warming temperature (Mira de Orduña 2010; Schultz, 2010).

A decrease in grapevine yield might be possible in those regions in which climate change is expected to induce lower precipitation and soil moisture deficits during critical growing phases (Ramos et al., 2008; Fraga et al., 2014; Lereboullet et al., 2014). According to Lereboullet et al. (2014), water scarcity during summer leading to lower yield are main stress factors for farmers in the Roussilon region in France. Another cause of water stress linked to climate change is the melting of glaciers. Castex et al. (2015) conducted specific studies regarding future water stress due to climate change's influence on the mountain cryosphere in the region of Mendoza in Argentina. They found that the glaciers' shrinking, and the severity of the ENSO climate variability may significantly impact water provisions and hence, wine grape production. Beside the climate change trend, inefficient water governance and regulation enforcement is leading to the rapid depletion of the resources, as wells are drilled illegally and water allocation can lack transparency (Castex et al., 2015).

Lastly, some studies identified increased likelihood of insect-borne diseases, such as malaria, due to rising temperatures, which push upper-temperature thresholds towards the poles (Mozell and Thatch, 2014). It is unlikely this will affect the Western Cape area, because of the drier conditions and because insects are expected to proliferate poleward as temperatures become more favourable in those areas.

2.2 Climate Change and Drought Adaptation in Agriculture

This section investigates the literature related to climate change adaptation in agriculture. This broader review includes literature on adaptation in agriculture commonly excluded from more specific literature on viticulture. An example is the general definition of incremental and transformational practices, the importance of the temporal dimension to adaptation measures and the barriers hampering its implementation.

As mentioned in the previous chapter, agriculture can be considered intrinsically sensitive to anthropogenic atmospheric changes (Banna et al., 2016). For this reason, the most recent IPCC assessment identifies agriculture as the sector which will suffer the most severe economic impact from climate change, which can also be a major driver of food insecurity (Porter et al., 2014). In order to limit damages caused by climate change, implementing adaptation is essential for the agricultural sector. The 2014 IPCC assessment included a chapter where it calculated the benefit deriving from crop adaptation measures: “the average benefit (the yield difference between the adapted and non-adapted cases) is around 15% and 18% of the current yield” (Porter et al., 2014, p.515).

Studies of climate change adaptation in agriculture often highlight the importance of understanding the *geographical context* in which adaptation options are implemented (Salman et al., 2016). Including geography means that the spatial dimension is considered in analysis. However, the temporal dimension of resilience strategies tends to be neglected. The temporal dimension seeks to understand how adaptation options have changed from before, in and after disasters such as droughts (Sun et al., 2012). Sun et al. (2012) studied both responsive mechanisms and adaptive strategies adopted by small farmers working on paddy field in southern China. The research revealed that the higher likelihood of drought occurrence pushed farmers to switch their temporal horizon, changing from short-term solutions to longer-term strategies. Therefore, priorities regarding actions to overcome the drought shifted from securing water sources to improving irrigation efficiency and diversification for long-term resilience.

The temporal aspects are significant, because climate change adaptation decisions in agriculture concern different timescales. As Nyamwanza et al. (2017, p. 117) assert, “operational crop management options” relate to a timeframe of 3 to 6 months; “tactical risk management” relates to a timeframe of6 months to 3 years; “strategical and policy planning decisions” refer to a timeframe of 3 to 20 years. The provision of more precise decadal climate information might incentivize more long-term investments and strategical planning for adaptation (Nyamwanza et al., 2017) and provide more solid evidence to support transformative measures. This could be particularly useful for perennial crops as wine grapevines.

2.2.1 Agriculture Adaptation Options

The literature demonstrates that many farmers are already adapting to climate change around the world (Fujisawa and Koyabashi, 2010; Olesen et al., 2011; Kristjanson et al., 2012; Porter et al., 2014; Ouédraogo et al., 2017). A common framework when approaching climate adaptation and resilience is Climate Smart Agriculture. Climate Smart Agriculture (CSA) aims at meeting the Sustainable Development Goals and incorporates social, economic and environmental dimensions of sustainability (FAO, 2013). Practices included in CSA concern clean and sustainable technology, farming practices for adapting to warming temperature and measures aimed at enhancing water efficiency and soil conservation. It is argued that these practices need to be tailored and applied with consideration for the context peculiarities, localised impact of climate change, as well as local policies and traditions (FAO, 2013).

The rich literature concerning adaptation in farming practices focuses on *incremental adaptation* options, which imply adjusting the system to reduce loss or enhance benefits of a change in climate (Kates et al., 2012). On the other hand, *transformational options* remain under-investigated. Transformational options require a proactive attitude, implying a radical modification and a shift in current farming processes (Porter et al., 2014; Howden et al., 2010).

Some transformative and strategic measures include farm management. Diversification of farming activities has become a common resilience strategy, which is often oriented to reducing risks (Thornton et al., 2010; Sun et al., 2012; Lei, 2016). Diversification can concern crops (Sun et al., 2012; Lei, 2016; Masupha et al., 2017), or the implementation of agriculture correlated activities, such as wine tasting, food and hospitality services (Mertz et al., 2009a; Kabir et al., 2017). In a study conducted on the rice paddy fields in China (Lei, 2016) diversification was the preferred long-term adaptation option. For example, to deal with recurrent droughts over the preceding thirty years, rice farmers decided to increase their crop diversification and thereby reduce drought risks. This strategy proved effective in reducing their vulnerability and increasing their resilience. However, it also potentially undermined grain security and general social benefit, as rice is still a staple on the Asian continent (Lei, 2016). These findings show that climate change adaptation is a complex process, which affect multiple dimensions and might have significant trade-offs.

2.2.2 Adaptation Drivers and Barriers in Agriculture

A part of the literature on climate change adaptation in agriculture concerns the factors that drive farmers' decisions to adapt and aim to inform policy related to contexts that enable adaptation. However, this area of study is still under-explored. The main drivers and barriers emerged from the reviewed literature are summarised in Table 3, here below.

Table 3 Driving factors and barriers to climate change adaptation in agriculture according to literature.

DRIVERS	REFERENCES	BARRIERS	REFERENCES
Financial capital	Long et al., 2016; Abdul-Razak and Kruse, 2017; Musetta and Barrientos 2015; Gebrehiwot and Van der Veen, 2015; Olmstead, 2014; Masupha et al., 2017	Limited access to credit	Masud et al., 2017
Access to insurance	Long et al., 2016; Cartwright et al., 2016	Limited access to markets	Masud et al., 2017
Flexible institutional arrangements	Long et al., 2016; Ziervogel et al., 2014; Hurlbert and Gupta 2016	Farm size	Masud et al., 2017; Roco 2016
Integrated turn-over and effective handover within institution	Ziervogel et al., 2014	Age	Masud et al., 2017
Integrated planning within different ministries and level of government	Ziervogel et al., 2014	Lack of capacity within institutions	Ziervogel et al., 2014
Devolution of decision-making process	Porter et al., 2014; Wood et al., 2014	Land Insecurity	Goldstein and Udry, 2008; Kepe and Hall, 2018
Participatory and local needs assessment	Sherval and Askew, 2012	Limited access to extension	Masud et al., 2017

Interdisciplinary research and knowledge	Ziervogel et al., 2014; Abdul-Razak and Kruse, 2017	Lack of experience and education	Masud et al., 2017
Access to weather information	Roco et al., 2016; Masud et al., 2017; Wood et al., 2014	Hanger and food insecurity	Shikuku et al., 2017; Kristjanson et al., 2012
Social Capital	Pelling et al., 2005; Abdul-Razak and Kruse, 2017;	Lack of a comprehensive policy on climate change adaptation	Ziervogel et al., 2014

One of the most common adaptation drivers identified is the availability of financial capital (Olmstead, 2014; Gebrehiwot and van der Veen, 2015; Pickering et al., 2015; Musetta and Barrientos 2015; Long et al., 2016; Abdul-Razak and Kruse, 2017; Masupha et al., 2017). Financing for new technologies or new infrastructure for water harvesting is essential to drive investment in adaptation (Pickering et al. 2015, Roco, 2016). This availability might be reduced by limited access to credit (FAO, 2013; Masud et al. 2017). Adaptation measures that contain heat and water stress might reduce production costs, both in the medium and long term. This reduction should be accounted for to incentivise investments in adaptation (Gebrehiwot and van der Veen, 2015). Investment capacity can be linked to age, farm size (Roco, 2016; Masud et al., 2017). Food security was also found to be important adaptation factors in research conducted across several countries in East Africa (Shikuku et al., 2017; Kristjanson et al. 2012).

Another adaptation driver that might be relevant in South African wine producing areas is land security (Goldstein and Udry, 2008), as the new land policy might require constitutional changes and the application of the principle of "land expropriation without compensation" under specific circumstances (Kepe and Hall, 2018). This reform might create uncertainty, thereby discouraging further investments in land (Goldstein and Udry, 2008).

Pickering et al. (2015) examined the main drivers influencing adaptation to climate change among eight selected determinants, namely: financial, institutional, technological, political, knowledge, perception, social capital, and diversity. Their research revealed that the most effective determinants are those related to perceptions and knowledge.

Institutional adaptation is crucial to create an enabling environment for farmers' adaptation, although this subject is relatively under-researched in literature concerning agriculture adaption. Flexibility in policy and institutional arrangements have been identified as important for being prepared for uncertainties linked to climate change (Long et al., 2016; Ziervogel et al., 2014; Hurlbert and Gupta 2016). With the view to have better informed institutions, there is a need to improve internal capacity and include traditional knowledge and assessment needs for better targeted interventions (Ziervogel et al. 2014; Sherval and Askew, 2012). In this regard, devolution of decision-making process could be useful to increase the national institutions' capacity in addressing specific local needs and priorities (Porter et al., 2014; Wood et al., 2014). Another important driver is technical and up-to-date knowledge, which include access to weather information and farmers education (Ziervogel et al., 2014; Abdul-Razak and Kruse, 2017; Roco et al., 2016; Masud et al., 2017; Wood et al., 2014).

It has been stated that an open-minded attitude, often deriving from enhanced education, is also an important driver of change. For example, Masupha et al., (2017) observed that the introduction of "unknown" maize cultivars in the Luvuhu River in South Africa, might be challenging due to farmers' traditionalist attitude. Finally, some other elements within the "social capital" (Eaking and Luers, 2006; Morse and McNamara, 2013) such as a solid social and family networks, was found to improve farmers' adaptive capacity (Abdul-Razak and Kruse, 2017). However, according to Dowd et al. (2015), strong knowledge networks facilitate the adoption of more transformational adaptation options, as they enhance the capacity and the attitude to innovate and go beyond the usual strategies proposed by usual social networks, such as friends, family and neighbouring farmers.

2.3 Climate Change, Drought and Water Shortage Adaptation in the Wine Sector

Studies about climate change impact on the wine grape sector forecast a shift in the main wine grape producing area (Jones, 2005; Jones 2012; Mozell and Thatch, 2014; Moriondo et al., 2011; Bonnardot et al. 2011; Lallanilla, 2011). However, Lecamus and Sova (2018) assert that these models may have underestimated errors in predicting small-scale microclimates and wine grape growers' capacity to adapt. Therefore, it is key to examine the literature on adaptation in wine grape farming.

Mozell and Thach (2014) provide an overview of possible solutions for the wine industry, associated with different climate change impact. They range from wind machines for counteracting cold and humidity to drones and satellite imagery to identify water stress and new pests.

Hunter and Myburgh (2001) recognise the importance of water management in South Africa, where water availability is limited. They propose diverse adaptation options to increase water efficiency, including vary agricultural practices, from site selection and soil preparation to irrigation and trellis system. The table below summarises the main adaptation options identified in the reviewed literature and highlights how the practice contributes to enhancing resilience to climate change. It also includes the aspects that might limit this contribution.

Table 4 Adaptation options to water scarcity adopted by wine grape farmers according to literature.

ADAPTATION PRACTICE	CONTRIBUTION TO CLIMATE RESILIENCE	LIMITATION	REFERENCES
Canopy management: increasing leaves and shade	Reduce the effect of rising temperature, improve the soil/water balance, therefore reduce sugars and enhance acidic contents	If too much shade: higher pyrazine levels and reduction in coloration. Increasing likelihood of pest and disease due to limited air circulation.	Mozell and Thach, 2014; Keller, 2010; FAO, 2013; Lecamus and Sova, 2018; Alonso and O'Neill, 2011; Web et al., 2012
Canopy management: decreasing the leave/fruit ratio	Reducing the effects of water stress.	Sun burn	Hunter and Myburgh, 2001; Mozell and Thach, 2014; Keller, 2010; FAO, 2013; Alonso and O'Neill, 2011; Web et al., 2012
Night-time harvesting and quick deliver to winery	Reducing the effect of rising temperature and avoid grape spoilage		Mozell and Thach, 2014; FAO, 2013
Cover crops (they could also roll on the ground at the end of the winter, having mulching effect)	Increasing soil water retention and nutrition, fighting weed water competing and decrease the likelihood of fungal growth	Fires risks, reduced absorption of day heat (higher risk of night frosts)	Hunter and Myburgh, 2001; Schultz, 2000; FAO, 2013; Mozell and Thach, 2014.

Mulching	Increasing soil water retention and nutrition	High costs	Myburgh et al. 2013; FAO, 2013
Enhanced soil structure and composition	Offsetting reduced water availability and improving soil/water balance		FAO, 2013; Lereboullet et al., 2013; Mozell and Thach, 2014
Reduce tillage	Offsetting reduced water availability and improving soil/water balance through reduced soil disturbance		FAO, 2013; Lereboullet et al., 2013; Mozell and Thach, 2014
Water recycling	Offsetting reduced water availability	High cost; Unclear regulation; Legal prohibition	Howell and Myburgh, 2018; Myburgh et al. 2015; Mulidzi et al. 2015; Mulidzi et al. 2016; Fourie et al. 2015; Howell et al 2015; Fraga et al., 2012; FAO, 2013 Mozell and Thach, 2014; Costa et al., 2016
Drip irrigation	Offsetting reduced water availability and improving soil/water balance. Reducing risk of soil salinity linked to intensive irrigation	Wine style and quality alteration.Possible yield reduction in the first years of technological change	Myburgh 2011, 2015; Hunter et al. 2014.Fraga et al., 2012; FAO, 2013; Lereboullet et al., 2013; Mozell and Thach, 2014; Fort and Walker et al., 2016.
Deficit irrigation strategies: Partial Root Drying (PRD); Sustained Deficit Irrigation (SDI); Regulated Deficit Irrigation (RDI)	Offsetting reduced water availability and improving soil/water balance. Promoting optimal grape maturity and wine quality		Myburgh 2011; Fraga et al., 2012,2014; Mozell and Thach, 2014; Costa et al., 2016.
Increased grapevine crop load	To offset the early onset of fruit maturation	If the early onset is linked to water scarcity the increased crop load could overstress the grapevine	Keller, 2010
Yield drop	Reducing the effect of water stress on the grapevine	Yield reduction	Orduña, 2010.
Strategic grapevines and row orientation	Reducing heat and excessive radiation effects		Hunter, 1998; Hunter and Volschenk, 2017; Keller, 2010; Mozell and Thach, 2014; Orduña, 2010; Webb et al., 2008; Nicholas and Durham 2012
Changing cultivars or rootstock	Offsetting changing temperatures or scarcer water	Scarcer wine quality; uncertainties regarding long term climate forecast	Deloire, 2005; Fraga et al., 2012 Mozell and Thach, 2014;

Soil probes and pressure bomb	Monitoring soil water requirements and plant water stress	High costs	Hunter and Myburgh, 2001; Mozell and Thach, 2014; Costa et al., 2016
Remote sensing	Identifying heat and water stress	High cost; lack of training	Carter, 2006; Bonnardot et al.2011; FAO, 2013; Costa et al., 2016

Many of the adaptation options against water stress which are applied in agriculture are also implemented in wine grape farming, such as mulching, cover cropping, reducing tillage, investing in water-storage facilities, improving irrigation systems, diversifying, etc. (see table above for specific references.)

Regarding adaptation practices in response to water stress in the wine industry, it is stated that irrigation, and irrigation efficiency are key adaptation strategies that may counter the drying trend of climate change (Myburgh 2011, 2015; Fraga et al., 2012; Hunter et al., 2014; Mozell and Thach, 2014; Costa et al., 2016). According to model projections, wine grape yields might decrease in the future and irrigation seems to limit this reduction (Myburgh 2011, 2015; Fraga et al., 2012, 2014). However, irrigation might alter the characteristics of local wine and increase the stress on already scarce water supplies (Myburgh 2011, 2015; Fraga et al., 2012, 2014).

Myburgh (2015) elaborated a method to estimate vineyard evapotranspiration in order to accurately estimate vineyard water use and improve irrigation water efficiency. The model needs to be applied on irrigated grapevines, or under climatic conditions where water constraints do not negatively affect grapevine physiology.

With regard to irrigation efficiency, drip irrigation has positive effects on water efficiency, when compared to sprinklers (Hunter and Myburgh, 2001; Fort and Walker et al.,2016)

However, this technological switch might result in temporary yield reduction (Fort and Walker et al.,2016). Farmers who changed from sprinklers to drip recorded a drop of production of around 64% in the first year due to reduced water supplied; while in the second year, the yield decreased only around 40%. In the following year the yield reached a stable level.

Strategies to increase water efficiency through irrigation include a soil drying and rewetting cycle that increases the plant’s efficiency in water use (Deficit

Irrigation). Another reported technique is Partial Root Drying (PRD), which increases grapevine water resistance by alternating the wet and dry parts of the root system (Mozell and Thach, 2014). Myburgh (2011) explored the impact of different drip irrigation methods on the vegetative growth, yield and quality of one Merlot variety and he compared it with vines without irrigation. The investigation was conducted in the coastal region of the Western Cape and it revealed that PRD irrigation with low frequency reduces evaporation losses and increases yield compared to non-irrigated grapevines. However, yield benefits are visible only up to 400mm of irrigation plus rainfall between bud break and the harvest; after this point, irrigation did not show any significant effect on the yield. It means that conventionally irrigated grapevines are in fact overirrigated. Furthermore, conventional irrigation and high frequency PRD negatively affected the sensorial quality of wine, while low frequency PRD did not.

Improving drainage in the field or creating a system for water recycling are also considered effective measures to limit water stress and reduce water wastage (Fraga et al. 2012; Mozell and Thach, 2014; Costa et al.2016). In this regard, South African scholars produced several studies as a response to the South African legislation requiring the improvement of wastewater usage for irrigation. The general emerging framework is that technology used to treat wastewater from winery to irrigate vineyards needs further improvement to guarantee safety in terms of nutrient toxicity and quality of the fruits (Howell and Myburgh, 2018; Myburgh et al. 2015; Mulidzi et al. 2015; Mulidzi et al. 2016; Fourie et al. 2015; Howell et al 2015). Finally, the use of technology, such as soil probes and remote sensing, increases irrigation efficiency through enhanced monitoring of grapevine stress physiology (Costa et al., 2016).

Adapting by changing agronomic practices can be classified either as reactive (if implemented as an immediate response to the impact), or anticipatory (if implemented as a result of a forecasted impact). Reactive agronomic practices applied on the field are linked to changes in pruning, harvesting time and canopy management, which consist of adjusting the fruit/leaf ratio according to the needs, i.e allowing more shade to avoid sunburn or increasing water retention in a drought period (Alonso and O'Neill, 2011; Webb et al., 2012). Another system to manage scarcer water is managing the yield by cutting down some clusters of green grapes to avoid placing stress on the plants (Mira de Orduña, 2010).

Examples of anticipatory options may be implemented earlier in the planting phase. Vineyards may be planted in a different location (Fig. 11) with a different orientation to diversify the plants' sun and wind exposure (Hunter 1998; Mira de Orduña, 2010; Webb et al., 2008; Keller, 2010; Hunter and Volschenk, 2017). For example, trellis system (Myburgh, 2015) and vine spacing (Hunter, 1998) might influence grapevine transpiration and thus plant water requirements. Farmers may also decide to plant more cultivars or rootstocks tailored to the climate (Deloire et al. 2005; Fraga et al., 2012). Nicholas and Durham (2012) observe that the most effective options for reducing vulnerability are reducing exposure by changing a vineyard's position or reducing sensitivity by changing cultivars. For example, late ripening variety planted in a cool climate will not be able to achieve the adequate maturity, whereas early ripening variety planted in a too warm climate will ripen too fast and ruin the wine aroma (Deloire, 2005).

However, those options are more difficult to implement due to the perennial character of grapevines. The extent to which more drought-resistant rootstock and cultivars are necessary should be balanced with the desired quality of the wine, the available soil and climate trends. Furthermore, changing varieties or rootstock takes much time. Grapevines require almost five years to produce fruit and generally, quality improves with the age of the grapevine. Planting cover cropping can help to control humidity in the soil and decrease the likelihood of fungal growth (Mozell and Thach, 2014).

All these strategies need an attentive assessment of the context and microclimate (see example in Fig.11) before being implemented and they often have limitations that need to be managed. For example, cover cropping can reduce the soil absorption of day heat, increasing the frosting risk during daytime, while intensive irrigation can increase soil salinity (Fort and Walker, 2016). A smaller canopy might enhance the risk of sun burnt on fruits, while a larger canopy to protect the fruit can decrease air circulation among vineyards and increase the likelihood of pests and diseases (Lecamus and Sova, 2018). As Hunter et al. 2014 affirmed that the capacity of grapevine to endure and buffer stressful conditions are the results of a combination of factors characterizing the terroir and the vineyard practices that are applied in response to the stress. Literature related to adaptation in wine grape production revealed that growing wine grapevines requires constant reactive adaptation and this concept is well summed in a common expression in the wine industry: “it takes bad vintage to judge a good winegrower” (Neethling, 2016, p. 795).

Nicholas and Durham (2012) conducted a study on farm-scale adaptation options in the wine growing region of Northern California. The study shows that farmers usually implement reactive options and if they investigate anticipatory options, these are generally short-term options. This short-term practise may not be ideal as farmers start to encounter new climate challenges.

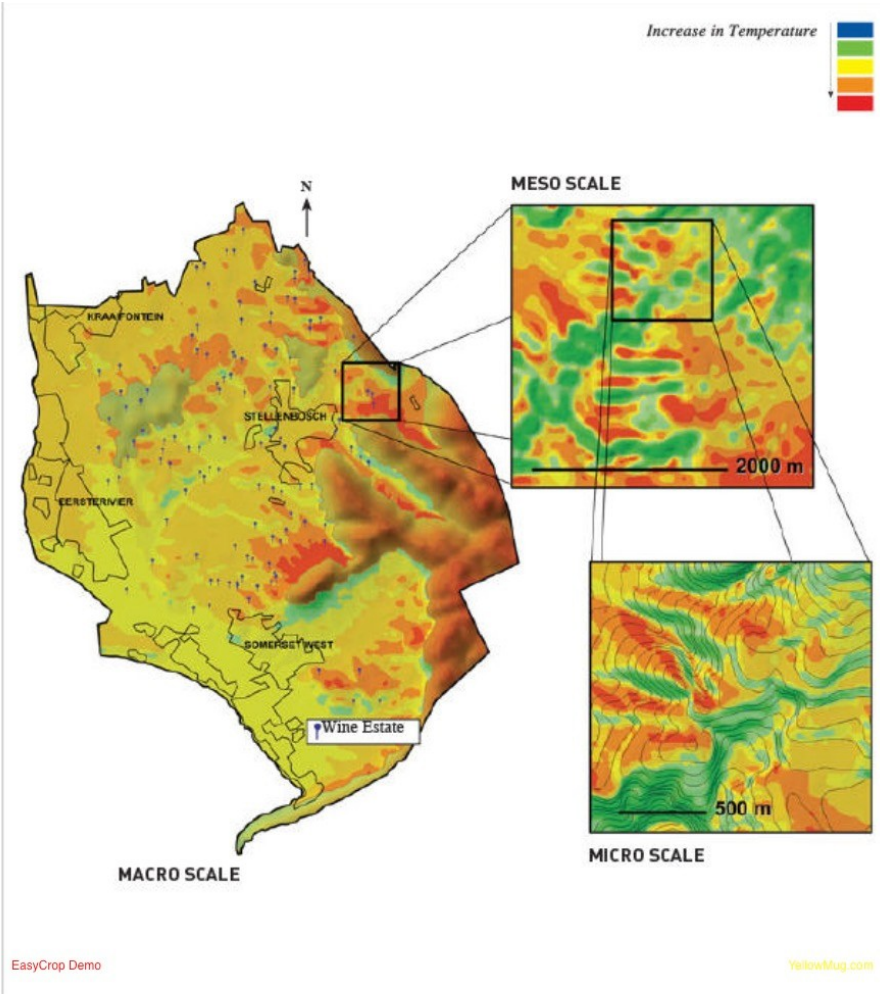


Figure 11: The map shows how computer modelling can illustrate the variation of solar radiation according to the altitude and slopeness of the vineyards (CapeWine, 2018

Fleming et al., (2015) found that the industry is adapting mainly through incremental options, such as improving water and energy efficiency.

However, considering the perennial nature of grapevines, wine growers need to also consider the longer-term perspective. Fleming et al., (2015) state that more transformational and anticipatory options are necessary, which include decisions related to farm management, such as moving the farm, diversifying the activity or changing industry. Wine growers also need to consider the longer-term perspective and consider long-term climate forecasts, as vineyards take up to five years to be fully productive and can last more than twenty years (Neethling, 2016). Lereboullet et al. (2013), argued that short term strategies will not be enough to adapt to higher temperatures and increased water scarcity in Mediterranean areas. They note that variations are going beyond the inter-annual variability.

As in agriculture, adaptation in the wine grape sector is a complex process that needs to be studied across different dimensions. As mentioned in the previous section, another aspect to consider for climate change adaptation in wine grape industry is the improvement in the social capital as an adaptive capacity. Social capital can be described as an ensemble of social cohesion attributes that can constitute a supportive network for adaptation, such as degree of cooperation, trust, inclusion and cohesion (Pickering et al., 2015). Limited access to social capital might be translated into limited access to resources for adaptation, which increases vulnerability to risk. Nicholas and Durham (2012) revealed that wine grape farmers generally look for individual adaptation strategies rather than organising and taking collective action. This “cooperation-competition nexus” is also studied in Australian wine industry by Galbreath (2015). The results show that knowledge exchanges generally occur in the same sub-region and tend to involve the local and “elite” firms.

Bernetti et al. (2013) assume a more economic and broad perspective on adaptation, by considering adaptation opportunities in the wine value chain. They identified the potential for lower quality linked to increasing temperature and the increased need for irrigation in the area of Brunello di Montalcino, in Tuscany. They predict that the drop of quality may lead to a lower revenue by the sector, which will produce the need for restructuring the value chain. Sacchelli et al (2017) investigated the drivers for adaptation, examining a case study in the wine industry. They found that economic considerations, especially price variations, deeply influence farmers decisions in taking adaptive measures. The authors also state that insurance schemes are too expensive, and they might be affordable only with low-level deductibles or supported by public funds.

2.4 Farmers' Climate Change Perception within the Wine Grape Sector.

Farmers' perception of climate change and its related risk is another interesting aspect of the research on adaptation. Several studies examine the way in which farmers' perceptions of climate change might influence their attitudes and action regarding adaptation and mitigation (Arbuckle et al., 2013; Niles et al., 2013; Niles et al., 2015; Prokopy et al., 2015). Investigating farmers' perception is key to understand potential behavioural changes and the extent to which they may support climate change policies. Perceptions of climate change and climate risk are more effective in shaping farmers' decisions than the actual climate patterns as measured by scientific methods (Adger et al., 2009; Mertz et al., 2009; Niles et al., 2016; Mase et al. 2017).

Wood et al. (2017), found that the likelihood of adopting adaptation measures is positively correlated with the degree of belief in climate change. However, other studies highlight that only a small portion of those who believe in climate change successively implement measures to counteract its negative effects (Roco, 2016). In some cases, perception can be linked to the *intention* to adapt only, and not to the practical adoption of the adaptation strategy (Niels at al., 2016).

For some, farmers' climate change risk perception is partially based on historical observations and influenced by recent climate events (Maddison, 2007; Gbetibouo, 2009; Haden et al., 2012). Research shows that climate change risk perception is higher in places where people are exposed to physical vulnerabilities linked to climate change impacts (Brody et al., 2008). The literature shows that climate change-related extreme weather events influence climate change risk perception because the immediate and tangible impacts reduce the "psychological distance" of climate change and trigger adaptation behaviour (Bar-Anan et al., 2006; Li et al., 2011; Spence et al., 2011; Haden et al., 2012; Ackerlof et al., 2013; Broomell et al., 2015). Adaptation behaviour were found to be linked more to farmers' personal interest than mitigation actions were and is therefore more likely to be triggered by extreme weather events (Haden et al.2012; Lubell et al., 2007). Haden et al. (2012) showed that water scarcity affected farmers' adaptation behaviour. They observed that water scarcity induced a preference for new irrigation measures rather than the adoption of new cropping practices, such planting more drought resistant varieties. This preference is probably linked to the potential of adaptation strategies for more immediate results.

However, there are still few studies examining and testing evidences of the causal link between experiences of extreme weather events related to climate change and subsequent adaptation behaviours (Haden et al., 2012; McDonalds et al., 2015; Brügger et al., 2016). The proximity to climate change by itself it is not enough to enhance action for climate change adaptation or mitigation (Brügger et al., 2016; Shuldt et al., 2018).

2.4 Summary

The reviewed literature has shown that:

1) Climate is an important driver of wine grape yields and quality, both globally and in the South Western Cape and list some of the key ways that climate has this effect.

2) Local industry level data show that recent drought had an impact on production and that industry is experiencing a structural decline due to the limited return on investments

3) A number of suggested climate change adaptation options to climate stress have been proposed or tested at global and at local level.

However, to date, there has not been any study of farm level response to the recent drought.

Therefor this research examines which of the reviewed heat and water stress impacts on wine grape (see Table 1), are also experienced by farmers in the study area during the recent drought. Literature on climate change highlights that the study area experienced an increase in temperature a decrease in rainfall and a long term trend of increase in extreme weather events. These changes are likely to be amplified by anthropogenic climate change. Therefore, important measures of adaptation need to be adopted and climate change projections at local and microscale are utterly important to inform adaptation decision. This research tries to understand whether interviewed farmers acknowledge the risk of more severe drought in the future, and whether they have adopted long term adaptation strategies.

Previous studies defined multiple categories of adaptation options according to their temporal dimension (Sun et al., 2012; Nyamwanza et al., 2017). This related to incremental (Kates et al., 2012) and transformative options (Porter et al., 2014; Howden et al., 2010); as well as reactive and anticipatory adaptation options. After having identified which of the reviewed adaptation options have been implemented in the study area (see Table 4), this research applies existent definitions to analyse the type of adaptation methods adopted, also focusing on long term and none-agronomic options (Nicholas and Durham, 2012; Lereboullet et al. 2013; Fleming et al.,2015; Neethling, 2016).

Finally, the research investigates whether one's proximity to and belief in climate change has triggered adapting behaviour or the implementation of adaptation strategies (Lubell et al., 2007; Adger et al., 2009; Mertz et al., 2009; Haden et al.2012; Mase et al., 2017; Wood et al., 2017); and whether the intention to adapt was actually translated into action (Brügger et al., 2016; Niels at al., 2016; Roco, 2016; Shuldt et al., 2018).

Chapter 3: Methodology

This chapter provides information about the study area, the interviewed participants, the questionnaire used to guide the interviews and the methods used to analyse the gathered data.

3.1 Study Area and Sample Selection

Data collection was conducted on a sample of 27 wine grape farms, all located in the Berg River Catchment area, as defined by the Department of Water and Sanitation. This includes the winelands located in the "Coastal region" of the wine of origin scheme (WOSA)(Fig.12).

This area was selected because it includes some of the most productive and well-known areas for wine grape production and is a highly intensive water area. (see Chapter 1). The interviews were conducted in Stellenbosch, Franschoek, Wellington, Paarl and Riebeek Kasteel.

Figure 12: This map shows the area of the Coastal Region wine of origin

The study area is characterised by a high variability of soils and rainfall average, which also determine wine characteristics and farming decisions. The table below (Table 5) sums up the average annual rainfall and the main type of soil in the study area. Table 6 highlights the main characteristics of the soil prevalent in the study area.

Table 5 Shows the soil and rainfall average of study area (Cape Wine, 2018; Fey, M., 2010)

REGION	AVERAGE ANNUAL RAINFALL	SOILS
Stellenbosch	600 – 700mm	Structure Swartland and Klapmuts; Tukulu and Oakleaf
Paarl	800 – 900mm	Structure Swartland and Klapmuts; Tukulu and Oakleaf
Wellington	700mm	Structure Swartland and Klapmuts; Stoney Glenrosa; Kroonstad
Franschhoek	800 – 1000mm	Tukulu; Oakleaf and Alluvial Dundee
Malmesbury (Swartland)	500mm	Structure Swartland and Klapmuts; Tukulu and Oakleaf

Table 6 Highlights the main characteristics of prevalent soils in the study area (Cape Wine, 2018; Fey, M., 2010)

Soils	Characteristics
Structured Swartland Stoney Gelnrosa Structured Klapmuts	Duplex soils Derived from Shale. Strongly structured. Subsoil with special characteristics and orthic topsoil Good nutrient reserve and water-retention properties.
Tukulu Oakleaf	Cumulic soils Derived from Granite. Generally found on mountain slopes and alluvial terraces. Young soil, with an orthic top soil but weakly developed subsoil. Usually red to yellow coloured. Good physical and water retention properties.
Kroonstad	Gleyic soil Subsoil with special characteristics and orthic topsoil In badly drained soil Protracted reduction in aquic subsoil or wetland
Alluvial Dundee	Derived from Table Mountain sandstone Sandy; Low nutrient and water retention property

Stellenbosch is the largest vineyard planting area in the region, followed by Paarl. The Wellington area has been defined as the “nursery of the grapevine”, as it supplies 85% of the South African wine industry with cuttings. The Franschhoek Valley has the wettest climate of the Coastal Region, while the

Swartland region has the lowest rainfall average of the area (Cape Wine, 2018). Here, many vineyards are drylands, as traditionally they do not require irrigation due to the deep granitic soil that allows good water retention. In the Swartland, the research focused on the Perderberg and the Riebeekberg areas.

3.1.1 Interview Participants

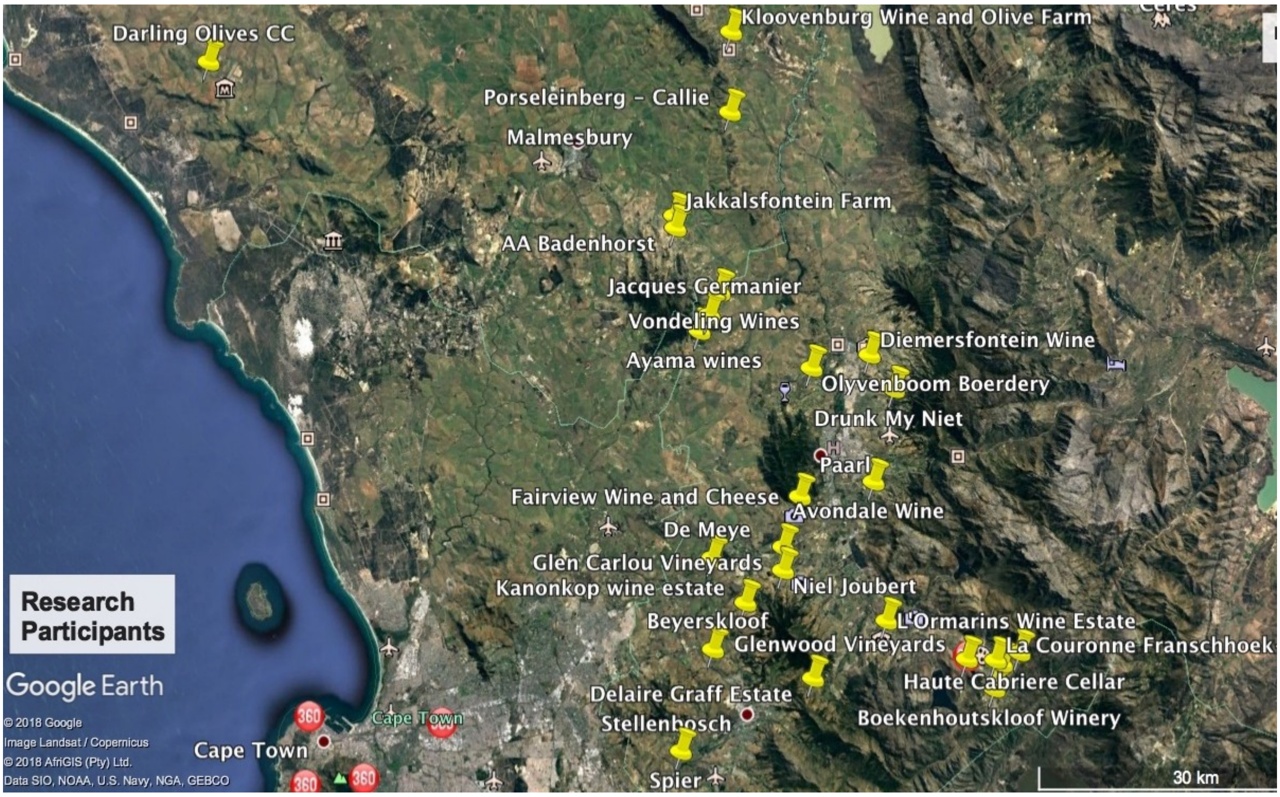


Figure 13 This map localises the farmers who participated in the research

The interview participants were 27 farmers cultivating wine grape in the selected area (see map here above). Most of the potential participants were identified by the researcher, some were recommended by other participants and some were contacted at the suggestion of VinPro. VinPro is one of the most important producer associations in the Western Cape.

All the farms fall within the “the Coastal Region” within the Berg River Catchment; however, as previously mentioned, the area has a high degree of variability of *terroirs* (temperature, soil, rainfall and management style) between farms and even sometimes even within the same farm. Therefore, when analysing the data, the study attempted to account for how results changed according to some of the farms' characteristics.

3.1.2 Questionnaire Design

The research method relied on qualitative data from face-to-face interviews with wine grape farmers in the Berg River area. Qualitative methods involve the subjective interpretation of the participants' testimonials, which are transcribed and analysed through a coding activity. Codes are used to identified themes, relations among facts and participants' perceptions (Hsieh and Shannon, 2005). Qualitative research is not about creating statistics and numerical analysis, but it is mainly about examining complexity and finding patterns and nuances (Rubi and Rubi, 2005).

This method and data were chosen because of the complexity of viticulture systems, which are affected by internal and external factors (Cilliers, 1998). The literature suggested that farmers receive feedbacks by the local climate, their plants and the socio-economic context. Hence, they are constantly learning how to adapt to maintain their essential functions and enhance their resilience. A qualitative study based on open-ended questions during interviews was the best tool to grasp this complexity.

Open-ended, rather than closed-answer survey method was preferred so that the respondent could add information spontaneously and ask for explanations. In addition, this tool allows the researcher to capture of participants' feelings and opinions.

The questionnaire was built around two main objectives: identifying a portfolio of drought adaptation options implemented by the farmers and understanding whether and how farmers changed their long-term farming strategies because of the increased likelihood of climate-change related drought.

The concept of climate change adaptation used is in line with the way it is used in the context of a developing country, where climate adaptation must occur in congruence with social and economic development. Therefore, adaptation to climate change is a complex process aimed at enhancing development chances within a changing climate (Cartwright et al., 2013). Adaptation means reducing people's vulnerabilities, reducing exposure and sensitivity, while strengthening people's adaptive capacities (Gaillard, 2010).

Besides the changes in agricultural practices operated to enhance plant water retention and farm water capacity, the questionnaire tried to investigate whether the drought affected farmers' social and financial capital and how they adapted to these stressors. Some questions were drawn from the livelihood framework assessment, which analyses people's entitlements and assets based on five types of capital: natural, social, human, physical and economic capitals (Eaking and Luers, 2006; Morse and McNamara, 2013). The questionnaire examines how farmers changed their farming practices to enhance their physical capital; how they modified their long-term farm management strategies to enhance their economic and financial capital; and how they strengthened their social networks to improve their social capital. The questionnaire aimed at identifying an adaptation options portfolio that could be used to share experience and knowledge among the wine grape farmers. The questionnaire was also designed to examine the farmers' beliefs and observations about weather and climate change and specifically, whether they believe in the anthropogenic nature of climate change.

Finally, the questionnaire sought answers to the following research questions:

1- What are the main drought impacts identified by the farmers?
2- Did the drought affect wine grape production?
3- Did farmers change their water conservation behaviour because of the drought? Is this change linked to water restrictions?
4- What are the adaptation options implemented by the farmers?
5- Did the farmers adopt more incremental or transformative adaptation strategies to the drought?
6- Did the drought trigger a shift in farming strategies?
7- How did farmers' belief in climate changes influence their long-term adaptation strategies?

The questionnaire used for the interviews is included as Appendix 1.

3.1.3 Data Analysis

All the interviews were transcribed and then analysed using NVivo 12[3].

The farms were classified according to three demographic characteristics, namely, reliance on the Berg River for irrigation (reliant or none-reliant); rainfall average over the three years of drought, 2015-2017 (over and below 500mm per year); and size of the farm (more and less than 30-40 hectares). It was observed how some of the results (production, water consumption) changed according to the farm's characteristics. A chi-square test was run to verify evidence of a relationship between the observed results and the related farm characteristics. The same test was used to identify the evidence of a relationship between farmers' climate change beliefs and the long term-adaptation strategies adopted by them.

The 'reliance on the Berg River' was chosen as a key characteristic to understand the role of water restrictions on some of the farmers' choices. The 'average rainfall' variable was chosen to indicate the link between water stress and the drought effects identified by farmers as well as to observe influence of water stress on the long-term strategies adopted.

The parameter related to rainfall level was defined based on the optimal rainfall average for grapevine cultivation (Johnson and Robinson, 2001). The rainfall information used in this research was provided by two sources. It was directly provided by the interviewed farmers who either measured rainfall on their farm or gathered it from a nearby weather station; or this information was calculated by the researcher from the rainfall measurements provided by six automatic weather stations of the South African Agriculture Research Council (ARC): Bellevue, Diemerskraal, Elsenburg Ciat, Fairview, La Motte and Stellenbosch Cordoba. The weather stations were selected for the proximity to the study area.

Identifying the parameter defining the farm size was more complex. Unfortunately, the definition of "small" farm is context-specific and highly

[3] NVivo is a qualitative data analysis tool and it helps to explore issues, organize data and find the patterns in unstructured data.

dependent on the observed industry. In this case, the farm size has been defined by dividing the range of the hectares of the sampled farms into three brackets: small, medium and big. The big and medium categories have been considered together, as the main changes related to farm size occurred between the small and the big farm (for example, capacity to implement large investments, increased diversification opportunities and availability of human resources).

The interviews were coded to identify the key concepts and themes that related to the research questions (Table 7). Most of the coding emerged during the analysis process as themes emerged, except for those codes related to production and water consumption.

Table 7 illustrates the NVivo codes which were considered for each of the research questions. It also highlights the independent variables which were applied to investigate potential related changes in one or more codes

Research questions	Researched feature	Related NVivo Codes		Applied Independent Variable (NVivo Family Case)
What are the drought impacts identified by the participants? Did the drought affect the production? Did farmers change their water conservation behaviour because of the drought? Is this change linked to water restrictions?	Drought impacts	Changes in harvesting calendar (Early harvest, Late Harvest, Impossible to say)		
		Changes in crop quality (Worse, Better)		Rainfall average
		Changes in crop Yield (Decrease, Increase, Steady)		Size, Rainfall average, Reliance on the BR
		Employment (Cut, None)		
		Psychological stress		
		Changes in water consumption (increased, reduced)		Reliance on the BR
		Water quality		
What are the adaptation options implemented by the participants? Did they adopt more incremental or transformative options? Did the drought trigger a shift in farming long-term strategies?		Short term/Reactive	Long term/ Transformative	Size, Rainfall, Reliance on the Berg River
	Water efficiency	Pruning, Fertiliser, Night irrigation, winter irrigation, maintenance, water recycling, invasive plants, wood chips	Drip irrigation	
	Water-storage capacity	Boreholes	On farm dams	
	Planting decisions	Mulching, Cover crops	Orientation, varieties, rootstocks	
	Social Capital	Exchanging information, Other	Other	

	Farming management		Business expansion (increasing, decreasing, steady), Diversification;	Size, Rainfall average, Berg river reliance.
Did the drought trigger a shift in farming long term strategies?	Interplaying between drought and industry low profitability	Long-term Strategy		Acknowledging industry low profitability
How did farmers' belief in climate change influence their long-term strategy behaviour?	Belief and action consistency	Long-term Strategy		Belief in Climate change

The first set of codes concerns the drought's impact on wine grape farming. In particular, the analysis was focused on examining the drought effects on the grapevine production and the characteristics of the farmers' that experienced a production drop higher than 20%. The second set of codes identified the adaptation options portfolio with attention paid to the adaptation measures concerning water efficiency. Observing this portfolio, the analysis identified the most common options, the options variation according to the rainfall average and the severity of the production loss, and the major barriers to an adaptation option's implementation.

Moreover, to understand how many farmers adopted transformative adaptation options because of the drought, the analysis looked for farmers who were diversifying their crops or activities, those who were investing in big water-storage works or those whose strategies included uprooting vineyards or suspending planting activities. These actions were defined as 'transformative' based on the definition and examples of 'transformative adaptation' illustrated in the literature review (see Chapter 2).

The study also examined the characteristics of the farms whose farmers adopted transformative measures, such as the farm size, reliance on the Berg River and the rainfall average received during the three years of drought.

Water conservation behaviour after the drought was also investigated. The researcher observed the number of farmers who claimed to have reduced their water consumption; those who adopted measures for enhancing their water efficiency; and those who declared that the drought changed their water conservation mindset. The aim was to understand how behavioural change was linked to the drought and water restrictions.

Finally, the research examined how farmers' beliefs concerning climate change influenced their long-term behaviour and preference for transformative adaptation options. A chi-square test was run to verify evidence of a relationship between those who claimed believe in climate change and those who implemented long term adaptation strategies. Another chi-square test was run to understand the relationship between those who claimed to believe in climate change and the choice to not expand their wine grape business.

Chapter 4: Results

This chapter presents the key results of this research. First, the general characteristics of the farms are described. Second, the identified drought impacts are examined; and third, a portfolio of adaptation measures adopted by the farmers is presented. The chapter ends by detailing how farmers' belief in climate change influenced their adaptation behaviour.

4.1 Farm Characteristics

Wine grape farming is characterised by a high degree of variability, both between different farms as well as within the same farm. Many elements combine to affect crop quality and yield, such as farm size, rainfall on the farm, type of soil or sun exposure. The table below provides information on some of the farms' characteristics, namely, farm location; hectares dedicated to vineyards; on-farm rainfall average during the three years of drought (2015, 2016, 2017); other crops on the farm; and other activities than farming. It would have been useful also to have the exact amount of water allocated per farmers, unfortunately many farmers were reluctant to provide this information.

Table 8 Characteristics of farms in the research

Name	Hectares	Location	Reliant on Berg river	2015/2017 Rainfall average	Other crops	Other activities
Farm 1	30ha	SW	No (Dry cultivation)	382 mm	No	Guest house; Restaurant; Wine cellar
Farm 2	65ha	PA	No (Own Spring[4] and own dam)	681 mm	Plums	Restaurant; Venue; Wine cellar
Farm 3	60ha	PD	Yes	304 mm	Pears; Olives; Artichokes; Special wheat and vegetables	Guest house; Restaurant; Shop with various products
Farm 4	87ha	ST	No (Own[5] rainfall dam)	399 mm	Olives	Restaurant; Venue; Wine cellar

[4] **Own spring and own dam:** it means that the farm has its own dam that is mainly fed but their own spring or small river.
[5] **Own rainfall dam:** it means that the farm has its own dam and it is fed only by rainfall.

Farm 5	9ha	F	No (Own spring and own dam)	1238 mm	Few cows	This is a complex company comprising different wine brands made in different farms
Farm 6	200ha	DA	No (Drycultivation)	347 mm	Olives; Cattle; sheep	Small shop of farm products; the owner has also another business by which he was able to cover losses
Farm 7	30ha	ST	Yes	453 mm	Vegetables and fruits	Guest house; Restaurant
Farm 8	25ha	ST	Yes	619 mm	No	Luxury Estate and Lodge; SPA; Luxury boutique; Restaurant; Wine cellar. The owner is the chairman of the Graff Diamond Holding
Farm 9	45ha	W	No (Own rainfall dam)	480 mm	Olives	Guest house; Restaurant; Venue; Wine cellar
Farm 10	13ha?	W	No (Own spring and own dam)	480 mm	No	Guest house; Wine cellar
Farm 11	350ha	PA	Yes	341 mm	Olives; Wheat; Cattle; Sheep	Guest house; Restaurant; Venue; Wine cellar
Farm 12	70ha	PA	Yes	280 mm	No	Restaurant; Wine cellar; Art gallery
Farm 13	44ha	F	Yes (Own spring and own dam)	897 mm	No	Restaurant; Wine cellar
Farm 14	24ha	F	No (Own rainfall dam)	540 mm	No	Restaurant; Wine cellar
Farm 15	75ha	PD	No (Own rainfall dam)	389 mm	No	Wine cellar
Farm 16	200ha	PD	No (Own rainfall dam)	382 mm	Cattle; sheep; wheat; maize	No
Farm 17	100ha	ST	No (Own rainfall dam)	424 mm	No	Wine cellar
Farm 18	130ha	SW	Yes	453 mm	Table grape; Olives	Restaurant; Wine cellar

Farm 19	200ha	F	No (Own spring and own dam)	667 mm	Blue berries; Olives; Cattles; Horses; Wheat;	Restaurant; Wine cellar; The owner has 3 other farms where they produce also wine grape
Farm 20	20ha	ST	Yes	480 mm	No	
Farm 21	20ha	F	No (Own rainfall dam)	901 mm	No	Restaurant; Venue; Wine cellar
Farm 22	18ha	F	No (Borehole)	505 mm	No	Guest house; Restaurant; Wine cellar
Farm 23	300ha	PA	Yes	457 mm	Fruit and blueberries	Wine cellar
Farm 24	120ha	W	Yes	507 mm	Rootstock; Citrus	No
Farm 25	90ha	SW	Yes	254 mm	No	Wine cellar
Farm 26	22ha	ST	Yes	368 mm	Cattle; Sheep	Guest house; Restaurant; Venue; Wine cellar
Farm 27	100ha	PD	Yes	389 mm	Olives; Oat	Guest house; Restaurant; Venue; Wine cellar

***Location Legend**: DA=Darling; F=Franschoek; PA= Paarl; PD=Paaderberg; ST= Stellenbosch; SW= Swartland; W=Wellington.*

Of the twenty-seven farmers interviewed, thirteen rely primarily on the Berg River for irrigation, while fourteen are mainly or totally independent and use mountain-runoff rivers running within the property or on-farm dams that catch rainfall or they do not irrigate their grapevines. Twenty farmers grow crops other than wine grape and almost all interviewed farmers engage in other commercial activity besides farming, mainly linked to the tourism industry. Observing the rainfall, twelve farmers received an average of less than 500mm of rain during the three years of drought, from 2015 to 2017.

4.2 Drought Impacts on Wine Grape Growing

The interviewed farmers identified the following drought impacts on wine grape growing: changes in the harvesting calendar, changes in crop quality, financial stress, psychological stress, mindset shifts regarding water conservation, reduction in water consumption, worsening of water quality, and decrease in crop yield. For each of the identified impacts, the table in section 4.2.1, below, summarises the related research results illustrated by quotes from the interviews.

4.2.1 Changes in Harvesting Calendar

The table here below summarises the drought impact related to phenology and harvesting time identified by the research.

Table 9 Identified drought Impact related to Change in Harvesting Calendar

Identified impact on:	Related interview results	Supporting Quotes
Harvesting calendar and phenology	Later Harvesting	“Seasons has moved at least 3 – 4 weeks later”
		“The harvesting time moved later, because of the drought, definitely. The grapevines took longer to ripen, if you have this drought and a grapevine would have enough water to live, that grape would have ripen much quicker than the others”
		“I can say, from the winemaking point of view, certain blocks struggled to ripen for some reason, they grew much later.”
	Different alteration for red and white wines	“So, I think in terms of when the grapes became available, it was different. It was early for the whites, and then there was this gap and then the reds just struggled at the end”
	Uneven budding	“That’s another thing this year, especially the bud you left there to grow they are far behind the other one, they are slower. I think it is because of the things that we did during the drought because you left them there, they do grow but the others are quick”

More than half of the interviewed farmers experienced changes in phenology and the harvesting calendar. Ten farmers affirmed that the harvesting period shifted a bit later compared to the years without the drought. However, results are not uniform. Four farmers believed that the harvest was earlier than usual, eleven affirmed that changes were not visible, or the variability was too high to define a trend. One of the reasons for this variance in response might be the presence of gaps in data recording, which might be less precise than the recording in the table grape industry. As one farmer stated, “with the table grape we are writing everything down, everything is very precise, so we are two weeks later than last year”.

Based on the available data, it was not possible to capture whether those changes are related to the characteristics of a specific region or terroir.

Two farmers noticed a difference between white and red grapes, where the whites were seen to ripen earlier than the reds. Although this is not the aim of this research study, further research on the effects of water stress on the phenology of different cultivars would be interesting. Another result which would require further investigation relates to the observation of uneven budding in the 2018/2019 seasons. Some of the farmers attributed this phenological alteration to the protracted drought and the pruning operations realised in 2017; whilst others believed that the main cause was the hot spells during winter/early spring season. For uneven budding as well, it was not possible to identify a relation with a specific region of the study area.

4.2.2 Changes in Crop Quality

The table below summarises the drought impact related to change in crop quality.

Identified impact on:	Related interview results	Supporting Quotes
Crop quality	Better quality, because of smaller berries	"Obviously the quality has been quite good in these drier years, but it is just acase of balance, if we get enough water the vineyards never go into stress because of the drought, but the drier atmosphere helped in quality"
		"The lower your yield the better the quality of your grape, but there is a balance if it is too dry, your grapevines, are going to struggle (..) some of the block were just struggling, and they did not produce any grapes"
		"But, on that, a grapevine can build up reserves and you can have a drought for maybe one, two, possibly three years and have decent quality. But after that, the grapevine starts to struggle. And you have to accept a smaller crop, really, because otherwise you're going to really strain the grapevine. Particularly on the aged grapevine"
	Farmers statements on quality are misleading as they declare a better quality in order to offset the bad results in terms of quantity	"A farmer would never tell you that he had a bad quality crop, but he has to tell that the wine is good to cover the losses."
	Farmers experiencing bad quality observed higher pH level	"Our pH levels are considerably higher – if you look at what's happening in the cellar, the wine analysis is not fantastic. Higher pH is definitely originated from more stress, more malic acid is going through. I don't normally acidify, but I had to acidify."
		"Very low acid and high pH's; this is the first time we've seen that."
		"But here and there you can see the pH isn't good. For example, 2015 was quite a good vintage concerning pH – it needed little intervention. But that's winemaking, you always adapt to your vintage, so I don't think the quality was bad, we had just much less crop."
	Quality is affected by a mix off actors including heat.	"I think that the wine quality was influenced by a combination of factors occurred during the season and not only by the water availability. For example, last year (2017/2018) we had a beautiful season without heat waves, unfortunately the production was scarce"

Table 10 This table summarises the identified drought impact related to change in crop quality

The statements included in the table are only some examples of all the statements highlighting the same type of identified change. The examples were selected based on their incisiveness. In general, the drought was found to have positively affected the quality of the wine, especially for the red varieties. 66,7% of the farmers affirmed that the quality of their crops was enhanced as the lack of water led to smaller berries. Those who affirmed that their crop quality increased seemed to be particularly happy with the wine of 2018. The quality of 2018 is related to the 2017 rain season -the driest in 150 years, according to Wolski (2018). However, the farmers highlighted that it is important to reach a balance between water and yield, as when water is too scarce grapevines struggle to ripen.

Some farmers believed that the drought was not the only factor to influence the grape quality and that it was temperatures from heat waves also played an important role in the berries' final characteristics. The effect of higher temperature on wine quality would deserve a further analysis, unfortunately this is beyond the scope of the present research.

The enhanced quality may be a potential way to set a higher wine price, with a view to balancing the negative effects on the yield. Four of the farmers who experienced a low-quality grape identified a higher pH level in the grape, which meant they had to adjust the wine making process by adding some acids, for example. During the interviews they referred generically to the pH changes as phenomenon occurring during the years if the drought.

4.2.3 Decrease in Crop Yield

Table 11 This table summarises the identified drought impact related to change in crop yield

<table>
<tr><th>Identified impact on:</th><th>Related interview results</th><th>Supporting Quotes</th></tr>
<tr><td rowspan="6">Crop yield</td><td colspan="2">Drought reduced the yield (74% of farmers)</td></tr>
<tr><td colspan="2">Farmers having the highest decline in production did not rely on the Berg River for their irrigation: 82% of the farmers who declared to have a yield drop higher than 40% do not relies on the Berg River. In particular 60% of those had their own dam but only fed by rainfall and 40% did not irrigated their vines.</td></tr>
<tr><td colspan="2">Water stress, emerged as a key determinant of yield reduction.</td></tr>
<tr><td colspan="2">The optimal rainfall threshold of 500mm per annum (Johnson and Robinson, 2001) is confirmed by the volume of the yield of the farmers in the sample.</td></tr>
<tr><td colspan="2">A heat wave started in 2014 and peaked in 2016 might have influenced the yield</td></tr>
<tr><td>Warmer and higher average of UV index might also have influenced the 2016 crop quality</td><td>“It was strange the first year 2015 was very good quality year, during dry years we get this full complex structure, because the berries are smaller, so the concentration is just much better, for some reason 2016 wasn’t very good, 2017 was a good year and 2018 was terrific, our wines are beautiful we are very happy”.
“2016-2017 was a big struggle with Cabernet, Malbec was also in 2016”</td></tr>
</table>

Of the interviewed farmers, 74% affirmed that the drought had a negative impact on their production; 18,5% declared that the production was steady and 7,5% declared that their production increased, compared to the years before the drought. Of those who experience a lower yield, 78,9 % had a production drop higher than 20% and 47% had a production drop higher than 40%.

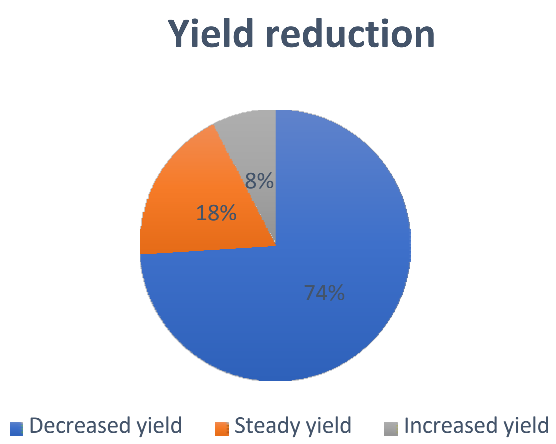


Figure 14: This graph shows the portion of farmers who experienced a yield

To verify evidence of a relationship between the yield reduction and the reliance on the Berg River for irrigation, a chi-square test was run (Fig.15). No significant relationship was identified between different degree of yield drop and the reliance on the Berg river (Chi square=0,086, df=3, p>0,05). There was also no significant relationship shown by a chi square test between farmers who experience some yield drop and those who did not experience any drop (Chi square: p= 1,451, df=1, p>0,05).

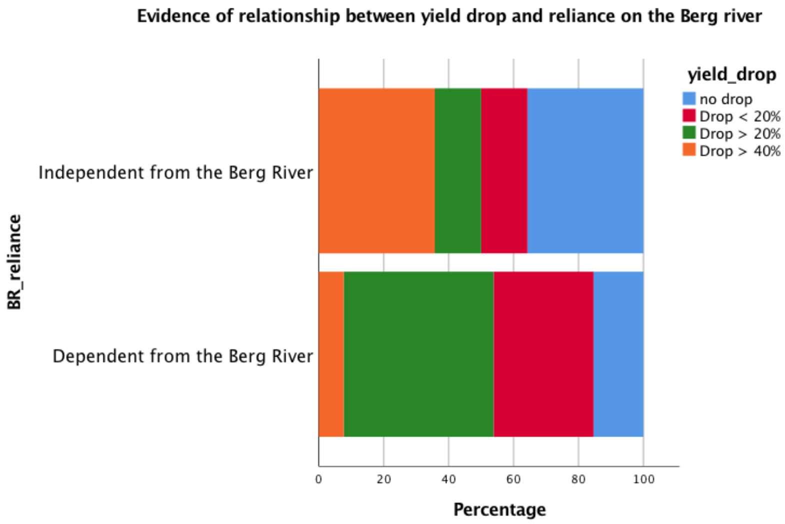


Figure 15: This graph shows for each of the two degree of reliance on the Berg river, how many farmers experienced each of the three different levels of yield reduction.

The researcher notes that a trend may be more evident if there had been a larger sample.

However, the graph (Fig.15) shows that of the farmers who experienced a yield drop higher than 40%, 83,3% used independent water sources for irrigation. It is probable that the reliance on the Berg river and the water use restrictions only impacted on production in the last year of drought, when water supplies were severely cut for agriculture. Instead, water scarcity affected earlier those farmers independent from the Berg River and relying only on rainfall or secondary streams, thereby having a bigger impact on their production.

Farmers who used independent water sources for irrigation experienced the highest percentage of drop but also, included the highest proportion of those who not experience any drop of production. A possible explanation might be the different locations and the related rainfall received by the farmers who relied on sources other than the Berg River. Those who experienced the highest drop were in the Swartland, Padeernberg and Wellington and those who experienced no drop were in Franschhoek, where rainfall was enough to maintain near "normal" business.

Furthermore, of those farmers who experienced a drop higher then 40% and who were independent from the Berg River, 60% did not have access to secondary river or spring on their property but they had their own dams only fed by rainfall. The rest 40% did not practice any irrigation.

The average annual rainfall received during the three years of drought and the consequent water stress emerged as a key determinant of yield reduction. All the farmers who experienced a yield drop higher than 20% received an average rainfall below 500mm during the three years of drought, and 93% received an average rainfall of below 400mm. Of those farmers who experienced a drop of 20% or higher, 50% were reliant on the Berg River. This means that even if vines were irrigated the quantity of rain received influenced water availability and thus the drought had an important effect on the yield. Farmers who were greatest hit in terms of production [with a production drop higher than 40%] were from the areas of Malmesbury, Paarl and Wellington.

On the other hand, farmers stating that they did neither experience any production decline nor experienced an increase in production tended to receive an average annual rainfall in the three years of drought of higher than 500mm per annum. Therefore, the optimal rainfall threshold of 500mm per annum identified by Johnson and Robinson (2001) applied in the case of the yield volumes of the sample.

In order to verify evidence of a relationship between the wine grape yield and rainfall scarcity from 2015 to 2017, a chi-square test was conducted (Fig.16). The test showed evidence of a relationship between the yield reduction and the average rainfall received from 2015 to 2017 (Chi square: $p=0,002$ $df=3$, $p<0,05$).

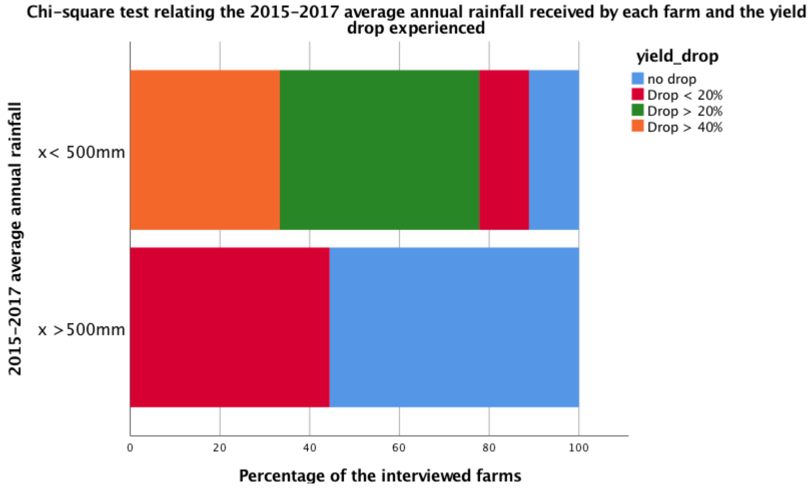


Figure 16 This graph shows for each of the two category of rainfall average, how many farmers experienced each of the three different levels of yield reduction

The relationship between the drought and the yield is also evident upon observing the production data of 2018. The 2018 harvest amounted to 1,238,000 tons of grape countrywide -- that is 14% smaller than 2017 and the smallest harvest since 2006 (Phakathi, 2019). This significant reduction was a consequence of the prolonged water stress on the vineyards, as 2017 was the driest year since 1981.

Another element that could reinforce evidence of water stress and its influence on wine grape yield is the production trend between 2016 and 2017. In 2016, wine grape production was lower than in 2017 (see Fig.7). Considering that the number of hectares of grapevines was lower in 2017 than in 2016[6], a key factor influencing the bad harvest in 2016 and the better harvest in 2017 was probably the different amount of rainfall recorded in 2015 and in 2016 from April to March, period corresponding to the vine growing cycle (Green Cape, 2017; Webb et al., 2012). According to the rainfall measures provided by the farmers, the participants' farms received on average a total annual rainfall in 2015 of around 487mm of rain, which was lower than the amount received in 2016 (approximately 578mm). Similar results emerged from the rainfall measures provided by the weather stations of the Agricultural Research Council of South Africa (ARC). Data gathered from the six weather stations located around the study area (Bellevue, Fairview, Elsenburg Ciat, La Motte, Stellenbosch Cordoba, Diemerskraal) confirmed that the total rainfall from April 2015 to March 2016 was lower than the total rainfall in the

[6] See section 1.4.4 where the analysis gives a possible explanation of the negative trend in hectares planted under grapevine.

period between April 2016 and March 2017 (Fig. 17). The only exception, it is recorded from the Elsenburg station. However, the difference between the two periods is only 14 mm, compared to an average difference of 124 mm of rain between the two periods for the other stations. The period between April and March corresponds to the grapevine growth cycle, such as winter nutrient accumulation, bud burst, flowering and veraison. We included rains starting from April as they are considered post-harvest rain and contribute for reserve build up in the grapevine.

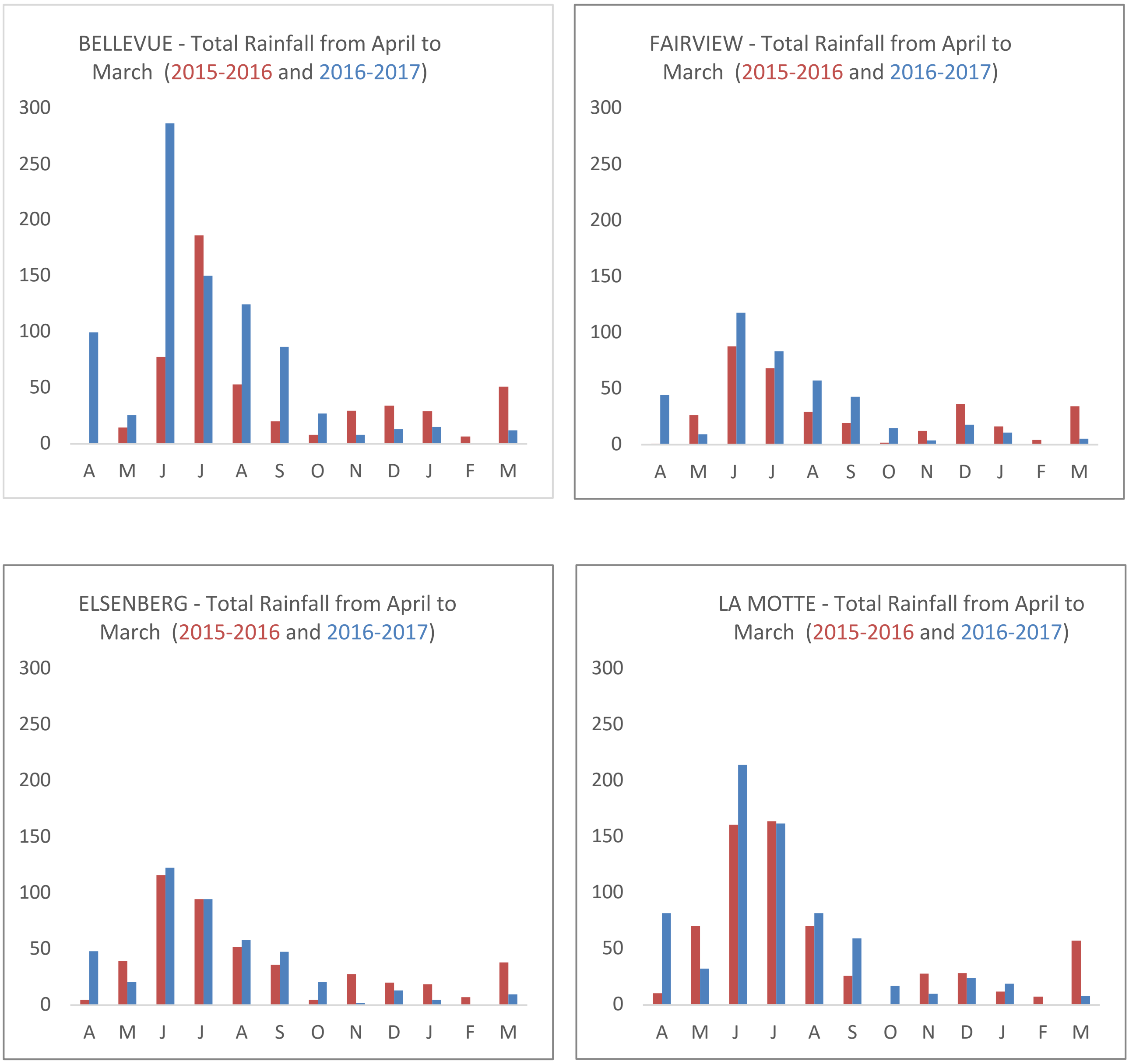
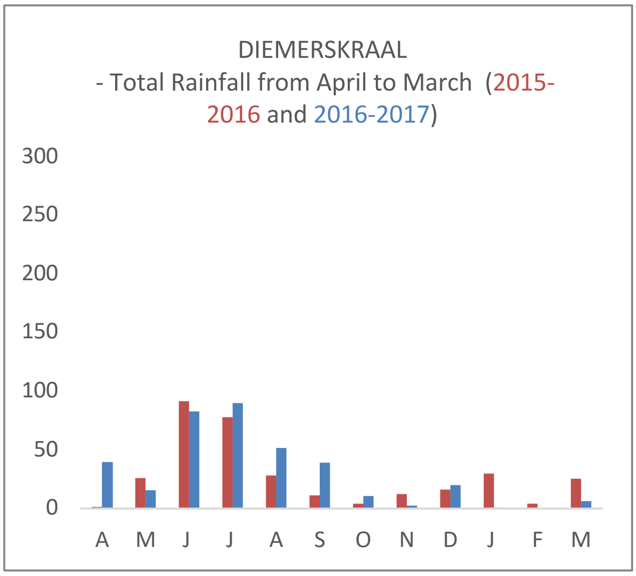
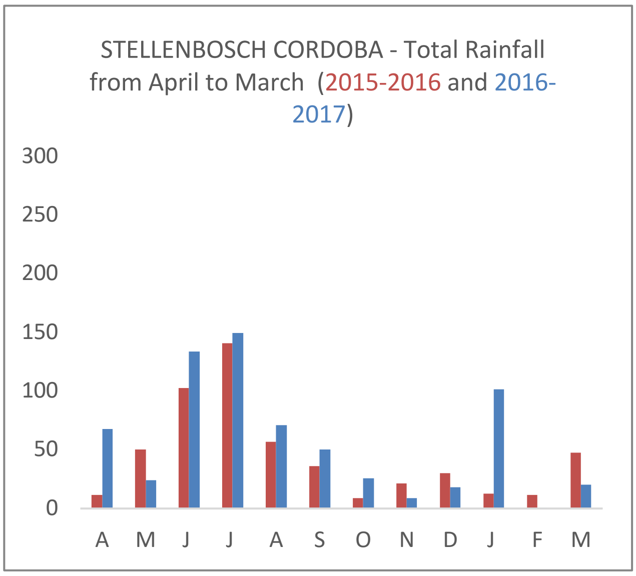


Figure 17 These graphs show the total monthly rainfall from May to February in 2015 - 2016 (Red column) and in 2016-2017 (Blue column)





Considering the effect of severe water scarcity on wine grape yield, it is necessary for farmers to increase their adaptation efforts to a drier climate as long- term rainfall observation in the study area revealed a decreasing trend in total annual rainfall (Fig.18). Long-term rainfall measures obtained from the previous mentioned ARC weather stations show a decreasing trend of total annual rainfall from 2007 in the study area.

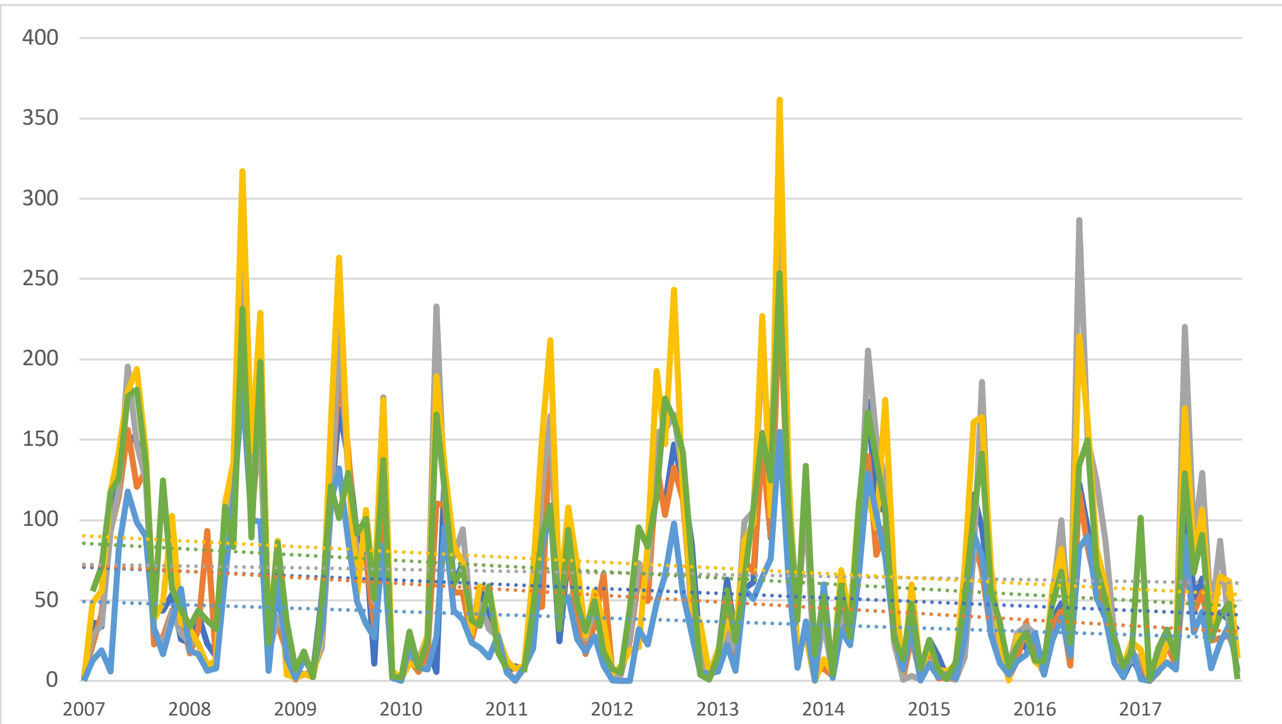


Figure 18: This graph shows the total monthly rainfall and their linear trend, recorded by 6 ARC automatic weather stations from 2007 to 2017: ***Elsenburg Ciat****,* ***Fairview, Bellevue****,* ***La Motte****,* ***Diemerskraal****,* ***Stellenbosch_Cordoba***

The yield reduction during the drought might be attributed to a combination of factors. Not only did some grapevines not perform due to water scarcity - and especially old grapevines - but farmers also adopted coping strategies to reduce the stress on the grapevines, such as reducing bunches and bud burst during pruning or eliminating grape clusters before ripening (cf. next section on Adaptation Portfolio).

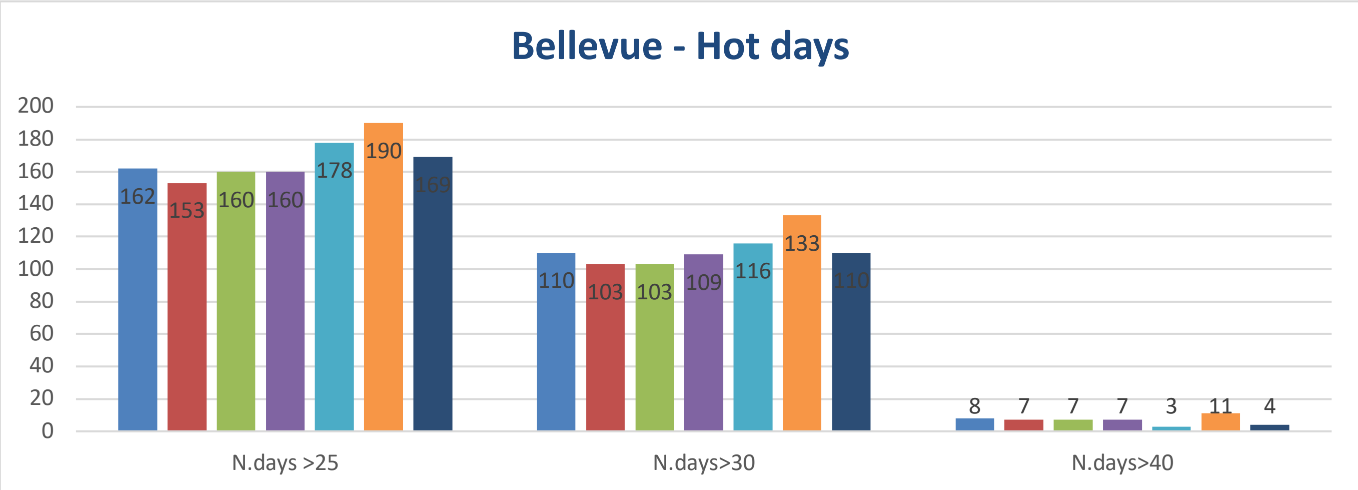
The drought effects and the production variation between 2015 and 2017 might also have been influenced by a higher number of hot days between the end 2014 and 2017, which is probably connected to the ENSO variability. It is probable that the warmer conditions also contributed to the reported poor quality of the harvests during this period.

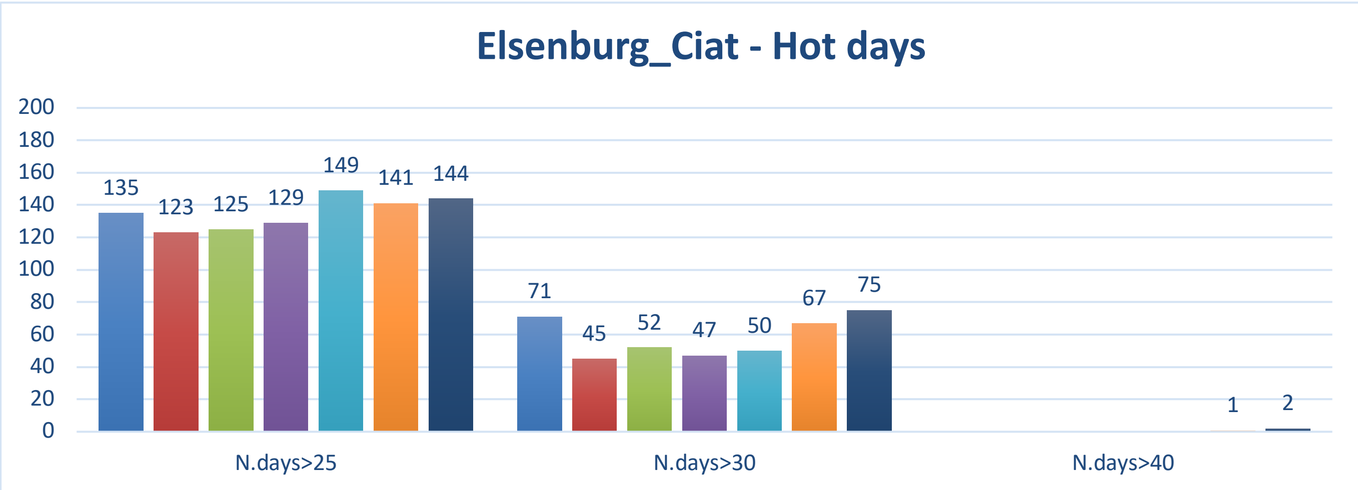
Data from 4 ARC automatic weather stations, Bellevue, Stellenbosch Cordoba, La Motte and Elsenburg Ciat shows that the grapevine growing seasons, from September to March, in 2014/2015, 2015/2016, 2016/2017 recorded the highest number of hot days over a period of seven years (Fig.19a)

However, it seems that prolonged water stress might remain one of the main drivers for low production. This is evident from the 2018 data on grape production.

As Fig.19b shows, temperature in 2018 were cooler than 2014, 2015, 2016 and 2017[7], however 2018 yield (1.238.000tons) was the lowest since 2005. Therefore, it seems that the prolonged water scarcity and consequential dryness of 2017 had a strong influence on the decreased production. Further research is required to better understand the attribution rate of the heat stress and water stress phenomena on grapevine yield.

[7] Unfortunately, it was not possible to analyse temperature data for 2018, directly from the ARC weather stations.





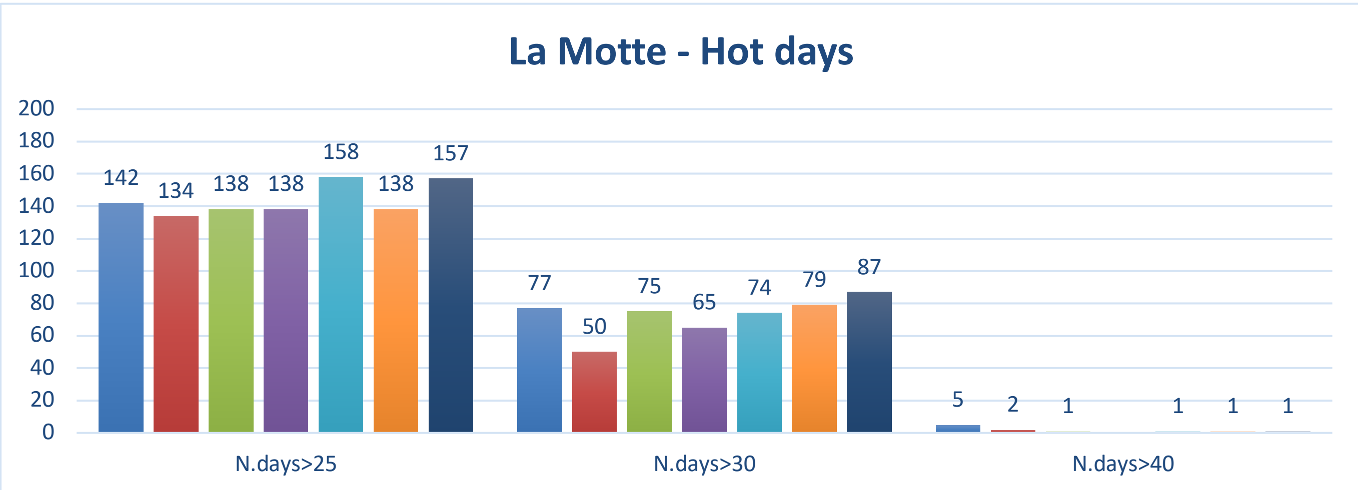
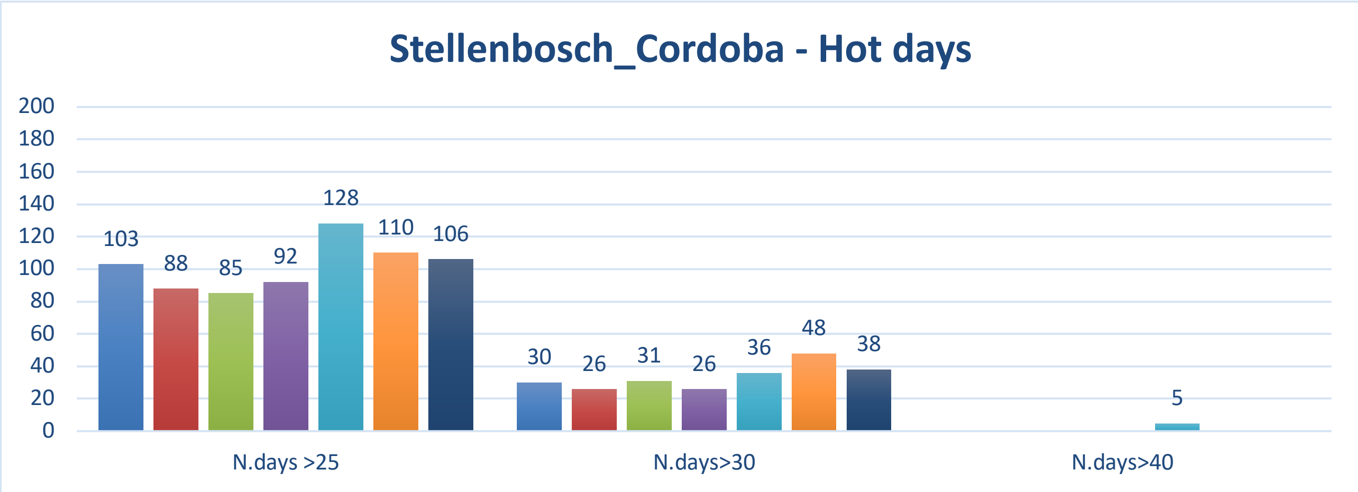
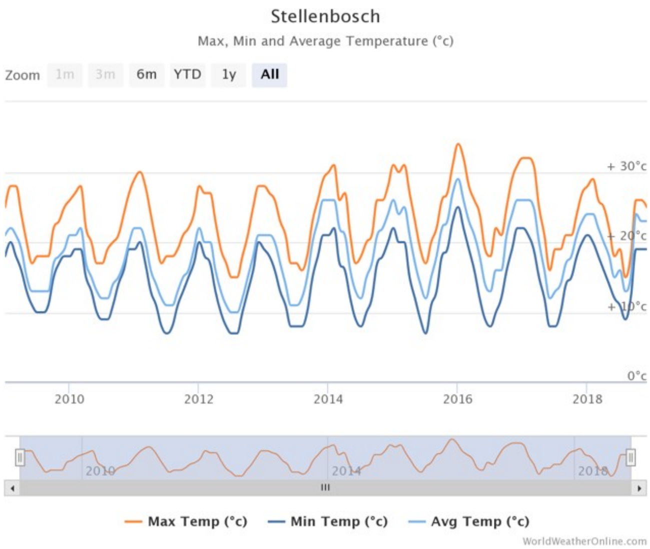
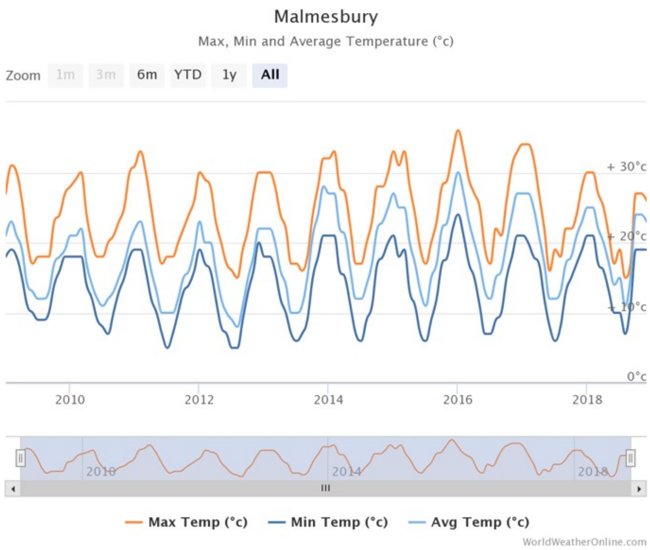


Fig.19a shows the number of hot days >25°C, >30°C, >40°C, recorded from 4 ARC automatic weather stations: Bellevue, Elsenburg_Ciat, La Motte, Stellenbosch Cordoba (next page). The reported records cover the period between September and March in 2010/2011, 2011/2012, 2012/2013, 2013/2014, 2014/2015, 2015/2016, 2016/2017.







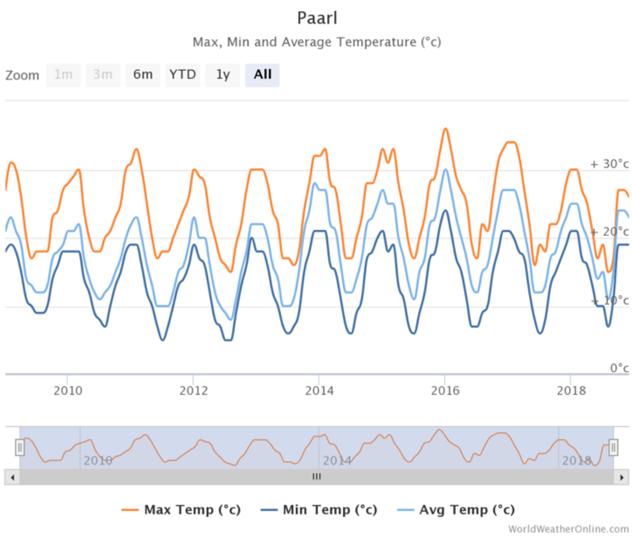


Figure 19b The graphs above show the maximum and minimum average temperature and the average UV index from 2009 to 2018, in the three main localities of the study area: Stellenbosch, Paarl and Malmesbury.

4.2.4 Financial Stress

The table here below summarises the drought impact related to financial stress identified during the research.

Table 12 Identified drought impact related to change in financial stress

Identified impact on:	Related interview results	Supporting Quotes
Financial stress	Financial stress was worsened by the drought. However, it is mainly due to low profitability of the wine sector	"I don't know what is wrong, but why the SA wine should be the cheapest in the world? It doesn't help you to have a good wine but having a good marketing, marketing is the main thing"
	Unsustainable price: production costs, inflation, quality not adequately reflected	"the yield in the cellar are low, the farming costs remain the same, so my price per litre goes up, and we can't put an increase on the bottle of wine, it's impossible because the people over sea moan, the British and the Americans they don't know what the inflation is and this is an inflationary country, everything goes up, I mean the diesel prices is going up".
		"Dryland cultivation in SA is not possible because people are not paying a decent price for our products"
		"I had at least 30% increase in production costs but the price per ton remained static"
	Job cuts because of the drought, especially seasonal workers (48% of the farmers)	

Those who experienced a reduction in the production yield affirmed they faced a period of financial stress. The main reason identified by the farmers was the low profitability of South African wine, which is sold both domestically and internationally at a price that does not reflect inflation and production costs, and thereby prevents a profitable return on investments (VinPro, 2018).

One of the farmers who manages land with adequate conditions for drylands cultivation affirmed that drylands cultivation is not feasible in South Africa because the final product is not valued high enough to cover the production costs. On the other hand, the higher prices that resulted from grape shortages were also seen as a problem for cellars. One farm manager stated,

"We buy a lot of grapes in the Swartland area, where a lot of our farmers' production went down 60% and even more. So, we were not able to get the raw product in the volume we needed. We had to start looking in the wine industry to buy wine. Since there is less wine, all the prices have been pushed up and this affect your final price, and your mid-level brand.

According to VinPro (Phakati, 2019), the crop shortage could create momentum for raising wine prices and hence make investment in wine grape farming more profitable. However, the lower yield and financial stress also affected labour demand. Of the interviewed farmers, 48% had to cut their labour force - mainly seasonal jobs. Seasonal workers are often paid according to the volume of grapes gathered where lower the volume translates into lower wages.

Farmers confirmed that the sector was already characterised by very limited return on investment compared to other agriculture production (cf. Chapter 1). The drought impacted on this by decreasing the volume of the yield and hence decreasing revenues and the capacities to cover the costs of production. Unfortunately, determining the relationship between drought and higher production costs is beyond the scope of this research. This subject would be worthy of further investigations, as it could incentivise water- wise adaptation strategy.

4.2.5 Psychological Stress

The table here below summarises the drought impact related to psychological stress identified during the research.

Table 13 Identified drought impact related to change in psychological stress

Identified impact on:	Related interview results	Supporting Quotes
Psychological stress	Psychological stress considered as a main impact of the drought	"It's more about the effects that drought has on people, on a psychological level, this is the main effect of the drought for many farmers. You know, when you plant things in the ground and you wait for the rain, there is a lot of stress. When you plant vineyards there is this kind of psychological stress that you are under, but we believe that when it rains, farmers always get a little bit more hope, when it rains a farmer can stay there hearing the rain on the roof and say - oh! Hear the money is falling - and they know that they will get some crop, you know? It's just to get out some crop early, just to get some income from that vineyard. If we don't get rain for three years, then we are in serious troubles"
		"Well I've been around for 7 years, and the previous 3 years have been very bad. The drought kept building up and getting worse and worse".
	Feelings of disorientation and helplessness	"I don't think that you can do anything to be prepared for a drought";
		"it's more on managing our irrigation and pray"
		"I think that it is the first time in 16 years of this work that I see a season where we had problems with water scarcity";
		"what can you do? There is not that much that you can do if you do not have water";
		"if God decides to send some water during the winter, if I go to Church enough, and God send some rain, then I can rest"
	Farmers confusion might lead to maladaptation	"My secretary told me that I was starting to get totally confused, she told me: you must stop now with making boreholes, because last year we drilled five boreholes and three of them were totally dry and it costs a lot of money, stop gambling, because you gamble now. I said: I understand your problem but what is going to happen if we get to February and there is still no water? And the secretary reply: I understand what you mean. So that was my emergency plan but fortunately it is still in God hands".

One key aspect that is not often investigated is the psychological stress on farmers caused by the drought's effects due to increased costs and the greater amount of work required during dry periods. Drought represented a source of stress, especially for those who experienced a large drop in production. For example, one farmer used the word “terrible” six times to describe the effects of the drought on his activity. Drought and the concomitant water restrictions disoriented farmers and induced a sense of powerlessness who believed that they had exhausted the options available to counteract the effects of the drought.

4.2.6 Changes in Farmers’ Water Conservation Behaviour

Table 14 This table summarises the identified drought impacts related to change in water consumption

Identified impact on:	Related interview results	Supporting Quotes
Water consumption	Most interviewed farmers reduced water consumption during the drought	“Yes, definitely, I gave less water, I experimented a bit, so most of my vineyards in the previous season, in 2016-2017, were actually down at 800 cubic meters of water. I do not have any moisture meters to see what was going on, but I look at the plants, I just started giving less and less water, then when I saw they were showing physical signs, I gave a little bit of water, maybe one good irrigation and then cut back again”.
	Vineyards were over irrigated before the droughts	“I think that I was giving just too much water, unnecessarily, really, because we have the water. When I started here, I saw that we could give water as much as we want”;
		“I think that some people use more water because of the tonnage, but in these years, they have seen that if they use less water, they can go through and have a better quality, even if with smaller crops. Vineyards are quite strong plants”.
		“I started really to cut back on irrigation and the grapevines were not showing any sign of stress of dropping yield so I started realizing that, wow, I was giving the water and it was running out into the river, so I will definitely keep a lower level then before”
		“So, we are going to manage it a bit differently, we were already on the right path, but I think that we can still reduce 10% more”
	15 farmers out of 27 declared to be more aware of water scarcity after the	“It was a positive outcome, a lot of positive outcomes compared to the negatives.”
		“I think that it was a wake-up call for a lot of people, not just farming, but also in everything else, at the domestic level if you see how people is saving

	drought. In that sense drought had a positive impact.	water now, before they just never care, I think that people will be more vigilant in saving water than before".
		"I believe that drought is sometimes a good thing, because it forces you to look at wastages and possibilities to save water".
		"I really think the drought was eye-opener for a lot of the farmers we have starting to understand in the Western Cape how to work without water, because in the old days you just open the water, you just spraying, now every time you open the tap you know that you must be responsible for that, and also the children play on the farm, everybody. I am not glad about the drought, but I think it really open the mind of the people in South Africa, in the Western Cape."

The drought had a severe impact on farmers' water conservation behaviour. Water scarcity appears to have triggered heightened awareness concerning the importance of water and its limited availability. Water scarcity is perceived as the result of a mix of factors, such as climate change, growing population and the increasing requirements of Cape Town. 74% of the farmers stated they had reduced water consumption. These farmers asserted that the restrictions were the main driver of their reduced water consumption. However, a chi-square test run to test the relationship between water reduction and reliance on the Berg river revealed no significant relationship (Chi square: p= 0,228; df=1; p>0,05). This probably means that the main factor influencing water consumption behaviours remain the drought-induced water scarcity and not government restrictions.

15 out of 27 farmers stated that the drought induced a shift in their mindset regarding water consumption. After the drought, they realised that water is a scarce resource that required efficient management. Participants also acknowledged that the increased awareness is a positive aspect of the drought. 41% admitted to over-irrigating vineyards, to wasting water in other phases of wine production and to not paying attention in domestic use before the drought.

4.2.7 Poor Water Quality

Table 15 This table summarises the identified drought impact related to change in water quality

Identified impact on:	Related interview results	Supporting Quotes
Water quality	The Berg River water quality decreased during the drought	"The river water is a big problem. The main problem is that most of the township are alongside the river, some of them do not have good places where to go to toilets, so the water quality is getting worse since I start working here, 16 years ago. Sometimes in Paarl the sewages get full and they dump it in the river. One day I woke up in the morning and one of my people said to go and have a look, the fishes were turning on the side, because the oxygen level in the water was down".
Water quality for irrigation	Quality used for irrigation was found to be poorer	" Water is dirtier, the solution to pollution is dilution. If the pollution is not diluted by rain, water is more polluted." "As far as the water quality for the irrigation water – I think it probably did change a bit, because I know there was talk of it. But I couldn't tell you scientifically if it has." "We got boreholes water going to the dam (…) we did not test water frequently, we test the water over a year, just to see if it is suitable for irrigation, it happened that the water turned a bit green, there was less fresh water coming into the system and it was warmer, and basically the only thing that we saw different, otherwise we try to keep it healthy." "Yes, that's serious, negative quality, part if thing is pollution. In our board, I take samples every week and every month to test e-coli and with the drought the level of water goes down. The concentration of pollution is really getting high. We are privileged that we are not beyond Paarl, the only pollution we get is from Franschhoek, where the shacks are. It is very serious, everything it is just running into the river, it's very serious, our pipes get block with leaves all the time, so we have to clean it. So from time to time, my staff go and dive and clean it , scrubbing this thing, but I cannot do it anymore, because they risk infections. It's too risk, it's not that bad for the plants, but we are really concern about that. People producing fresh fruits noticed that fruits started to get spoiled, but with the vines is different story, grapes go through fermentation etc.. it's not that it can affect our wine" " The quality of the river decreased a lot, and I use that water for irrigation. It decreased I think because of the drought, water wasn't flowing, so there is a lot more wastes from the birds, the fishes, so the e-coli and other stuff

		definitely went up." " The subterranean water actually improved, even though the surface water gets worse. We test it because we use it in the vines.

The drought was also found to have impacted on water quality, especially the quality of water from the Berg River. The Berg River crosses several urban settlements, both formal and informal, which contributes to river pollution. Diminished rainfall decreased the quantity of fresh water entering the river, thereby reducing the process of dilution and increasing the level of water pollution. The latest studies on the Berg River water quality show that water quality conditions, in terms of salinization and eutrophication, are considered intolerable for almost 60% of the catchment (DWA, 2011). The database of the Department of Water and Sanitation (DWS) reports that the average level of E-coli reached a level of high risk and required a full treatment process to make it drinkable (DEA, 2018). Farmers' observation confirmed the poor-quality of the water used for irrigation; however, none declared that their crop was negatively affected by river pollution.

4.3 Adaptation Options Portfolio

Grape wine growing is an activity requiring constant adaptation to weather and climate. Most of the farmers observe and interpret their grapevines' signs and behaviours. The interviewed farmers did establish adaptation measures to limit the negative effects of the drought. The research shows that most of the applied adaptation options are incremental and reactive, instead of transformational and anticipatory.

From the interviews, I was able to extract a portfolio of adaptation options, which could be divided in five macro categories: farming practices to increase water efficiency at biological and physical level; strengthening social collaboration; investments to enhance water storage; planting decisions; and management strategies (adapted from Nicholas, 2012). The last three categories relate more to strategies geared towards the long-term and indicate a more transformational attitude.

The table below summarises the adaptation options adopted by the interviewed farmers. For each practice identified the table indicates whether it is a short-term or long-term practice as well as its contribution to enhance drought resilience and the constraints related to its implementation.

Table 16. The table summarise the adaptation options identified during the interviews. It highlights the practice temporal dimension, its contribution to drought resilience and its limitations

Adaptation Options	Short term/Reactive	Contributions to drought resilience	Constraints and/or Inconveniences
Farming practices to increase water efficiency	Modification of pruning method	Reducing the number of bunches and shoots in order to have less fruit and reduce the grapevine stress, limiting thereby the yield loss.	Yield reduction
	Green grape drop	Reducing the grapevine yield to reduce the grapevine stress and yield loss	Different wine quality, harder wine making process
	Limiting fertilizer	Reducing canopy and leaves, in order to reduce plant water demand.	Yield reduction. Canopy reduction might lead to sun burn fruit
	Irrigation during night time	Reducing evapotranspiration. Reducing electricity costs	Maintenance works are difficult, as leakages or other problems are less visible. Security concerns if the irrigation is activated manually. The field is too extended, and the only night hours are not sufficient.
	During winter	Allows a better water penetration into the soil, as the winter period has more rain and lower evapotranspiration.	Excessive runoff and water wastages if the soil has a bad water retention

	Enhancing maintenance	Reducing water wastages. Reducing production costs.	
	Water recycling	Reducing water consumption	High costs of installation. Small quantity to be recycled. Tight regulation and long procedure for the set up.
	Cleaning invasive plants	Reducing water competition Increasing the flow within the river and the catchments Reducing fire risks	Reducing plants and trees implies negative effects for carbon mitigation if the clearing is not followed by a replanting phase with indigenous species.
	Wood chips	Increasing soil water retention and moisture, reducing evapotranspiration, controlling weed	High costs of production Tree cut implies negative effect for mitigation.
	No tillage	Increasing soil water retention by decreasing soil disturbance. Reducing soil erosion and water runoff	High cost of “no-till drill” machinery Unsuitable for all type of soil Higher weed growth Residues are not used for livestock Higher management required
	Disking	Better incorporating crop residue into the soil, allowing thereby their faster deterioration and making the soil easier to manage. Cutting soil capillaries, reducing thereby water evaporation.	Not adequate in wet soil. Herbicides might become part of the soil composition after disking.
	Crop prioritisation	Limited economic loss by prioritising higher value crop, or more drought-resistant crops	Worsening loss on the neglected crop
	Long term/ Transformative		
	Drip irrigation	Reducing water consumption compared to sprinklers	Compared to dryland cultivation, irrigation might increase soil salinity and alter wine aroma. Possible yield reduction in the first years of technological change.
	Pressure bomb		High initial costs

	Soil probes	Increasing water efficiency and monitoring capacity Reduction of production costs	High initial costs Fast changing technology Imprecisions in some of the technology on the market.
	Fruitlook satellite monitoring	Increasing water efficiency Reduction of production costs	Not very user friendly Time consuming
Increase water-storage capacity	Short term/Reactive		
	Boreholes	Increasing water-storage capacity Additional water source	High cost of drilling Uncertainties in finding groundwater Contributing to water resources depletion due to unregulated drilling.
	Long term/ Transformative		
	Building or improving on-farm dams	Increasing water storage and harvest capacity	High costs of implementation Long and complicated administrative procedures Increased water diversion and competition with other users
Planting decisions	Short term/Reactive	.	
	Mulching	Increasing soil water retention and nutrition	High costs of implementation
	Cover crops	Increasing soil water retention and nutrition, fighting weed water competing and decrease the likelihood of fungal growth	Fires risks
	Long term/ Transformative		
	Changing grapevines direction	Reducing heat and excessive radiation effects, limiting thereby evapotranspiration	Alternative positions not available Difficulties in buying new land
	Planting drought resistant varieties Choosing drought-resistant rootstocks	Limiting yield loss and water consumption	Scarcer wine quality; uncertainties regarding long term climate forecast; low consumer elasticity, subsequent lack of consumers demand for this type of varieties.
	Short term/Reactive		

Strengthening social network	Exchanging information	Knowledge and technology transfer, increasing thereby adaptation capacities	Limited access to update information Limited time to consult information Lack of evidence-based information
Farming management	Long term/ Transformative		
	Suspending or reducing the business expansion	Reducing production costs, increased capital availability for investment in other crops or activities.	Risk of financial unsustainability, jobs reduction, loss of cultural heritage link to viticulture.
	Diversifying crops or activity	Diversifying the risk, investment in more profitable crop or activity	

4.3.1 Farming Practices to Increase Water Efficiency in the Short Term

The main adaptation measures farmers claimed to implement to enhance water efficiency are: modification of pruning method; canopy management; limiting fertiliser to contain canopy; drip irrigation; night irrigation; winter irrigation; fixing leakages and enhancing irrigation maintenance; water recycling; cleaning invasive and alien plants; and using wood chips for soil moistening. Except for drip irrigation, which will be analysed in the next section, all these measures were implemented with a short-term view as tactical responses to a drought already in course.

The most common adaptation option concerned the modification of pruning for controlling the grapevine growth. Of the respondents, 48% stated that they had changed their pruning by reducing bunches and bud burst to limit grapevine stress. One farmer claimed, "*We changed our pruning – we knew we were going to have a very dry summer, so we decided that we were going to restrict the production*".

Four farmers used a new pruning system proposed by an external consultant. The method involved shaping a branch's development while respecting the grapevine's organic growth, reducing "cutting surface" and limiting the wound exposition (Simonit & Sirch, 2018). Four farmers also limited the canopies' growth, allowing the grapevine to retain more water and channelling the plants' efforts towards berry growth. One farmer stated, "*You should leave fewer shoots on your grapevines. The smaller the canopy, the less water you use*". Moreover, two farmers limited their use of fertiliser to contain canopy growth, and five farmers limited grapevine stress by cutting down the green grape clusters considered to be in excess (green grape dropping).

Another adaptation was adopting changes in irrigation. Changes in irrigation system, schedule, or period are key to enhancing water efficiency (FAO, 2013). Of the farmers, 41% started to irrigate during the night to limit evaporation. When manually activated, the implementation of night irrigation is limited by security concerns, or by the difficulty of doing maintenance due to poor visibility. Some farmers cannot switch to night-time irrigation because of the extent of the vineyards, as the field is too big to be covered during night time only.

Two farmers experimented by changing their irrigation season and began to irrigate in winter. These Swartland farms have soil consisting of mainly sand and clay, which has good water retention potential. One of the farmers asserted:

> *"During rains is the best time to irrigate, just to get really good penetration and fill the soil properly. Because water likes to stay together, when you have a drip and you're dripping on very dry soils, the water is just running straight through. But when it's wet, it spreads out and has a much better wetting action."*

In addition, all farmers dedicated increased attention to irrigation maintenance, fixing the leakages immediately, not only on the farm but also on the different premises on the property. A farmer highlighted the importance of training staff for usual maintenance. Wastages were also better controlled in the cellars and during the wine making process:

> *"We had a brainstorming session in the cellar, because the cellar uses more water than the vineyards. So, we spent a lot of time going through each process, identifying where we waste most of the water, and trying to address it".*

These efficiency efforts have had a general positive impact on the farm's economy as they contribute to reducing production costs. Increased water efficiency also led to prioritising in water use. One farmer decided to prioritise table grape, as it has a higher economic value: "*Our table grape is our most economical influence because of exports, we try to give them at least 80% of the normal water.*"

Most of the farms also have other activities, such as a restaurant and a guest house, which require garden maintenance. During the drought, water for gardens and private houses was also cut in several cases. One interviewee noted, "*So, where we can cut is our gardens and lawns – they take a lot of water and they're ornamental.*" Other farmers said that they cut water designated to paddocks:

> *"We had big water rights out of the river on this farm, we had to get all the way down to 10% on those water rights, so all of the sudden the water rights were just taken away from us, that's when do you not irrigate paddock. Because that water is mainly used for the paddocks, for the horses and the cattle, so we had to bring in our fodder, whose price went up drastically."*

Similarly,

> *"We do have some cows and we had some grazing for cows. In 2016, I stopped irrigating that completely, because that was using a lot of water, and I actually get rid of most of the cows, we have just three cows left, for the look of it. Two of the fields of cow paddock have been diverted to vineyards again."*

Interestingly, 55,5% of the interviewees have a partial water recycling system. Generally, they gather water coming out from the cellar to be used in gardens and paddocks or they pump the irrigation run-off into on-farm dams. However, none of those interviewed had a full system of water recycling in place that could allow the use of grey water to irrigate vineyards. The main constraints for this kind of system are the high costs of recycling infrastructure, the small volume of water to be recycled and the over complexity of regulation.

One of the most criticised measures used to counteract drought effects is drilling boreholes. After the second year of drought and the tightening of the restrictions, privates and farmers started to over-drilling boreholes, often ignoring the regulations and undermining the sustainability of groundwater reserves (Galvin, 2018). This adaptation measure has been included in the short-term options due to its unsustainability. Interviewed farmers assumed two opposite positions regarding the utility of boreholes as a possible adaptation option. Of the interviewees, 37% drilled boreholes after the drought a third of which did so to a have a back-up in case of extreme emergency. Some had not yet drilled but had identified the area where a borehole could be drilled. Another third was not satisfied with the results they had from the drilling as the groundwater they found was insufficient or the hole was dry. A third of interviewees who had invested in boreholes were satisfied with the investment and only one farmer identified boreholes as the main strategy to overcome the drought.

However, four farmers expressed a strong opposition to boreholes as a possible drought adaptation option. One stated,

> *"The only thing I am very much against are people who irrigate using borehole water. It's fine to use it for households, but to just pump it up and spray it should be criminal."*

Another stated similarly,

> *"But when the drought comes…oh oh oh……then you got problems, then people go down, drilling some boreholes and doing all this non-sense things. The problem is that when there is no rain, where do you get water? Underneath? And where this water come from? from the top! So, they are making one problem, two problems. They might worsening the situation."*

Another adaptation measure implemented by a few farmers was clearing riparian rivers and catchments of invasive and alien plants. This activity was implemented in collaboration with the government of the Western Cape within a programme to enhance water efficiency and the quality of the Berg River Catchment (Inland Water, 2018). Other farmers are cutting trees along the side of water courses to reduce competition with the crops and use the wood chips to enhance soil water retention. One farmer described this process:

> *"We did 900 cubes of gum trees cutting along the river sides, we get big machine to cut, chip them up".*

A few farmers are trying to use wood chips to increase soil moistening, diminish evaporation and control weed growing. All farmers claimed to have experimented with this practice during the drought and saw results in the following years.

Weed control was also used to avoid competition for water. For the same purpose, four farmers decided to cut cover crops. These are usually maintained to control humidity and enhance soil health (FAO, 2013). Many of the farmers interviewed decided just to roll them in advance to contribute to the mulching procedure. Fifteen farmers reported to use cover crops, where 37,5% introduced them during the drought. One farmer is experimenting with different types of cover crops, such as radish, which opens the soil and increases its water infiltration.

Another cover crop in use is clover planted on the river banks and the vineyard rows. This same farm also uses pickets to plant cover crops to reduce tillage and soil disturbance.

Another adaptation option typical in organic and conservation agriculture is 'mulching'. Most of the farmers had adopted this measure before the drought (fourteen farmers were mulching at the time of interviewing and ten reported mulching prior to the drought). The identified constraint to implement this practice is the fact that it is a "costly and labour intensive" operation.

Only one farmer said he stopped the tillage to increase water retention. Another farmer reported to have tried 'disking', which operates to retain crop residue in the soil, thereby allowing faster deterioration. This makes the soil easier to manage. Disking also cuts soil capillaries and reduces water evaporation. This farmer asserted, *"Other farmers say that disking is not working here in South Africa. According to me, it was worthy; we probably saved the production also thanks to disking".*

The effectiveness of the adaptation options identified was evaluated based on those options implemented by farmers who had limited production drop (not more than 10%) and limited rainfall average during the drought (below 500mm). Three farmers met these requirements. Their adaptation methods included the extensive use of soil props, pressure bomb, wood chips, cover crop, mulching, new methods of pruning (Simonit & Sirch, 2018), drip irrigation, evening irrigation, increased irrigation maintenance, and investment in further water storage.

4.3.2 Long-term Drought Adaptation Measures

Considering the evident climate change effects on rainfall variability in the Western Cape, the need to investigate strategies adopted by wine grape farmers to adapt to more frequent drought is essential to the longevity of the sector.

Being perennial crops, decisions concerning grapevine planting relate to long-term aspects of farm management. Some of the planting measures adopted to adapt to a drier climate are changing grapevine orientation to more drought tolerant grape varieties or more drought-resistant rootstocks. Farmers in the Swartland area are already growing drought-resistant varieties, such as

Grenache or petit Shiraz. Farmers in other areas assert that consumer demand remains a key driver to what is cultivated. One of the interviewees stated,

> *"We would like to plant more resistant varieties, but it is a bit difficult to bring in weird cultivars, the usual stuff is Cabernet Sauvignon, Merlot, Shiraz, those are what everybody knows. When someone start to bring weird cultivars as, Carminiere or Italian varieties, it is still a careful learning for the consumers".*

Of the farmers interviewed, 18,5% used drought-resistant rootstocks and another 18,5% planned to introduce them in the future. A main concern with drought-resistant rootstocks is their suitability for the soil, the potential lower grape quality and the uncertainty concerning the future rainfall trend. This was

> *"So, you have to find the right balance to choose the right rootstock; it's not going to be drought for the rest of the life, so you must have a balance between wet and dry, you know the soil can differ also from block to block."*

Some farmers invested in technology to detect water stress and increase irrigation efficiency. The most common technology options are soil probes and 48% of the farmers adopted this tool to measure soil moisture. This technique allows farmers to irrigate according to the soil's actual need and avoid water wastage linked to over-irrigation. Of the interviewed farmers, 18,5% were planning to introduce soil-probing soon. Interestingly, three farmers had probes before the drought, but had stopped using them due to the time required or because they had become obsolete from technological development.One of the farmers who had only recently adopted these tools affirmed that they were a key element during the drought and allowed the farm to have the best yield ever. He stated, "*I am putting more probes in other blocks. It's expensive; it cost 80.000 Rand for eight probes,10.000 Rand each probe, but the loss in crops is a lot more of what I am spending on that, I really cannot complain".*

Two other tools used to detect water stress are the pressure bomb, which measures leaf pressure to identify its water needs, and Fruitlook, which uses satellite imagery to identify a plant's water and nutrient requirements with the view to increase water and fertiliser efficiency (Jarmain et al., 2018). Of the farmers using Fruitlook, 50% adopted it during the drought. The main constraints of this method are the slowness of the software and its excessive complexity.

Following the drought, and to enhance their preparedness for rainfall scarcity, 18,5% of the farmers invested in weather stations which can provide temperature information. All interviewed farmers take rainfall measures.

Another long-term adaptation measure was investment in farm water-storage capacities. This includes building or improving on-farm dams and using water-efficient irrigation systems. Drip irrigation has proved to be more water efficient than sprinklers or other irrigation systems (FAO, 2013). All the interviewed farmers used drip irrigation and 15,5% of the farmers used a mixed system with drip being prevalent. Of the farmers, 84,5% introduced drip irrigation before the drought. The rest had recently switched to drip and appreciated the water saving derived from the change:

> *"All the vineyards had overhead sprayers. (…) It is quite expensive to change, and in the next 3 years we are changing the whole farm from sprinklers to drip. Changing with drip irrigation, it means 70% less water, so our dam can stay full or fuller."*

Of the interviewed farmers, 30% invested in on-farm dams during the drought, either to build a new one or to improve or restore those existing on their property. All the farmers who did this kind of investment have more than 100ha of crop field. Therefore, the size of the farm might be a driver for big investments in water storage.

Some farmers had included improvements in their water-storage capacity in their business plans. Others expressed their desire for kind of investment, but lacked the financial or administrative capacity to get the relevant permits:

> *"We want to build some dams for storage because a lot of rain in the winter is going down to the sea, so that we can just have a back-up for years where the season is like what we got, but it is not that simple. There are a lot of things to get through, to get the permit. I know that there a lot of guys that built dams this season without permit, and they are going to have a lot of problems. (..) We planned to build a dam on these two farms, but we cannot build a dam that is more than 50.000 cubic metres. Some of the neighbours got a BEE or a partnership with their workers so they can build the dam up to 80.000 cubic metres. We are going to build a dam, but we have to do it in the right way, we*

need to have someone to come and do the survey and all the written stuff, so, it costs a lot of money at the end of the day".

Long-term adaptation implies also decisions relating to general farm management strategies, such as expanding the hectares of vineyards or diversifying income streams.

41% of the interviewees were expanding the area under grapevines; 18% were maintaining the business at its current size, and only replacing old vineyards. Another 37% of the interviewees had suspended plant replacement procedures or were reducing the number of grapevines while one farmer interviewed had decided to sell the farm.

When asked why they kept planting despite the limited returns, farmers had varied responses. Some declared themselves to have an optimistic attitude stating that they would have kept farming vineyards anyway, "*I am a farmer, I have to be positive, I won't stop farming*". Others admitted they had good rains, so they could carry the business without too many obstacles linked to the drought, "*We are expanding, a lot of people are pulling out and we are planting. We have planted extensively over the last four years. We are one of the few people to still plant in SA (South Africa). It's all about water*".

On the other hand, of those who were not planting, 60% stated that the drought increased the uncertainties linked to profitability of the wine grape sector, which is acknowledged by all the farmers. As one stated:

"It costs you money to produce grape. The cost to produce grape and the income doesn't compare, especially during the drought, it is the cause of the tonnage that you can get. And with that in the background, with the drought, those two together is not worth farming with wine grape anymore".

Similarly, another farmer asserted:

"Unfortunately, I cannot start to come bigger and bigger, because I am using all my land at the moment but if you don't have enough water to go on, you start to get smaller and then you start to think about the most economic benefit to the farm, that is the most important".

It is probable that this trend could increase in upcoming years if prices are not re-structured, by trying to reallocate the south African wines on the international market through promotion of the quality of South African wine, agreement among the producers, etc . As stated, the long-term trend of rainfall is decreasing, which will affect wine grape production.

Two farmers highlighted that their decisions concerning the business expansion depended more on the uncertainties linked to land reform. One remarked, *"I think that decisions related to the expansion are more linked to the uncertainty around land and the government; it's a big concern".*

However, for many, long-term plans relate to diversification. Of the interviewed farmers, 93% practise another activity beside wine grape farming, such as restaurants, guest houses, fresh produce shops or open cellars for wine tasting. Moreover, to balance the low profitability of the wine sector, some farmers diversified the crop on the farm by planting fruit, which has a return on investment of around 8%-10% compared to the current 1% of the grapevines (VinPro, 2018).

> *"Stellenbosch people do not plant vineyards, they are planting citrus[8], they are changing on what is more profitable, because return on investment for grapevines is just 1%. You see? The average return should be 15-20%. So, if someone has to survive with farming, they think hard to replant vineyards".*

However, in some cases the drought prevented them from further investing in fruit and vegetables, as they realise that water availability is limited in the region and the fruit water demand per hectare is higher than those for grapevines (Green Cape, 2017). Below are some quotes related to diversification and the drought:

> *"We wanted to plant more citrus to diversify a little bit our income, but then we decided with the water problem it's not going to be better. If you look at the water usage just in the Western Cape, it's not that the farmers are planting more vineyards or more fruits, it's mainly because in the last past five years a million people came from Kwa-Zulu Natal and Gauteng to Cape Town, do the calculation of how much water they use per day, so I do not think that the water problem is getting better"*

In related to fruit farming, another farmer stated,

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[8] *Citrus industry is growing in South Africa. The ha planted on citrus were 3% higher in 2017/2018 than in 2016/2017, this growth is expected to continue based on the significant investments and aggressive plantings of soft citrus and lemons.* (USDA, 2019). *After the results of 2018/2019 season, South African increased further the hectares planted on citrus, especially in the Robertson area "as farmers replace wine grapes with citrus". (Wasserman, 2019).*

"A lot of people are planting prunes or citrus, table grapes and berries but all this stuff use more water than grapevines."

Similarly,

"Actually, we were quite fortunate, farmers who had mostly fruits, such as peaches, citrus, had a big knock. The drought definitely affected the crop of one guy I know, he farms plums and he was looking into the trees to see if there were plums, the blooming of the flowers was uneven, the bees did not work.

Vineyards do not have problem related to pollination, but fruit had problems with the drought. Definitely in the fruit industry, the drought played a bigger role than in the wine industry."

A third farmer stated,

"And we used to have fruit etc., but now we don't have enough water to plant fruit trees. Unless, we have very strong underground water – we've always treated underground water as our drinking water and not for irrigation purposes. Maybe that's wrong – I don't know what's better".

Examining the options adopted by farmers to face the drought, short-term and incremental options were preferred to transformative long-term strategies. Farmers who planted more drought-resistant rootstock or cultivars, diversifying crop and activities because of the drought, investing in water-storage capacity and those who decided to stop expanding their wine grape activity are in the minority compared to those who preferred reactive and incremental adaptation options. Looking at the farmers' answers, we can assume that the main determinants of action or lack thereof was the uncertainty regarding the climate trend, the limited financial capacity for big investments, the belief in grapevine drought resilience and the cultural attachment to viticulture. As one of the farmers said, "*It's more a cultural thing; people grown up with this; it's a love for their grapevines."*

4.3.3 Social and Knowledge Network

Only 26% of the farmers engaged in any sort of cooperation with other farmers to adapt to the drought. Research participants claimed to exchange information about their situation at informal levels, with one saying, "*We generally do exchange information, in front of a beer, at the bar*". Cooperation also ranged from clearing invasive plans, preventing fire and building channels to connect dams, to water donation for public facilities such as primary schools and museums. A farmer said that the drought was a positive thing as it strengthened the relationship between his farm and its grape providers. On the contrary, another affirmed that the drought was a major source of tension with neighbours. He stated that he was accused of exceeding his water allocation as he was seen to maintain a high level of production despite the scarce rainfall and tight restrictions.

One way to strengthen social capital is through producers' associations. All the farmers interviewed were members of a producers' association, but only a few used the services frequently. Of all the farmers, 67% believe that the service provided by producer associations is useful, especially the recent research available on the sector and soil mapping consultancy.

Moreover, prior to the drought, farmers had formed researching groups using some grapevine blocks of a members' farm to run agronomic experiments. A recent research started during the drought concerns the use of different types of cover crops and the effects they have on soil water retention capacity. According to Dowd et al. (2015), strong knowledge networks facilitate the adoption of more transformational adaptation options, as they enhance the capacity and the attitude to look forward and go beyond the usual strategies.

4.4 Climate Change Beliefs

The research also investigated the farmers' perception of climate change. Interviewees perceived changes in climate such as more thunderstorms, which are unusual for the area. They also noticed scarcer rainfall compared to the previous years; a shorter and later spring season; fewer consecutive rainy days than in the past; weaker winds and cooler night temperature.

Among these weather changes perceived by the farmers, the change in wind raised the attention of the researcher. The wind is favourable to Western Cape wine production, especially in the Berg River district as it cools mid-day temperatures and decreases the incidence of disease. Therefore, weaker winds might constitute an unfavourable long-term change, as they could reduce transpiration, contribute to raising plant temperature, thereby reduce photosynthetic activity (Hunter and Bonnardot, 2007).

Wind run decline has also been identified by Hoffmann et al. (2011), which studied 20 climate stations in the predominantly winter-rainfall Cape Floristic Region (CFR) of South Africa over 30 years. According to this study wind declined significantly at all climate stations by 25% over 1974 -2005. Examining the data of the monthly wind average from the ARC weather stations (Stellenbosch Cordoba (Fig. 20), La Motte (Fig.21), Bellevue (Fig.22), Diemerskraal (Fig.23)), it revealed that the wind shows a decreasing trend over a ten years period (2007-2017) in the areas of Stellenbosch and Franschhoek, while it seems stable in the Paarl and Swartland areas.

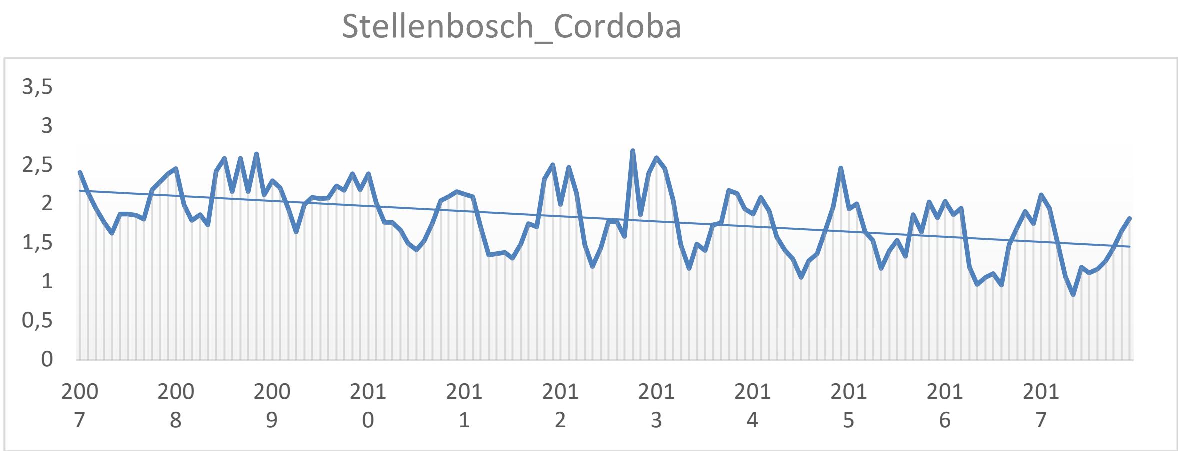

Figure 20: ARC Weather Station, Comp 30663-Stellenbosch_Cordoba. (Stellenbosch area) - Monthly average wind (m/s)

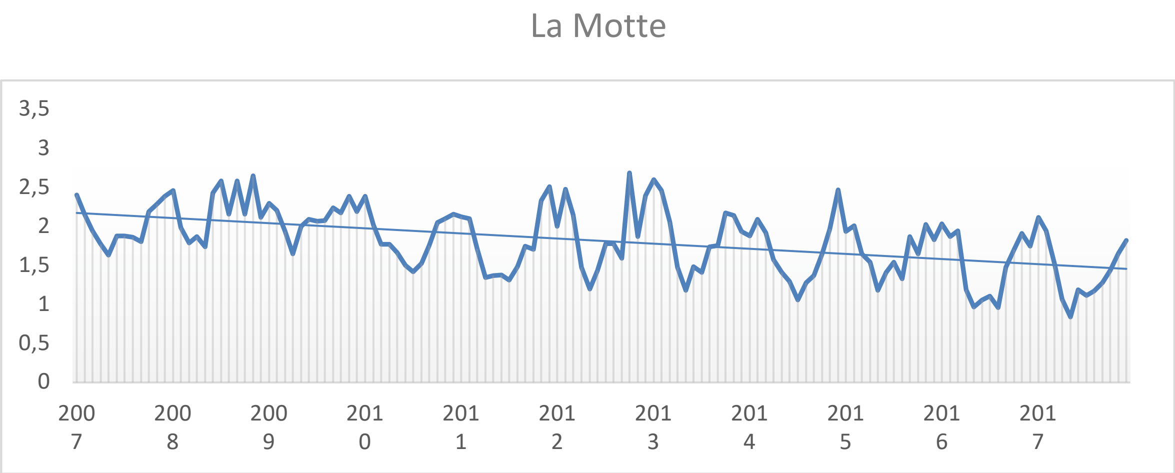

Figure 21: ARC Weather Station, Camp 30453: La Motte (Franshoek area) - Monthly average wind (m/s)

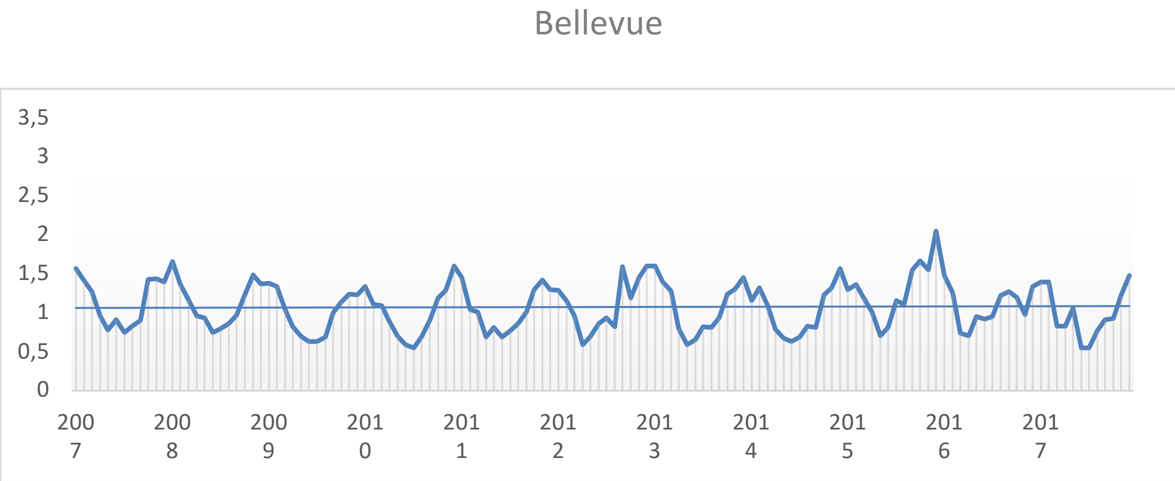

Figure 22: ARC Weather Station, Camp 30667: Bellevue: (Paarl area) - Monthly average wind (m/s)

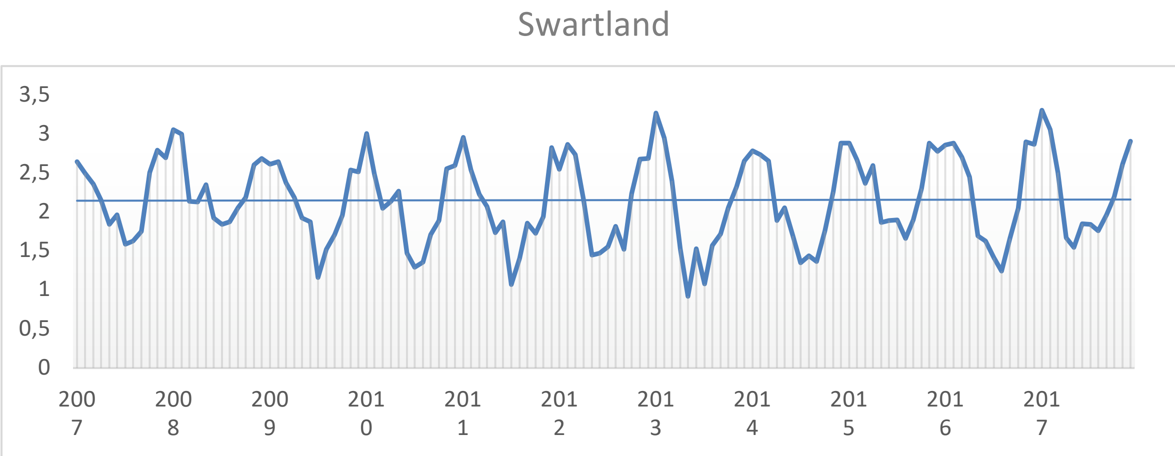

Figure 23: ARC Weather Station, Camp 30404: Diemerskraal. Swartland area. Monthly average wind (m/s)

Interviewees were asked if they believed that anthropogenic climate change might increase the frequency of drought in the future. 67% confirmed their belief in this causality. The rest (23%) did not confirm belief in climate change or in the possibility of more frequent drought in the future. Some preferred not to express an opinion on what they saw as a "technical" topic; some believed in a cyclical trend and that the climate will be "normal" again; some believed that the main cause of higher competition for water sources was due to population increase in the area.

A Chi-square test was conducted to verify the evidence of a relationship between farmers' belief in climate change and those who adopted long term adaptation strategies[4] to counteract the drought's effect. The aim here was to better understand if farmers' actions are motivated by their beliefs. The Chi-Square test showed is no statistically significant relationship between the two variables (Chi square: p= 0,315; df=1; p>0,05). Moreover, no relationship was found between climate change belief and the choice of expanding the business (Chi square: p= 0,148; df=1; p>0,05). This suggests that the main driver for long-term and transformative changes is not linked to perception of climate change but is caused by other factors such as production cost or return on investment.

[4] As mentioned in the previous section, long term adaptation strategies, includes changing grapevines direction, introducing drought-resistant rootstock, introducing drip irrigation, using soil moisture meters, investing in water storage capacity, reducing or suspending grapevines planting operation, and diversifying crops or business.

Chapter 5: Discussion and Conclusions

This Chapter summarises the main findings for each of the research questions. The findings are evaluated in relation to issues examined in the literature review. Finally, some issues worthy of further research are suggested.

5.1 Drought Impact and Wine Grape Industry Vulnerabilities

The 2015-2017 drought highlighted the vulnerability of the wine grape industry in the Western Cape. Interviewed farmers identified many drought impacts: later ripening of red varieties because of water stress; high pH level in 2016; uneven budding caused by adaptive pruning methods; worsening of the Berg River water quality; yield reduction; as well as increased financial and psychological stress.

Phenological alteration due to water stress varied according to the grape variety. Experiences of later ripening are in line with the study from Hunter and Bonnardot (2011) and Pickering et al. (2015), which highlighted the risk of unripe fruit and slower photosynthetic process in cases of severe water stress. Farmers producing red wine confirmed that water stress limited the size of the berries and the smaller size enhanced the quality of the product, as suggested by the literature (Hunter and Bonnardot 2011; Myburgh, 2011,Paliotti et al., 2014; Keller, 2010; Mira and Orduña, 2010; Shultz, 2010). On the other hand, a higher number of hot days over the growing seasons between 2014 and 2017 might have negatively influenced the wine grape quality. This would be in line with the literature on heat stress, as heat stress is catalyses higher alcohol concentration, higher pH level in the berries and wine aroma alteration (Hunter et al, 2010; Hunter and Bonnardot, 2011; Jones, 2005; Keller, 2010; Schultz, 2010; Mira de Orduña, 2010; Webb et al., 2012; Paliotti et al.,2014).

The major impact linked to water stress was the decrease in grape production, where 74% of interviewees experienced a yield drop because of water scarcity. The analysis of the industry's production performance from 2015 to 2018 and the observed rainfall from 2015 to 2017, suggests that water stress remains a main determinant of the crop yield. The chi-square test conducted on the relationship between yield drop and rainfall received on the farm, showed a strong evidence of correlation between the two variables. The research also confirmed the optimal annual rainfall threshold of 500mm. However, yield reduction was linked both to plants' biophysical reaction to water stress but was also partially due to measures adopted by the farmers to limit grapevines stress. Measures included cutting green grapes clusters and reducing bud burst.

According to farmers' statements, governmental water restrictions aggravated the yield loss, even though the greater crop damage was experienced by farmers who had to rely on rainfall and independent irrigation systems and not by those relying mainly on the Berg river. The suspension of water supplies to the agriculture sector was only implemented in 2018, towards the end of the drought, while farmers practicing dryland viticulture or relying on on-farm dams began suffering from drought effects before February 2018. However, the research could not confirm a statistically significant relationship between yield drop and reliance on the Berg river for irrigation. A better understanding of the interaction between these two variables would require examining a larger sample of farmers.

5.2 Cause of Change in Water Conservation Behaviour.

The 2015-2017 drought and water restrictions appeared to have raised water scarcity awareness in the region. This led to reduced water consumption reported by almost all the farmers. 41% of the interviewed farmers admitted to over irrigating their vineyards before 2015. This confirmed the theory that proximity to extreme weather event can trigger adaptation behaviour (Lubell et al., 2007; Adger et al., 2009; Mertz et al., 2009; Haden et al.2012; Mase et al., 2017; Wood et al., 2017). In this regard, it would be interesting to gather more on-field water consumption data and observe if the water consumption lowered permanently following the drought, embracing thereby a long-term horizon.

At the time of research, all the farmers had established drip irrigation systems. 15,5% of the farmers switched from sprinklers to drip irrigation during the drought and acknowledged the latter's benefits both in terms of water efficiency and cost reduction. After the drought, all the farmers engaged in more rigorous maintenance of their irrigation systems and trained their staff to report and fix leakages promptly.

5.3 Adaptation Options Implemented by Farmers

The research sought to answer what adaptation options had been implemented by farmers. It identified an adaptation options portfolio, related both to long-term strategies and short-term responses. The measures adopted can be grouped in four main categories:

1.) **Farming practices** to increase water efficiency (modification of pruning method, cutting exceeding green grape clusters, limiting fertilizer, night time irrigation, winter irrigation, invasive plants cleaning, using of wood chips, avoiding tillage, disking, switching to drip irrigation, using pressure bomb machines, soil probes and remote sensing technology);
2.) **Investment** to increase water storage capacity (boreholes drilling; building or improving on-farm dams); planting decisions (mulching and cover crops, changing grapevines orientation, planting drought resistant varieties and rootstocks);
3.) **Strengthening social and knowledge networks**;
4.) **Adapting farming management strategies**, such as suspending or reducing business expansion and diversifying crop or activity.

The most common water efficiency practice is the modification of pruning and having smaller canopies and fewer grape clusters. The most contested adaptation option was borehole drilling, where some farmers expressed disapproval due to the low sustainability of the practice. The use of technology, such as soil probes or remote sensing, was limited due to the cost or complexity. The research suggests that the effectiveness of soil probes should be further investigated as these tools appeared to have potential to limit production loss and save water.

5.4 Incremental vs. Transformative Adaptation Strategies

The two main transformative adaptation strategies adopted by the participants were income diversification and business expansion management. Diversifying activities were used to offset the financial risks inherent to agriculture and to overcome the structural low profitability of the local wine sector. 93% of the farmers have another activity beside farming, generally in the food and hospitality sector. The research showed that only 14,8% of the farmers decided to diversify their activity because of the drought and two farmers decided to stop their diversification investments in fruit because of water scarcity.

The analysis of the interviews showed that farmers who experienced the highest yield drop from water stress operated in the Swartland District. This result corresponds to the results of the Hannah et al.'s (2013) study, which found that a portion of the Swartland was becoming less suitable for wine grape growing due to climate change effects. The study from the Green Cape association also suggested that farmers in the Swartland should consider less water-intense crops to overcome water shortages issues related to higher competition on water resources in the area (Green Cape, 2018).

Regarding the business expansion, the drought interplayed with the pre-existent trend of low profitability in the local wine sector. This had caused 37% of the interviewed farmers to suspend or reduce plant replacement. Interestingly, the primary producers and number of vineyards were decreasing already prior to the drought, even though production had increased. This may be read as a sign of a general pessimism around the profitability of the sector, which might further limit investment in future adaptation.

Most of the farmers preferred adopting incremental rather than transformative strategies. The major barriers to transformative adaptation were: the uncertainty regarding the climate trend, the limited financial capacity for big investments, the lack of tangible alternatives, the believe in grapevine drought resilience and the cultural attachment to viticulture.

The research also showed that the information exchange among farmers occurred mostly at the informal level and cooperation among farmers is limited, which confirms the behaviour patterns suggested by Nicholas and Durham (2012). The lack of organised knowledge networks might limit the implementation of more transformative and innovative strategies for adaptation. The literature highlights the importance of strengthening knowledge networks both within and outside the industry to enhance transformational adaptation capacities (Dowd et al., 2014).

5.5 Belief in Climate Change and Water Conservation

Most farmers affirmed their belief that the drought was linked to climate change and that water scarcity events might become more frequent in the area.

However, it was found that the adopted adaptation options were related more to short-term solutions. Hence these are conceptualised as coping responses rather than strategic choices implemented to adapt to long-term changes in climate. This was confirmed by the chi-square tests which showed no clear evidence between belief in climate change and the adoption of long-term strategies, particularly regarding business expansion decisions. Hence, it seems that the declared awareness of the link between the drought and climate change might not be translated into long-term adaptation actions. These findings confirm the study from Niles et al., (2016) and Roco (2016), which shows how climate change beliefs often remain at the intentional level without being translated into actual actions.

5.6 Limitations of Study

One of the main limitations of the research is the high variability of factors influencing wine production between farms and within the same farm, which increase the difficulties to identifies common trends for impact and adaptation. Furthermore, it was not possible to provide a thorough analysis of the financial impact of the drought due to time and because of the type of information available to the researcher. For example, the grape price variation and income loss data for the interviewed farmers was not available, for privacy reasons, or the time it would take to gather the data.

Overall, the time constraint was one of the major limits of the research, as it affected the size of the sample as well. It would be useful to analyse a larger sample of farmers to have a clearer idea of the relationship between some of the chosen variables, especially regarding the correlation between the reliance on the Berg River for irrigation and the yield drop experienced by the farmers.

5.7 Suggestions for Further Research.

The interviews revealed many fertile areas for future research. Further investigation might be needed to better understand the relationship between water deficit and grapevine yield at a biophysical level, to identify the actual capacity of grapevine to be drought resistant. Another area for research includes comparing the water intensity and the ROI of various crops to provide farmers with profitable and water wise alternatives for crop diversification. This would be relevant in those areas where crop switching should be considered.

Farmers might increase their adaptation capacities by keeping more systematic temperature and soil moisture records and by monitoring the effects of the adaptation responses they implemented during this drought. This would provide a baseline for future observations and sustainability evaluation.

Considered the key role of production costs in farm management, further research about the drought influence on wine grape production costs and the potential cost limitation deriving from adaptation would be useful to provide an evidence-based incentive for adaptation and an economic value to farmers' adaptation efforts.

It would be also interesting to explore alternative ways to support adaptation measures, such as the creation of crowdfunding at wine club level, for example, which could finance mulching operations or the acquisition of soil probes instead of relying solely on government subsidies.

Furthermore, creating more fluid knowledge networks to enhance evidence-based knowledge and technologic transfer could be evaluated for their improvements in the producers' transformational capacity.

Finally, in order to create a better enabling environment for wine grape farmers' adaptation, government could improve drought monitoring, early warning systems and emergency plans, as farmers struggled to ration water due to the erratic announcement of restrictions. In order to improve monitoring, the development of micro-climate modelling of complex systems should be supported. The administration might also support or implement a system for irrigation evaluation and increase the clarity and the transparency of water allocation procedures.

Appendix I: Questionnaire

Questionnaire	
FRAMING	**General questions** a- How many total ha do you manage? b- In a typical year, do you manage any other crop or animal? What is the percentage of your main crop? c- Did this percentage change in the past 3 years? Are you planning to change the cultivation portion in the future? d- Do you have any other activities source of income besides farming (restaurant, wine tourism, etc.)? Would you like to diversify your activity? Why?
WATER	**Water use** a- Which sources of water did use before the drought? On which are you mainly reliant? (dependent on/independent from the Berg river). And how did it change after the drought? b- Are you planning any further investment in water sources? If yes, Which one? c- If you irrigate, which methods of delivery do you use (furrows/floods, sprinklers, drip, microsprinklers, etc.)? Did it change in the last three years? d- Did you use any methods/tools to measure water consumption and needs? e- How did your water use change from 2015? f- Did you change the irrigation timing/schedule? g- Have you noticed any changes in water quality after the drought? Did it cause any problem for your production?
	Water wise practices/innovations a- What did you do to save water or improve your water efficiency? What are you planning? b- Have you diverted a portion of water to (or away from) wine grapevines at the expense (for the benefit) of other crops? (if they have other crops on farm) c- Have you introduced any **technology** for saving water (which one?)? If yes, when (before or after the drought)? Will you maintain it? Why? d- Have you introduced any **farming practice** (groundwater harvesting, soil moisture practices ex. mulching) for saving water (which one?)? If yes, when (before or after the drought)? Will you maintain it? Why? e- Do you use **recycled water**? When did you start it? If not, would you be willing to re-use water adequately treated? (why?) f- Do you use **Fruit Look**? Why do you think it is useful?

FARMERS' DROUGHT EXPOSURE	**Vineyards exposure** a- How water restrictions affected your production? How do you think they will affect you in future? b- If your water resources are independent from the WCWSS, how water scarcity affected your production (in terms of grape volume and quality)? c- Did you avoid cultivating a portion of land? d- Did you increase or decrease the area devoted to wine grape cultivation? Do you plan to do it (increasing or decreasing)? Why? e- Have you, or do you intend to, switch to more drought resistant grape cultivars or rootstock **Impact on general farm management** f- Did you experience any particular financial or social stress linked to the drought? How did you react to them? g- How the drought affected your long-term planning? h- Did you reduce the labor force after the drought? If yes, how(seasonal/permanent)? i- Did you buy an insurance? Why?
CLIMATE CHANGE	**Preparedness** a- Were you prepared for this drought? **Changes** b- Do you keep records of rainfall? And temperature? c- Do you believe in the fact that climate is changing at the global level? d- Have you noticed any particular change in past local trends in weather? (Temperature increasing, temperature extremes more frequent, annual rainfall, frequency of drought/floods, etc.) e- Do you think that the Western Cape drought is linked to climate change?
NETWORK	a- Have you engaged in any sort of cooperation with other farmers? (if yes, which one?) b- Are you member of any producers association? Do you think producers' organizations provide useful service? Which service do you generally use? c- How do you think the government could support you to overcome the drought? d- Where do you get your information about weather? e- Do you use these services more often after the drought?

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