Economic impact of climate change on milk production: a case study of selected areas in the Free State

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LIST OF ACRONYMS

ACPC	African Climate Policy Centre
AGCMs	Atmospheric General Circulation Models
CSAG	Climate System Analysis Group
CV	Coefficient of Variation
FAO	Food and Agriculture Organization
GCMs	Global Climate Models/General Circulation Models
GHG	Green House Gases
IDF	International Dairy Federation
IPCC	Intergovernmental Panel on Climate Change
MPO	Milk Producers' Organization
NOAA	National Oceanic and Atmospheric Administration
OGCMs	Oceanic General Circulation Models
RH	Relative Humidity
TC	Total Cost
THI	Temperature Humidity Index
TR	Total Revenue
UNFCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children's Emergency Fund
USDA	United States Department of Agriculture
US	United States
WWF	World Wide Fund

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ABSTRACT

Dairy cows are sensitive to increasing temperature and humidity, which affects their feed intake, and causes a direct as well as an indirect impact on milk production. This study aimed at computing the economic impact of climate change-induced heat stress on milk production in the Free State, South Africa. The semi-arid regions of Free State – Bloemfontein, Bothaville and Bethlehem – were selected as representative regions, based on availability of climate data. In this current study, a model developed by - St-Pierre, Cobanov and Schnitkey (2003) was adopted in order to estimate the milk production losses for all representative study areas.

The baseline (1950–1999) and mid-century (2040–2070) climate data as well as Temperature Humidity Index thresholds ($THI_{thershold}$), 70 and 65, were used. Taking present time prices, it was found that with a $THI_{threshold}$ of 70 for Bloemfontein, Bothaville and Bethlehem, a loss of 17 cents, 16 cents and 2 cents, respectively, per cow each day, on average was incurred. Thus, taking the average number of cows in the Free State (Lacto data, 2015) as an example, a farmer would lose about ZAR8 687.00 in a year, on average. While, for a $THI_{threshold}$ of 65, milk production loss showed an increase amounting to 60, 50 and 17 cents per cow/day, on average, for Bloemfontein, Bothaville and Bethlehem, respectively. For the mid-century 2050s data with a $THI_{threshold}$ of 70, and no mitigation strategies being employed by farmers, milk production loss doubled for all the three study areas.

To understand dairy farmers' perceptions on climate change-induced heat stressed, a semi-structured questionnaire was used for Bloemfontein as a sample region. Farmers responded that increasing temperature and variability of rainfall as comprising one of the reasons for their lower milk production. However, this awareness is not consistent with the fact that almost all interviewed farmers employ no measures to adapt to the increased heat, nor do they use any measures to mitigate heat stress.

Using a model applied by St-Pierre, Cobanov and Schnitkey (2003), this paper computed milk production loss when farmers employ moderate heat abatement strategies (wetting and forced ventilation) for the mid-century climate data (2040–2070). It was found that production loss per cow reduced by more than 50 % and consequently lowered revenue losses for farmers. It is recommended that exhaustive analysis of the economic impacts of climate change-induced heat stress on milk production should be done, as it is an important sector in alleviating household food insecurity in South Africa.

Keywords: Climate change, Heat stress, milk production, Economic loss, Revenue loss

CHAPTER 1: INTRODUCTION

1.1. Background and Motivation

Economic growth (and with it, poverty alleviation) has unequivocally been one of the major goals pursued by world leaders for centuries. These goals have resulted in an expansion of large-scale industries and increased rate of population growth; and with it, the most expensive and inevitable opportunity cost – climate change – has followed. The direct as well as the indirect impacts of climate change, affect the production level of every sector in a given economy; primarily, the agricultural production potential, including the animal productivity (meat and milk), of the agriculture sector is highly affected. According to Kaiser (1993), agriculture takes the leading role among the many systems which are expected to experience alterations as a result of climate change. The productivity of major crops, for example, will be lowered due to occurrences of high temperature during the reproductive period (Teixeira, Fischer, van Velthuizen, Walter, and Ewert, 2013). Kaiser (1993) further stated that the vulnerability of agriculture is technically complicated because of the changes in temperature, precipitation and solar radiation that have a direct impact on agricultural production levels. The effect of climate change is expected to influence crop and livestock production, water balance, raw material supplies and other components of agricultural systems (Adams, Hurd, Lenhart and Leary, 1998).

In developing economies, where rain-fed agriculture is highly practised and very few farmers use irrigation systems, current agricultural methods are less likely to be able to mitigate climate change. Comprising many sub-sectors within it, such as livestock and dairy farming, and being the primary source of national income for many developing countries, agriculture does need special attention. Adams et al. (1998) noted that crop and livestock yields are directly affected by changes in climatic factors such as the incidences of intense events like droughts, floods and wind storms. Agriculture is also directly impacted upon by the extreme events that occur owing to climate change, which the world has dealt with over the past decade. All of these are aggravated by the hunger of human beings for larger manufacturing industries and faster cars, urbanisation and the inefficient use of grazing land which have led to deforestation (Poska et al., 2016; Pease, 2016).Without a doubt, climate change is one of the most environmentally challenging phenomena the world is facing today. According to Pachauri et al. (2014), human activities have altered the environment, resulting in adverse impacts on agriculture and natural resources. Acknowledging this fact, many countries are now striving to protect their susceptible sectors from the effects of climate change by considering and putting forward different adaptation strategies.

The agricultural sector, in general, encompasses two types of economic activities. One involves crops and the other livestock farming. Within the livestock farming practice, other economic sub-components are found, including dairy farming. Dairy farming contributes to both the cultural and economic values of society. According to the Food and Agriculture Organization (FAO, 2015) the value of milk, on a global scale, represented 8.9% of the value of all agricultural products in 2010. Dairy also plays a vital role in creating employment, particularly in developing countries. The International Dairy Federation (IDF) (2013) stated that globally 750 million people are engaged in milk production and that to these, millions of jobs linked with transporting, processing and marketing the milk can be added. The FAO estimates that in East Africa and the Near East, for every 100 litres of milk produced locally, up to five jobs are created in related industries (IDF, 2013). Comprising up to one billion people all over the world (FAO, 2015), dairy farming has become a vital contributor to the enhancement of food security for subsistence farmers, to the sustainability of rural household income and to a country's economic growth and economic development.

Dairy farming in South Africa caters for about 1.2 million dairy cattle, employs about 60000 farm workers, and provides 40000 people with indirect jobs within the value chain, such as in the milk processing and milling industries (Lacto Data, 2014; DAFF, 2015). Based on the production systems currently prevalent in the regions, milk producing areas in South Africa are divided into six regions. These are KwaZulu-Natal, Southern Cape, Western Cape, Central Highveld and Free State, Central Eastern Cape, and Southern Eastern Cape. However, South Africa contributes very little dairy products to the world market, about 0.5%, with the European Union and New Zealand contributing about 31% and 30%, respectively (MPO, 2014). South

Africa, on average has imported dairy products in value amounting to over ZAR440 million over the past ten years, and in quantity amounting to over 28 million kg (MPO, 2014). One possible reason for these figures could be that the existing dairy farms in the country have not produced enough to fulfil domestic demand. The numbers of milk producing farmers in Free State, for example, have reduced from 919 in 2008 to an astonishing 281 in 2015. One of the reasons for milk production loss in the semi-arid areas is the changing of climatic conditions. Thus, Climate change is likely to affect milk production due the sensitivity of dairy cows to excessive climatic variables such as temperature and humidity. These losses of milk production occur mainly in the summer months that have a potential to significantly impact the economics of dairy industry in arid and semi-arid areas.

1.2. Problem Statement

Food insecurity is a major challenge faced by many developing countries, specifically countries with a large number of households practising small-scale farming in conventional agricultural systems. Among the many challenges that put pressure on countries striving to meet food security are increasing population sizes coupled with unstable climatic conditions (Stringer, 2000). Countries with agriculture as their economic backbone need to find means to sustain their economy through adaptation strategies and by mitigating the effect of climate change, so as to improve household income through increasing productivity of crops, livestock and dairy products.

Dairy, as a sub-sector of agriculture and an important part of human nutrition, can play a major role in the formidable challenge of achieving food security. As part of a balanced diet with essential nutritional values, dairy products contribute to households' food security (MPO, 2014). It is also an important source of income and employment for households. The 2014 South African Dairy Market Value Chain report states that the dairy industry is important to the job market, with over 1961 producers having high employment capacity. This is essential in creating household food security indirectly through income earned by farmers. The Report further explains that milk production is a major source of foreign exchange, for example, it accounted for exports to the value of ZAR1, 101 million in 2012.

However, the dairy sector is no exception in sharing the impacts of climate change. Dairy cows are sensitive to heat stress and high humidity and being faced with such circumstances, experience lower milk production, which increases costs to farmers. According to Maugeret al. (2015), the annual loss attributable to heat stress in the USA could more than triple, and be over and above UD$2 billion by the end of the twenty-first century. Climate-induced heat stress, the inefficiency of feeding systems, and post-harvest mismanagements are challenges to dairy farming and are challenges which lower revenue earned. According to Calil et al. (2012), dairy farmers have slim profit margins and are also vulnerable to fluctuations in production and milk prices. Dairy production faces many challenges, especially in smallholder dairy farming, including heat stress (Key et al.,2014; Calil et al., 2012), efficiency of feeding systems (Gertenbach, 2006; Saha et al., 2004) and in general, pre-harvest and post-harvest management systems (Yibeltal et al., 2014). Given the aforementioned problems, it is important to make an economic analysis of the factors which have a significant impact on dairy production and then furnish basic information for designing appropriate and locally applicable intervention options at various stages of the milk production chain. Hence, it is plausible to study the factors which have the potential to affect this vital dairy sector so that that appropriate measures could be put in place.

Many studies have been conducted to estimate climate change and climate-induced effects on dairy production in the United States of America. Notable among such studies are Calil et al. (2012), Key et al. (2014), Mauger et al. (2015), and Key and Sneeringer (2014), to mention a few. These studies have all shown the importance of the sector to the economy and its vulnerability to climate-induced heat stress resulting in an estimated annual loss of millions of dollars. Knowing these figures will have implications for the adaptation strategies that should be followed, and on the sector's importance in achieving food security. However, few studies could be found relating climate change to dairy farming in Africa. Moreki and Tsopito (2013) studied climate change effects on dairy production in Botswana and suggested certain mitigation strategies, such as using smaller dairy breeds like

Jersey, growing fodder crops, and utilisation of crop residues. Nesamvuni et al. (2012) assessed the impact of heat stress on dairy cattle productivity and reproductive performance under projected future climate conditions using the Temperature Humidity Index (THI) as an indicator of the degree of heat stress. They suggested low- to high-cost adaptation strategies. Low-cost measures include reducing overcrowding, maximising shade, and improving ventilation, while high-cost measures include designing and installing of thermo-air conditioning. These limited studies that have been done did not project the economic loss of milk production attributable to climate change and hence underestimated the impact of climate change on the agricultural sector.

Studies conducted by different institutions and researchers have shown that climate change has enormous potential to affect agriculture and hence threaten food security. Thus, with its immense economic potential owing to its high employment, the dairy industry's importance in achieving food security and high capacity to earn foreign currency justify the interest in examining the potential economic loss of milk production due to climate change. The findings of this study give the different parties in the dairy sector the understanding required to bring about a meaningful change and exploit the potentials of milk production. The current study, therefore, focused on the following research questions:

i. How can the current or historical milk production losses be assessed in comparison with future projected scenarios, with and without improved adaptation strategies?

ii. How much revenue from annual milk production of dairy cows is lost due to changes in temperature and relative humidity?

1.3. Research Objectives

The main aim of this study is to:

Estimate the revenue loss of milk production in dairy cows as influenced by changes in temperature and relative humidity. The estimation is done for baseline (1950–1999) and mid-century (2040–2070) climate scenarios with and without the application of adaptation strategies, in three selected semi-arid regions of Free State Province, South Africa.

Specific Objectives:

The specific objectives in this study are to

i. Compare the milk production loss for the historical (baseline) period and the projected future climate scenarios, with and without adaptation strategies, in all selected study areas.

ii. Assess the economic losses of milk production from dairy cows with changing temperatures and relative humidity in the three selected semi-arid areas of Free State.

iii. Investigate the perceptions of dairy farmers on milk production losses and their adaptation strategies with changing climate in selected dairy farms in Bloemfontein.

1.4. Organisation of the study

The primary focus of the current study is the economic loss in milk production attributable to changes in temperature and relative humidity.

This thesis comprises of five chapters. Chapter 1 deals with the introduction part that includes background, statement of the problem, and research objectives. In Chapter 2, the impact of climate change on agriculture in general, and in dairy sector in particular, is addressed. Chapter 2 begins with reviewing related literature and includes historical, theoretical and empirical reviews. In Chapter 3, the study area description and the research methodology are presented, including data sources and variable descriptions, the model selection and methods of analysis, and the questionnaire set-up. Results and discussions of the findings are presented in Chapter 4 in the form of tabular and graphical representations, together with their interpretations. Finally, in Chapter 5, conclusions and policy implications are presented.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter gives a summary of relevant literature, including empirical findings on the influence of climate change on the production of livestock in general, and milk production specifically. The concept of climate change, which is usually manifested in heat stress and its impact on a country's economy, is also part of the discussion in this chapter. Furthermore, a detailed review of relevant literature on measurements of heat stress and empirical findings on the impact of climate change on milk production are discussed. Finally, this chapter concludes by relating the relevant literature to the current study.

2.2. Climate change

Climate change is undoubtedly one of the major challenges that the world faces today. Recurring droughts in many parts of the world, El Niño events, and the persistent and increasing heat stress are all indications that the earth's environment has changed, and according to the Intergovernmental Panel on Climate Change (IPCC, 2007), this time the changes are anthropogenic (climate change originating from human activities). According to the United Nations Framework Convention on Climate Change report (UNFCC, 2011), climate change refers to the alteration of climate that is attributed directly or indirectly to human activity and which changes the composition of the global atmosphere. Further, UNFCC (2011) suggests that these anthropogenic pressures on climate variables have increased in a multidimensional way due to factors pressurising earth, affecting natural resources and ecological balance. A wider explanation of climate change is given by the IPCC defining it as the alteration in the condition of the climate that can be identified by changes in the mean and/or the variability of its properties persisting for longer periods, typically decades or longer, whether due to natural variability or as a result of human activity (IPCC, 2007). In both definitions, climate change could be taken as a persistent change in the properties of climate for a prolonged period. Whether caused by human beings striving for economic growth or by natural causes, every country has to deal with the decision of how to adapt to the changes.

Newell and Bulkeley (2010) stated that climate change is not just a phenomenon in one country but is rather a global issue. They suggested that this global effect comes from the physical nature of the problem; that is, emissions in one place and time contribute to increasing atmospheric concentrations, which in turn will have impacts across the globe. According to IPCC (2007), the concentrations of carbon dioxide, methane, and nitrous oxide in the atmosphere have increased strikingly as a result of human activities. Under such high levels of these greenhouse gases, thorough research and development about how to live and adapt, by growing crops that can tolerate heat and extreme weather must not be taken for granted.

Economic productivity – the efficiency with which society transforms its human and other natural resources into new goods or services – is a key outcome in any society because it has a direct impact on individual well-being (Burke, Hsiang and Miguel, 2015). Climate and weather influence activities in both agricultural and non-agricultural productions. However, as Burke et al. (2015) stated, it remains poorly understood how the impact of climate change aggregates within complex human societies to affect overall economic productivity. Distinguishing these influences of climate change on the economy remains an essential problem, in the emerging field of coupled human–natural systems. This has implications for our understanding of historical patterns of human development and for how the future economy might respond to a changing climate.

Average surface air temperatures so far this decade are about 0.9°C higher than they were in the 1880s. According to Burke et al. (2015), if future adaptation imitates past adaptation, unmitigated warming is expected to change world economy by reducing average global incomes roughly by 23% in 2100. This adds to the widening global income inequality, relative to scenarios which do not pertain to climate change. Labour supply, labour productivity, and crop production all declined when temperature thresholds reach between 20 °C and 30 °C (Burke et al., 2015). With the increasing temperature, economic productivity and efficiency decline, making poverty alleviation and achieving food security even more hard for developing countries.

2.3. Global Climate Model's (GCMs)

Climate models are based on well-established physical principles and have been verified to replicate observed characteristics of recent climate and past climate changes (Randall et al., 2007). Climate is driven by a general circulation of the atmosphere. General Circulation Models, or commonly known as Global Climate Models (GCMs), are mathematical models designed for forecasting and understanding climate change. They are advanced tools for simulating the response of a climate system to increasing greenhouse gas concentrations (IPCC, 2013).

Although GCMs are used for many applications such as simulating and investigating evolutions, as well as interaction, of climate systems, they are mainly known for projecting future climates under different scenarios of increasing carbon dioxide (Lupo et al., 2013). GCMs specifically have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact analysis. Since the first IPCC assessment in 1990, GCMs have provided outputs which have been important sources of information (Perez et al., 2014). Technically, to represent the climate, GCMs divide the earth, the atmosphere and ocean into a grid where the values of the predicted variables (surface pressure, wind, temperature, humidity and rainfall) are calculated at each grid point over time, to forecast their future values (World Metrological Organization, 2016). The two important components of GCMs are scientifically known as Atmospheric General Circulation Models (AGCMs) and Oceanic General Circulation Models (OGCMs).

2.4. Economic impact of climate change

Measuring the economic impacts attributable to climate change is a very complex matter in any given economy. This might be attributed to an extremely broad economy and diversified society, as well as sectors. Many studies argued that climate change hurts sectors of the economy, especially the agricultural sector (Calil et al., 2012; Key et al., 2014). Climate change is projected to affect the rate of economic growth through adverse impacts on natural systems and resources, infrastructure, labour productivity, and reduced income opportunities (Kreft et al., 2010). In contrast to these arguments, Deschenes and Greenstone (2015), using a country-level panel data file from the Census of Agriculture, developed measures for the impacts of climate change on the profits from agricultural operations that accrue to the owner of land. They discovered that climate change could actually benefit some owners of agricultural land positively by earning them $1.3 billion (in 2002 dollars) in a yearly increase in agricultural-sector profits. This, however, could only be possible if farmers were to take appropriate adaptation methods and use crops which could adapt to changes in climate, which is not the case for most developing countries.

The change in climatic factors alone are unlikely to verify winners and losers, as the vulnerability differences and adaptation strategies which are taken can notably shift the outcome for any of the changes (O'Brien & Leichenko, 2000). Furthermore, O'Brien and Leichenko (2000) explain that when it comes to climate change, a win might refer to any net advantage from changes in temperature, rainfall, or climate variability where such advantages could be measured by increased productivity.

Climate change mostly has a negative impact in many areas of the world (Gregory et al., 2005), but it has a positive impact for a limited period of time by providing a favourable air temperature for plant and animal life (Gornall et al., 2010; Thuiller et al., 2005). For instance, the increase in atmospheric temperature of the temperate region provides the region with a longer growth period and also increases in atmospheric CO_2 level, which will serve as additional nutrient for trees growing in the area (Hardy, 2003; Gornall et al., 2010). However, adverse impacts of climate change are more dominating than its advantages (Munasinghe & Swart, 2005; Hardy, 2003). The 'winners versus losers' concept is said to be counter-effective when it comes to attempts to achieve global harmony or agreements in decisions on climate change. This is particularly the case where most of the world's population have very few alternatives to adapt or mitigate climate change, and thus the 'winners versus losers' concept is unconvincing and to some extent illogical.

Multiple factors are responsible for climate variability and climate change, and are mainly anthropogenic in nature (Hardy, 2003; UNFCC, 2011). The pressure from human beings on the climate system is apparent, and recent anthropogenic emissions of greenhouse gases are the highest in history (Pachauri et al., 2014). Variations in many extreme weather and climate events have been observed since the year 1950, including changes which have been linked to human influences. Such changes include events such as decreases in cold temperatures and increases in warm temperature extremes, increases in sea levels, and increases in the amount of heavy rainfall events in many of the regions (Pachauri et al., 2014).

Climate variability and climate change are expected to disturb sustainable economic growth, make poverty reduction more difficult, increase the inequality gap, further erode food security, and extend existing and even create new poverty traps (Pachauri et al., 2014). Increased greenhouse gases are furthermore projected to increase the dislocation of people, particularly in developing countries with low incomes (Pachauri et al., 2014). These displacements can indirectly increase possibilities of conflicts and violence by intensifying well-documented drivers of conflicts, such as poverty and economic shocks. Political issues with respect to natural resource management are also crucial to any government in the world because they determine the existence and extent of strategies for solving problems associated with climate change (McCright & Dunlap, 2011).

The places where people live are chosen with respect to the local climate (Gowlett, 2006). Global warming creates extremes of precipitation in areas near each other, and an increase in precipitation causes storms (Lonfat et al., 2004). It can also result in drought by relocating the precipitation, resulting in a lack of rainfall, and an increased temperature (Gregory et al., 2005). The other reason is that global warming cause's oceanic evaporation and soil erosion, resulting in many problems (Solomon et al., 2007). Some other effects of global warming on the livelihoods of human being are its effects on ecological niches (Walther et al., 2002) and its creation of complementary conditions for the spread of invasive plant and animal species (Gregory et al., 2005; Garrett et al., 2006; Thuiller et al., 2005). The number of newly emerging diseases are increasing from time to time (Algore, 2005; Joly et al., 2004) and vectors for emerging infectious diseases, like rodents, mosquitoes, lice, fleas, snails, ticks and bats, are expanding their ranges (Gregory et al., 2005; Pascual et al., 2006; Lafferty, 2009; Patz et al., 2005). Furthermore, the re-emergence of formerly eradicated diseases, like Evian flu and the West Nile virus, is being observed (IPCC, 2001; Obi et al., 2010). In addition, ground and marine species loss, both plant and animal is progressing at a rate much higher than the normal rate (Balmford et al., 2005; Thompson et al., 2009). Global warming also reduces water availability (Munasinghe & Swart, 2005; IPCC, 2007; Gore, 2006).

2.5. Climate Change and Africa's Agricultural Sector

The agricultural sector is one of the economic sectors of a country that is closely linked with, and highly dependent on, the environment. This makes it one of the most vulnerable sectors expected to be affected by climate change. Agriculture takes the leading role in undergoing changes as a result of climate change (Kaiser, 1993), technically because changes in temperature, precipitation, and solar radiation have a direct impact on crop and livestock production. Agriculture, as one sector of the economy that is directly and indirectly linked to climatic variables, is likely to be affected by climate change (Fisher et al., 2015).

The IPCC (2007) projects Africa to be highly susceptible to major changes in climate. With its high dependence on agriculture, Africa is already a continent prone to be adversely impacted on by the outcomes of climate change. One third of the African population is expected to live in drought-vulnerable areas and about 220 million people face the impacts of drought each year (Nkondze et al., 2013). African countries are indeed vulnerable to greater impacts of climate change and variability, in part because they often lack adaptive ability or strategies. Because large proportions of the population are greatly reliant on climate-sensitive livelihoods like agriculture, the continent's vulnerability to climate change will increase (Nkondze et al., 2013).

African countries are faced with many challenges including poverty alleviation, reduction of illiteracy, weak institutions, low levels of health care, poor access to resources (including forests), desertification, and land degradation. All of these exacerbate the impact of climate change on the continent (UNDP, 2007). The African Climate Policy Centre (ACPC, 2011), has underlined the challenges African farmers are currently facing due to climate change (let alone expected future increases in temperature):

> "Currently, at 0.74 °C of warming, African farmers and pastoralists are seeing changes in the timing of rains, in the severity of rains, in the temperatures they and their crops and animals are exposed to, and in the progressive drying of their soils. Food production is already threatened by the temperature rise of the last century, and the committed warming due to greenhouse gas emissions of the last decades." (ACPC, 2011)

Climate variability, through its impact on agriculture's output, is anticipated to erode food security. According to Pachauri et al., 2014 due to expected climate change by the mid-21st century, global marine biodiversity reduction in many regions will challenge the sustained provision of fisheries productivity and other ecosystem services. Furthermore, the Pachauri et al., 2014 explained that global temperature increases of ~4°C above late 20th century levels, together with increased population might put pressure on food security. Climate change is also expected to reduce renewable surface water and groundwater resources in most dry subtropical regions, thus increasing competition for water among sectors. The impact of climate change on the agriculture sector of the African continent will increase the challenges faced in the efforts to achieve food security. Increasing population expansion may continue to be one important hindrance to achieving improvements in food security for some countries, even when the world's people as a whole ceases growing sometime during the present century (Thornton, 2010). According to a Haen (2003), more than 814 million people in emerging countries are malnourished, of whom 204 million live in countries of sub-Saharan Africa.

Worldwide, Africa is the only continent where populations are projected to continue increasing throughout the twenty-first century (United Nations International Children's Emergency Fund, 2014). The United Nations International Children's Emergency Fund (You, 2014) states that with 1.2 billion people living in Africa, and expected to double by 2050 to 2.4 billion, food security is and will continue to be one the major challenges faced by the continent. With the growing population and projected economic growth of the continent, demand for dairy products will increase. According to Rakotoarisoa, Iafrate and Paschali (2012), both dairy and other livestock products have a high income-elasticity of demand, especially at low-income levels.

This means that increases in income lead to large increases in demand for livestock products. Thus, per capita income growth will translate into significant increases in demand for livestock products.

Southern Africa is a largely semi-arid region with high rainfall variability, characterised by frequent droughts and floods (Shiferaw et al., 2014). According to a Goldblatt (2010), climate-soil combinations leaves 12% of the country suitable for rain-fed agricultural outputs and only 3% is considered truly fertile land because of climate and soil combinations, unlike India where arable land covers 53 % of the country. Ranking fifth in terms of population size in Africa, South Africa has been striving to achieve household-level food security. South Africa is particularly susceptible to the impacts of climate change because many of the agricultural sectors are sensitive to climate change (Griffin, 2012). Griffin (2012) further noted that it is not only small-scale farmers who are highly vulnerable to the effects of climate change, but large commercial farmers will also be affected by water restrictions. Calzdilla et al. (2014) explained that South Africa is likely to experience higher temperatures, coupled with lowered rainfall, as a result of climate change. South Africa would have to improve its baseline investment in agricultural research and more than double its irrigation development (Calzdilla et al., 2014) to adapt to the adverse consequences of global climate change. The Food and Agriculture Organization (FAO, 2009) has stated that temperatures are likely to increase by between 1.5 and 4°C. The African Climate Policy Centre (ACPC, 2011) has reported that crops will fail too often for maintaining current livelihood strategies and that the temperature rise might be beyond capabilities for agriculture in Africa, making adaptation in some regions impossible.

The major threat that climate change poses will be on food security and extended drought in Africa. By 2020, it is expected that between 75 and 250 million people could be exposed to increased water stress because of climate change in Africa (FAO, 2007). The feeding crop sector, together with livestock sector, needs to come up with a way out and new strategies for maintaining and increasing production potential under the altered climatic conditions and increasing food demand of a growing population (Babinszky et al., 2011).

It has been said, and empirically proved; on many occasions that African agriculture is highly dependent on climate and is consequently vulnerable to any change which occurs in the environment (Calzdilla et al., 2014; Babinszky et al., 2011; Griffin, 2012). There are high levels of poverty in the rural parts of the continent because many of the rural households rely heavily on agricultural yields for income generation. There is no doubt that the impacts of climate change should be considered in policy formulations if sustainable economic growth is to be achieved in the continent. The efforts in combating the challenges of climate change are proven to be daunting, financially costly, and may be even more challenging when it comes to economic policy designs for African countries.

2.6. Milk Production and Climate Change

Animals have their own thermo-neutral zone (zone of thermal comfort), which is a range of temperatures in which the animal can maintain normal body temperature without becoming stressed. Above this range of temperatures, the animal will reduce its dry matter intake (DMI), reduce reproductive performance, and decline overall in productivity (St-Pierre et al., 2003; Mauger et al., 2015; Key et al., 2014). Although many factors limit an animal’s development and performance, the variability of climate events is among the first and critical limiting factors (Renaudeau et al., 2012). Environmental factors, including temperature, rainfall (quantity and distribution), sun hours and soil types, play a significant role in livestock production (Gertenbach, 2006). Heat stress impairs production (growth, meat and milk yield and quality, and egg yield, weight, and quality), reproductive performance, metabolic and health status, and immune response (Nardone et al., 2010; St-Pierre et al., 2003).

In the event of increased heat, which can be attributed to increased temperature, dairy cows have proven by many studies to be less productive (Key et al., 2014; Calil et al., 2012; Key and & Sneeringer, 2014; Mauger et al., 2015). Any extreme weather conditions (cold or hot) are major factors which can adversely affect milk production in dairy cows, especially in animals of high genetic merit (Nardone et al., 2010). In dairy cows, a range of factors which are part of the environment, such as temperature and humidity, play a major role in the fertility, reproductive performance and milk yield of the animals (Babinszky et al., 2011). Their feed intake will decrease and they will take up a higher bodily energy demand to maintain a constant body temperature, which according to Allen et al. (2013), is energy which could have been utilised for the production of milk.

A reduction in feed intake will lead to a decline in milk production due to biological reasons (Rhoads et al., 2009; Allen et al., 2013). Moreki and Tsopito (2013) explained that for dairy animals, a lower milk yield and a decline in animal weight gain are results of high environmental temperatures and poor feeds. Seasonal variability's in milk yield and composition are evident in cattle due to the direct and indirect effects of increased temperature (Collier et al., 2011). Furthermore, Collier et al. (2011) stated that heat pressure in cattle is characterized by decreased feed intake which contributes to the decreased milk yield. The thermo-neutral zone for the lactating dairy cow is estimated to be a temperature varying from -5 to 23.9ºC, however, the temperature above 23.9ºC, however, known to lessen solids-not-fat, protein, lactose and fat percentage of milk (Collier et al., 2011).

One widely used heat stress measurement is the Temperature Humidity Index (THI), initially aimed at calculating heat stress for humans by Thom (1958) and later on applied to dairy cows by Berry, Shanklin and Johnson (1964). It includes the combined effects of environmental temperature and relative humidity: lower temperatures at high humidity give similar heat stress as do higher temperatures at lower humidity (Dunn et al., 2014). With stable temperature, milk production loss will rise with increasing humidity, mainly because of the direct impact of humidity on the THI_{max} (Mauger et al., 2015). Dairy cattle are said to be in their comfort zone when the THI is less or equal to 72, whereas any rise above that brings stress to the cows. The THI threshold has been identified to be between 70 and 72 by many studies – St-Pierreet al (2003); Du Preez (2000); Mauger et al. (2015) – but modern high-producing cows will start to experience heat stress at a THI of 65–68 (Dunn et al., 2014).

Economically, a decrease in milk production means a loss of profit for the dairy farmer, a reduction in the supply of dairy products for the consumers, and loss of foreign exchange that could have been earned from exports to other countries, as a whole. Mauger et al. (2015) studied the impact of climate change on milk production in the US and found that an amount of $670 million is lost per year and this could amount to $2.2 billion per year by the end of the twenty-first century. Key et al. (2014) studied the impact of climate-change-induced heat stress on milk production by using an econometric model which estimated the relationship between yearly average heat load and dairy productivity. They found that in 2010, the annual milk production for the average dairy farm was lowered by about $39000, compounding to $1.2 billion in lost production for the whole dairy sector.

Although not much work has been done to estimate milk production loss in currency terms, some studies have shown that climate change could have a significant impact on milk production in Africa. Moreki and Tsopito (2013) studied climate change effects on dairy production in Botswana and suggested some mitigation strategies, such as using smaller dairy breeds like Jersey, growing fodder crops and utilisation of crop residues. Nesamvuni et al. (2012) assessed the effects of heat stress on dairy cattle productivity and reproductive performance under projected future climate conditions. They used the Temperature Humidity Index (THI) as an indicator of heat stress likely to be experienced by dairy cattle, and from their findings, they suggested low-cost to high-cost adaptation strategies. Low-cost measures include reducing overcrowding, maximising shade, improving ventilation, and high-cost measures include designing and installation of thermo-air conditioning. According to Donnelly (2012), there are three heat stress symptoms in dairy cattle which trigger economic loss:

1. **Decreased dry matter intake:** Cattle and specifically dairy cows, will considerably reduce dry matter intake during heat stress to reduce heat production from digestion and metabolism of nutrients.
2. **Low milk production:** There could be a significant loss of milk production during periods of heat stress. Studies in the USA indicate that a loss of $670 million per year in milk production occurs due to heat stress (Mauger et al., 2015).
3. **Impaired reproduction:** Heat stress also affects dairy cows’ reproductive performance and results in impacts which can be observed for months. Heat stress

leads to decreased fertility, which can lead to an increase in non-lactating periods, and disrupts the cycle in which a cow enters and exits the milking herd. Furthermore, embryo loss is 3.7 times more likely in times of heat stress (Thatcher et al., 1994).

Accordingly, adaptation and mitigation measures are important to keep production, as well as productivity of inputs, close to optimal. Key et al. (2014) suggested mitigation strategies, such as sprinklers and fans, changing the feeding times to coincide with the cooler times of the day, and reducing the exertion required by animals to gain access to food, minerals, and water. However, producers also need to look at the cost of using these mitigation techniques and compare it with the benefits in terms of revenue earned. Key, Sneeringer, and Marquardt, (2014), explained the trade-off between heat stress mitigation cost and revenue gained in a simple graph shown in Figure 2.1. The figure represents revenue earned from livestock as a function of heat stress abatement strategies, while the bottom curve represents the total cost of heat stress abatement strategies. Above M*, the cost of mitigation increases at a rate higher than the rate of increase in revenue earned due to abatement strategies used. Below M*, the producer will be better off applying or increasing abatement strategies because revenues will exceed the rate of increase in cost. Thus, the optimal point where revenue is maximised would be at point M*, and increasing mitigation beyond point M* will not be economically smart.

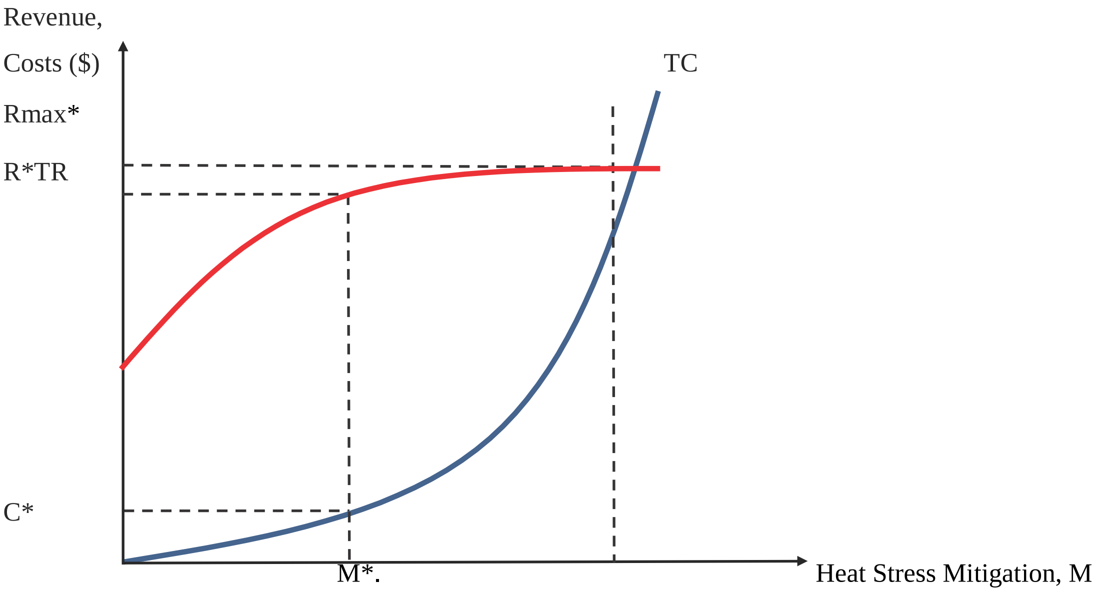

Figure 2.1: Optimal Heat Stress Mitigation

Source: USDA, Economic Research Service

Heat stress on dairy cattle can be reduced by different heat moderation processes such as fans (forced ventilations), sprinklers and shades. However, each moderation system differs in its ability to control thermal conditions and minimise production losses (Schefers, 2008). According to Thomas (2012), heat stress abatement strategies are based on four modes of heat exchange between cows and their surrounding environment:

- Conduction: a system where heat is transferred from a warm object to a cool object. For example, heat transfer from the cow to the air.

- Convection: a system where heat is transferred from a warm object where the substances are moving. For example, air movement over the cow's body.

- Radiation: a system where electromagnetic radiation is experienced at the surface of an object. For example, a radiant exchange from sunlight to the cow.

- Evaporation: cooling mechanism where water is converted from liquid to gas. For example, sweating or breathing.

After their extensive literature review, St-Pierre, Cobanov and Schnitkey (2003), derived three models to measure three different heat abatement strategies (Moderate, High, and Intense heat abatement strategies).The models describe the efficiency of the heat abatement strategies expressed as the decrease in apparent THI experienced by the animals.

2.6.1. Moderate heat abatement

In moderate cooling systems cows are cooled by wetting and forced ventilation. The actual THI will be replaced by the apparent THI in the model when heat abatement is used.

$$\Delta THI = -11.06 + (0.25 \times T) + (0.02 \times H) \text{........Equation 2.1}$$

Where ΔTHI is the change in apparent THI, T is ambient temperature (°C), and H is ambient relative humidity (%).

2.6.2. High heat abatement

High heat abatement is a combination of fans and sprinklers used in a dairy. St-Pierre et al. (2003) used the following equation to measure the effectiveness of high heat abatement:

$$\Delta THI = -17.6 + (0.36 \times T) + (0.04 \times H) \text{.......................... Equation.2.2}$$

2.6.3. Intense heat abatement

This method uses high-pressure evaporative cooling systems in a dairy. St-Pierre et al. (2003) applied field data from a commercial manufacturer (Korral Kool, Inc.,Mesa, AZ) in order to quantify the cooling effect of an intense heat abatement system. For intensive heat abatement, the equation followed is:

$$\Delta THI = -11.7 - (0.16 \times T) + (0.18 \times H) \text{ .... Equation 2.3}$$

Climate change adversely affects milk production indirectly through its effect on the different inputs of production. According to Calil et al. (2012), climate change events, such as rising temperature, will change prices of inputs, including feed, fuel and electricity, for dairy farmers, indicating a decrease in their profit. According to Silanikove and Koluman (2015), the most significant indirect effect is predicted to occur as a result of a major reduction in worldwide grains (concentrate feedstuffs) production. Climate change will also have a great impact on dairy farmers in many ways, such as changes in crop yields due to variations in climate, thus affecting feed costs to farmers and of course reducing the amount of nutrients being fed to the cows (Moreki and Tsopito, 2013).

2.7. Temperature Humidity Index

The Temperature Humidity Index (THI) was established in the late 1950s as a way to measure the impact of temperature and humidity in a given climate (Allen et al., 2013). The endurance and performance of animals during heat stress seasons is highly dependent on several weather factors, especially temperature and humidity (Du Preez 2000). THI accounts for the combined effects of environmental (air) temperature and relative humidity: lower temperatures at high humidity give similar heat stress to higher temperatures at lower humidity (Dunn et al., 2014).

Studies on climate change and dairy cows use an index to measure heat stress and established a heat stress threshold at 72 THI, although some researchers have shown that developments in genetics and increases in milk production have lowered the heat stress threshold to be between 65 and 68. Moreki and Tsopito (2013) studied climate change effects on dairy production in Botswana, while Nesamvuni et al. (2012) assessed the role of heat pressure on dairy cows' productivity and reproductive performance under anticipated future climate conditions using the Temperature Humidity Index (THI) as an indicator of heat stress. According to Jones and Hennessy (2000), heat stress in dairy cows is associated with high temperature and humidity, resulting in a decline in milk production. When lactating dairy cows are exposed to high ambient temperatures (Ta), high relative humidity (RH) and solar radiation for extended periods of time, their ability to disperse heat will decrease. With lactating cows producing their own metabolic heat, the accumulated heat from the environment and no cooling systems implemented will induce heat stress for the cattle. Figure 2.2 indicates the various THI values with different relative humidity and air temperatures. For instance, at a temperature of 27 °C and humidity of 30 %, the THI will be 72.

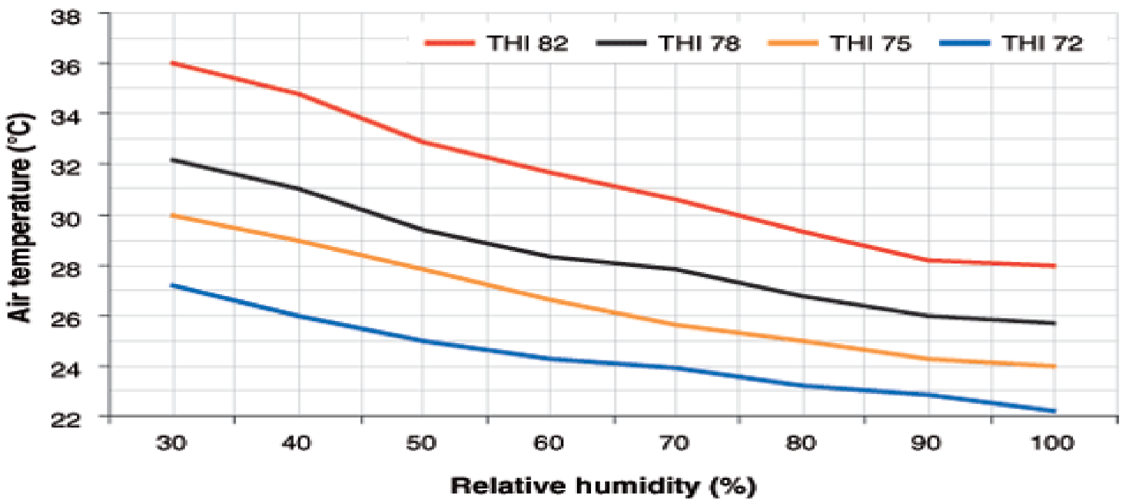

Figure 2.2: Temperature (°C) across relative humidity (%)

Source: Dairy Australia, 2012

Calculations of THI do not include wind speed and solar radiations, but wind speed is more dependent on topography than humidity and temperature (Dunn et al., 2014). The temperature-humidity index (THI) is still the best, simplest and most practical index (parameter) for quantifying temperature which causes heat stress in dairy cattle (Preez, 2000). THI could be calculated from air temperature and relative humidity using the following formula:

$$THI = (0.18 \times Tair + 32 - (0.55 - 0.55 \times \frac{RH}{100}) \times (Tair - 26).. \quad \text{Equation 2.4}$$

T_{air} is the air temperature in degree Celsius, measured by a thermometer freely exposed to the air, and RH is the relative humidity in percentage points. Table 2.1below shows that mild stress for dairy cows begins when relative humidity (%) reaches 68–72, while at a relative humidity (%) of 80 and degree Celsius of 27, dairy cows will become severely stressed.

Table 2.1: Temperature Humidity Index (THI) for Dairy Cows

	Humidity %																		
Temp °F	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**
72	64	65	65	65	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71
74	65	66	66	67	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73
76	66	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75
78	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76
80	68	69	69	70	70	71	72	72	73	74	75	75	76	76	77	78	78	79	79
82	69	69	70	70	71	72	73	73	74	75	75	76	77	77	78	79	79	80	80
84	70	70	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83
86	71	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84
88	72	72	73	74	75	76	76	77	78	79	80	81	81	82	83	84	85	86	86
90	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88
92	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90
94	74	75	76	77	78	79	80	81	82	83	84	86	86	87	88	89	90	91	92
96	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94
98	76	77	78	80	80	82	83	83	85	86	87	88	89	90	91	92	93	94	95
100	77	78	79	81	82	83	84	85	86	87	88	90	91	92	93	94	95	96	98
102	78	79	80	82	83	84	85	86	87	89	90	91	92	94	95	96	97	98	100
104	79	80	81	83	84	85	86	88	89	90	91	93	94	95	96	98	99	100	101
106	80	81	82	84	85	87	88	89	90	91	93	94	95	97	98	99	101	102	103
108	81	82	83	85	86	88	89	90	92	93	94	96	97	98	100	101	103	104	105
110	81	83	84	86	87	89	90	91	93	95	96	97	99	100	101	103	104	106	107

[ ]Mild heat stress [ ] Severe heat stress [ ]Moderate heat stress [ ] Dangerous heat stress

Source: Collier et al. (2011).

2.8. Empirical findings on the impact of climate change on milk production

Dairy cows are influenced by many factors, specifically during their lactation period, and particularly in their mid-lactation period where milk production is at the highest (Chebel et al., 2004; Nardone et al., 2010; Walsh et al., 2011). Chebel et al. (2004) studied factors which affected conception rate and concluded that exposing cows to heat stress, before their artificial insemination experiment, is associated with a reduced conception rate, and compared with cows not exposed to heat stress. Many of the developing countries in the world have difficult conditions for milk production, in the form of higher ambient temperatures (Scholtz, 2013).This directly implies uncomfortable environment for the dairy cows, and in many cases a reduction in the expression of the full genetic potential of the cows (FAO, 2012). Dairy cows are sensitive to high temperatures, and milk production declines during such events to the extent that the loss will be so significant as to affect farmers’ profits.

Mauger et al. (2015) used downscaled climate data for anticipating milk production losses for Holstein dairy cows in the United States. A study conducted in the United States by St-Pierre et al. (2003) concluded that out of the total production loss across animal classes due to heat stress, which averaged $2.4 billion annually, dairy production loss took the lion's share, amounting to $897 million on a yearly basis. According to Calil et al. (2012), climate variability is expected to impact on the dairy industry negatively in the future because climatic events, such as rising temperatures and increasing greenhouse gas concentrations, will change the prices of inputs for dairy farms, such as feed, fuel and electricity. Key et al. (2014) also studied the impact of climate change on dairy cows and concluded that dairy cows are prone to heat stress and that the dairy sector takes the lion's share of the costs of current heat stress for the livestock industry. Allen et al. (2013) also found results in support of the above studies, concluding that heat stress affects several aspects of the dairy industry and reduces milk production.

A few studies have also been conducted in Africa concerning the impact of climate change on dairy cows and milk production. Moreki and Tsopito (2013) studied climate change effects on dairy production in Botswana and suggested certain mitigation strategies, such as using smaller dairy breeds like Jersey, growing fodder crops and the utilisation of crop residues. Du Preez et al. (1990) studied the THI values applicable to South Africa and Namibia and concluded that every year, heat stress risk areas increase from August to January. They also concluded that during the months of November to March, there is the possibility of moderate to high heat stress in many of the South African dairy cows. They suggested cautious planning of facilities and adaptation strategies. Du Preez et al. (1990) called for further research to be undertaken on heat stress on dairy cattle, which is essential if the South African dairy industry is determined to achieve more cost-effective milk production, improved health, and adequate supplies of high-quality raw milk.

2.9. Farmer's Perception of climate change

It is evident that agriculture is vulnerable to climate change and heat stress. Identifying the perceptions of farmers about the impacts of climate change/heat stress becomes a plausible step to take. The way in which farmers understand and interpret climate change will determine whether they take adaptation strategies, and which adaptation strategy they choose (Maddison, 2007; Barnes and Toma, 2012). To assess how farmer's perceive climate change, data collection methods such as interviews or questionnaires could be applied. For instance, Mertz et al. (2009) used focus group interviews and a household survey to analyse the perceptions on climate change and adaptation by sedentary farmers in central Senegal. They found that farmers were aware of climate change and that farmers attributed reductions in crop yields and the health of livestock to climate change. However, the authors recognised that the mention of climate in their questions did influence responses of farmers. Okonya, Syndikus and Kroschel (2013) interviewed 192 farmers in six agro-ecological zones located in Uganda and found that ninety-nine percent of the farmers interviewed observed a change in climate over a period of 10 years. Barnes and Toma (2012) analysed a survey result of 540 dairy farmers in Scotland and found that only half of the respondents agreed on a rise in temperature occurring in the future. Furthermore, they suggested that farmers' perceptions could significantly hinder the adoption of voluntary measures to meet emissions targets. To help bring about behavioural changes, Barnes and Toma (2012) identified six segments of dairy farmer perceptions, ranging from the highly sceptical farmer who does not think that climate change will affect future decision making, to the positivist who assumes climate change to have a positive impact (Appendix D).

Despite its importance for productivity as well as income, most agriculturalists in general, and farmers specifically, are unaware of the difference between climate and weather (Maddison, 2007; Weber, 2010). Climate is a statistical phenomenon, a term that describes average weather conditions, whereas the gradual change in these conditions is called climate change (Weber, 2010) and 'weather' describes the short-term behaviour of the atmosphere. The knowledge of climate change for dairy farmers is important when it comes to their choice of genetically modified dairy cows or their geographical settlements for their farming activities. It is also important when deciding whether to adopt small-scale adaptation strategies, such as growing drought-resistant crops and installing shade cover for their cows, or large-scale adaptation strategies including high-cost ventilation systems.

2.10. Milk Production in South Africa

Dairy products have highly volatile prices in the international market. Many economic theories suggest that where there are many suppliers relative to the demand for a competitive product, price adjustments will provide basic competition tools for producers. The price for dairy products increased to a peak at the beginning of 2014, and decreased by 35 % by the first month of 2015. This is mainly because, according to Lacto Data Statistics (2015), prices will be detached from international product prices in countries where imports and exports play very small roles.

South Africa, with total cattle dairy cattle population of 1.2 million, contributes almost negligible amount (0.5%) to world milk production (Lacto Data Statistics, 2014; DAFF, 2015). Four major dairy breeds exist in the country, namely Holstein, Jersey, Guernsey and Ayrshire (Lacto Data Statistics, 2012). The dairy industry is an important contributor to the job market, employing 60000 farm workers and providing 40000 people with indirect jobs. In terms of foreign currency, the dairy industry earned over ZAR521 million in 2009; however, South Africa is an importer of dairy products, with an average value from 1999 to 2009 amounting to over ZAR440 million, with the quantity imported amounting to over 28 million kilograms (Lacto Data, 2015). Milk production was marginally higher in the first half of 2014, compared with production during the same period for 2013 in South Africa (Lacto Data, 2015). However, compared with June 2015, production reduced by 5.8% in June 2016, mainly due to a rise in input prices.

Amongst input costs, feed cost per tone was the most vital cost item for milk producers. Internationally, the prices of maize and soybeans are used as a proxy for feed prices; which is a derived feed price, weighted price per kilogramme, of maize and soybeans, comprising about 70 % maize and 30% soybeans (Lacto Data, 2016). Drought conditions in 2015, the weaker rand, and uncertainty about the 2016 maize crop resulted in a sharp increase in input prices. Because milk production is dependent on many factors, such as weather conditions, biological and genetic factors, geographical factors and economic factors, farmers will not have a perfectly elastic supply curve. An increase in prices of inputs may reduce the amount of milk produced; however, keeping other things constant, the reduction will not be at the rate of the increase in prices. That is, if producer milk prices decrease in relation to feed prices, farmers will tend to produce less, and if prices increase relative to feed prices, production will increase; however, unfavourable milk–feed price ratios will result in slower production growth or lower production, over time (Lacto Data, 2016).

Table 2.2 describes raw milk prices in Rands per litre, where the producers' rate of price increase is lower for South Africa, compared with other countries. Although dairy is an important economic sector for the South African economy, producers face many challenges to stay in the market due to various reasons (drought, increased feed cost and lower profit margin). After 2007, the number of milk producers in South Africa declined from 3899 to 1834 producers in 2015, which is a decline of 53 % (Lacto Data, 2015).

Table 2.2: International calculated standardised raw milk producer prices (ZAR/litre)

Country	Jan-2012	Jan-2013	Jan-2014	Jan-2015
Belgium	3.23	3.94	5.54	3.85
Germany	3.35	3.84	5.51	3.72
Denmark	3.35	3.73	5.51	3.82
Finland	4.14	4.67	5.83	5.47
France	3.58	3.90	5.68	4.38
Great Britain	3.47	4.07	5.35	4.69
Ireland	3.40	3.75	5.25	3.95
Netherlands	3.55	3.92	5.60	3.84
New Zealand	3.22	3.15	5.44	3.26
USA	3.25	3.78	5.13	4.47
***South Africa**	3.10	3.60	4.05	4.45

(Source: Lacto Data Statistics, 2016)

* Based on MPO price survey)

Although price does play a role in a producer's motive to produce more or less, climatic events throughout the year are also responsible for an increase or a decrease in production. Figure 2.3 shows that production fluctuates throughout the year; for example, production in January and December experiences a decline, while during September and October production seems to reach its peak. Similar results were found from the weather data collected in Free State regarding these monthly differences, which are discussed in Chapter 4 of this study.

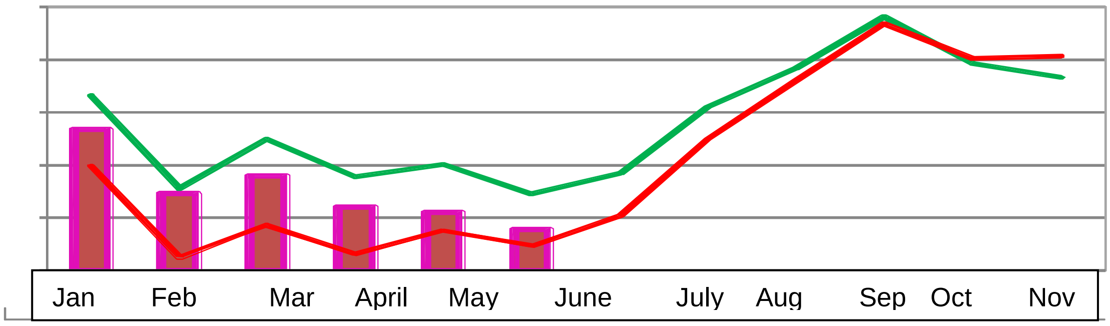

Figure 2.3: Monthly Milk Production ('000 L)

Source: Lacto Data Statistics (2016)

2.11. Milk Production in the Free State

According to South African Government information (2016), the agricultural sector is dominant in the Free State province, with cultivated land covering about 32 000 square kilometres, and natural fields, as well as grazing, cover up to 87 000 square kilometres of the province. The report further explains that livestock products contribute up to 30 % to the agricultural income of the province. Table 2.3below shows that between January 2007 and January 2009, the Free State took the leading role in the number of milk producers, while it took the second place, following the Western Cape, between January 2011 and January 2015.

Table 2.3: Milk Producer numbers per Province

Province	2007	2008	2009	2011	2012	2014	2015	2015	% change
Western cape	827	815	795	683	647	526	533	515	-37.6
Eastern Cape	420	407	387	314	283	264	262	256	-39.04
Northern Cape	37	34	37	28	21	25	14	16	-57 %
KwaZulu-Natal	385	373	373	323	322	281	267	262	-32 %
Free State	987	919	884	601	535	389	328	281	-72 %
North West	596	549	540	386	352	233	222	191	-68 %
Gauteng	245	228	217	127	126	109	100	98	-60 %
Mpumalanga	357	302	286	201	164	117	94	92	-74 %
Limpopo	45	38	32	23	24	14	14	12	-73 %
Total	3 899	3 665	3 551	2 686	2 474	1 961	1 834	1728	-56 %

Source: Lacto Data Statistics (2015)

The Free State Province experienced fractional exports of milk and dairy products from the Motheo, Lejweleputswa, Thabo Mofutsanyane, and Northern Free State District Municipalities. The Motheo District Municipality provided the greatest share of milk and dairy products during 2000 to 2001, and then again in 2008, while the Northern Free State District Municipality had a share of 11.05 % only in 2009 (MPO, 2012). Figure 2.4below shows that the number of milk producers in the Free State Province declined drastically from 987 producers in January 2007 to 281 producers by August 2015 (approximately a 72 % decline). This decline could be attributed to many factors which contribute to a decrease in the marginal profit, and thus a loss of revenue for producers. Although South Africa plays a very small role in contributing to the international market, the decline in dairy farmers does indicate a loss of foreign currency from the sector and a loss of many other economic benefits for the country.

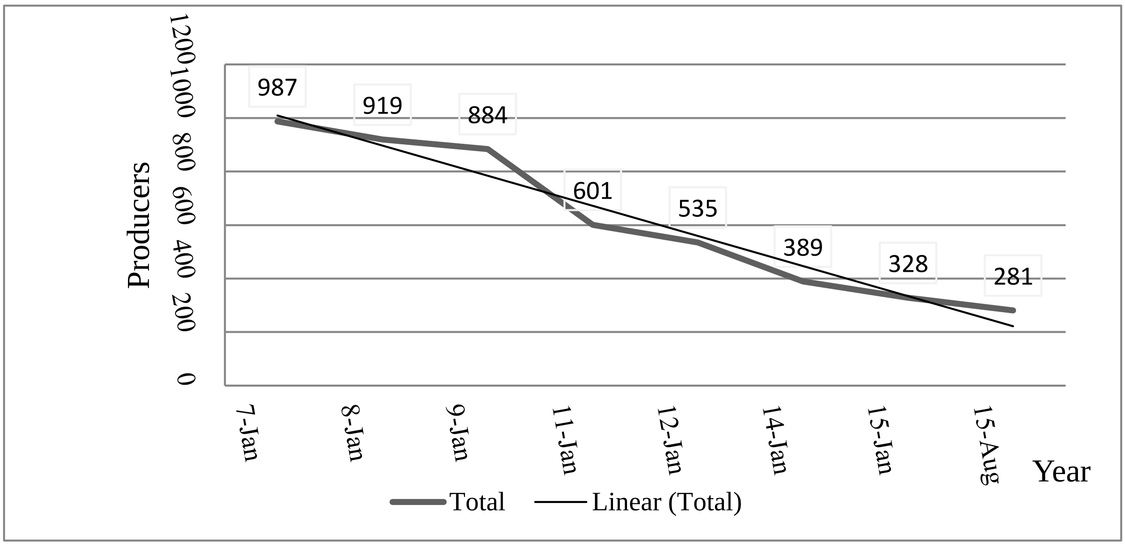

Figure 2.4: Number of milk producers in Free State, South Africa

Source: Lacto Data (2015)

2.12. Conclusion

Economic theories, such as the Prebish–Singer theory, state that deterioration in the terms of trade for primary products might be experienced because of both low income and price elasticity. Production of these types of goods must be tracked by cautious short-term and long-term economic analyses for African economies, which are mostly dependent on agriculture. Thus, primary products with high-income elasticity should be given greater attention than those whose demand decreases with an increase in income. Dairy and other products of farm animals have a high income-elasticity of demand, particularly at low-income levels. With growing population and projected economic growth of the continent, the demand for dairy products is projected to be highly elastic. This means that any change in the price of these products, as well as changes in income of households, will result in a higher change in demand for the products.

Dairy products are also highly nutritious goods, which make their production vital in alleviating the household food insecurity problem that many African countries are facing. Worldwide, Africa is the only continent where the population is projected to continue increasing throughout the twenty-first century. Currently, with 1.2 billion people living in Africa and expected to double by 2050 to 2.4 billion, food insecurity is, and will continue to be, one of the major challenges faced by the continent. The fact that the dairy sector has an immense employment capacity (directly and indirectly), foreign currency earning capacity and household food security, justifies for the sector to receive attention in agricultural research and studies.

Literature on the effects of climate change on productivity, efficiency and general economic growth have shown that increasing temperature widens income inequality and reduces economic productivity (Kreft et al., 2010). Climate change is a challenge to almost every sector of an economy, from the agriculture to the manufacturing sectors: all are affected, although on different levels. The agricultural sector is one of the most susceptible sectors to being affected by climate change amongst all other sectors, mainly because agriculture is directly linked to the environment. Given that many African countries are dependent on climate-sensitive productions, such as agriculture, climate change is more likely to be a formidable challenge to their productivity and economic growth, in general.

From the discussion on the impact of climate change on milk production, it was seen that when cows are exposed to an environment where temperature is above their thermo-neutral zone, which is a range of temperatures in which the animal can maintain normal body temperature without becoming stressed, they will reduce feed intake (reduce dry matter intake), resulting in a decline in milk production.

Various studies (St-Pierre et al., 2003; Mauger et al., 2015) in the literature have proved, through their different experiments and empirical findings that dairy cows, especially cows genetically modified for increased production are vulnerable to heat stress, as well as cold stress. Heat stress was measured according to a Temperature Humidity Index in all of the relevant studies. For dairy cows, studies have shown that a Temperature Humidity Index of 70 is the maximum threshold above which cows will become heat stressed, and hence will start to make adjustments, which will lead to a reduced milk production. The Temperature Humidity Index and different Temperature Humidity Index thresholds were included in the model specified for this study.

CHAPTER 3: RESEARCH METHODS

3.1. Introduction

The main objective of this chapter is to describe the research methods and model used for estimating milk production loss (ltr/cow/day) and to compute revenue losses. The chapter commences by describing the three selected semi-arid areas in the Free State for the study. Data collection methods for the baseline (1950–1999) and future mid-century (2040–2070) are described in this chapter, together with brief explanations of the five Global Circulation Model (GCMs) used in this study. Model selection, with and without heat abatement (adaptation) strategies and the different $THI_{thresholds}$ which are necessary for estimating milk production loss due to heat stress are discussed and applied. Methods for computing revenue loss from heat stress are also briefly discussed. The chapter also includes a description how the collected data was analysed and interpreted and briefly outlines the dairy farmers' perception on climate change.

3.2. Description of the Study Area

This study was conducted in the Free State province of South Africa. Three sites were selected which represent the major dairy production areas across the Free State, South Africa. The three selected areas are Bloemfontein (29º06'S, 26º18'E, 1351 m), Bethlehem (28°01'S, 18°09'E, 1585m) and Bothaville (27º05'S, 27º23'E, 1425 m), as shown in Figure 3.1. These semi-arid areas are characterised by an annual mean rainfall varying from 415 to 620 mm. The mean annual relative humidity (%) for the study regions varies from a minimum of 30 to a maximum of 71, while maximum and minimum temperatures (°C) range from 7 to 28, on average (Table 3.1).

Table 3.1: Mean Climate Variables for the Study Area

Climatic variables	Bothaville	Bethlehem	Bloemfontein
Annual precipitation(mm)	460	620	415
Annual Tmax (°C)	27.6	28.1	23.5
Annual Tmin (°C)	11.4	10.5	7.1
Annual RH max (%)	71.0	71.0	69.2
Annual RH min (%)	30.7	32.9	30.4

Dataset source: ARC-ISCW climate databank

Tmax &Tmin represents maximum and minimum temperature respectively, while RHmax & RHmin represent and maximum and minimum relative humidity.

Bloemfontein is located in central South Africa, on the southern edge of the Highveld, at an elevation of 1400 meters (4600ft.), bordering on the semi-arid region of the Karoo (Figure 3.1).The area is generally flat with occasional hills, and the general vegetation is Highveld grassland. Bethlehem is a town in the eastern part of the Free State province of South Africa, situated on the Liebenbergs River along a fertile valley just north of the Rooiberg Mountains. Bothaville is one of the major centres of agriculture located near the Vaal River in the northern reaches of the Free State.

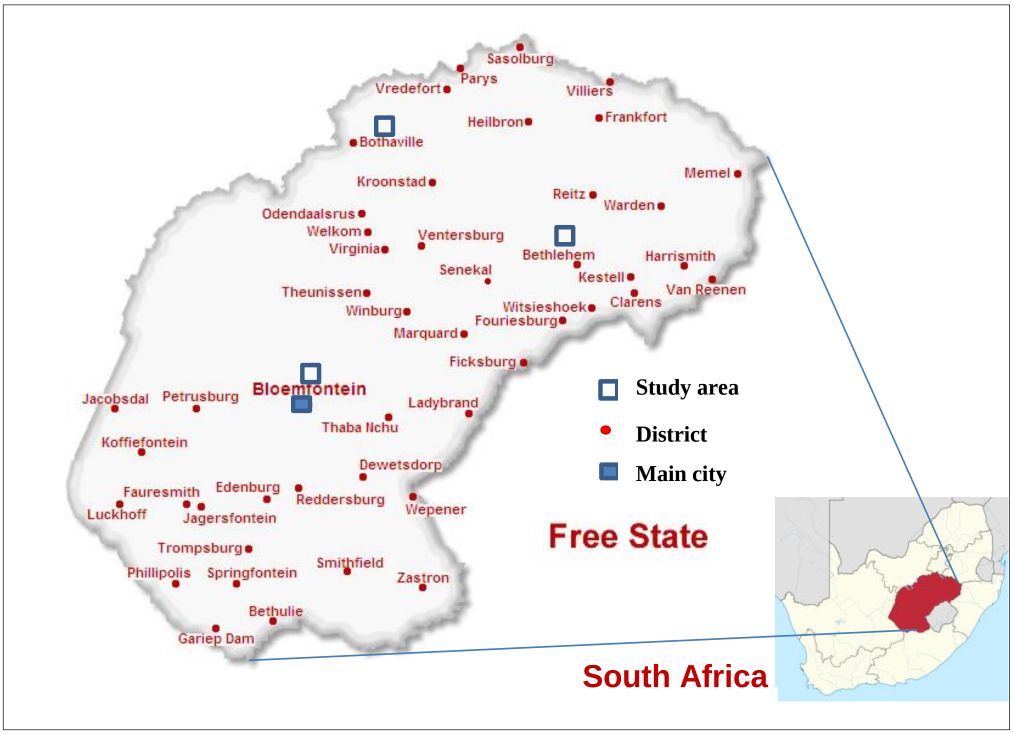

Figure 3.1: Map of Free State showing Bethlehem, Bothaville and Bloemfontein

3.3. Data Collection and Description

This research was designed to be qualitative and quantitative in nature. Daily averages of maximum and minimum temperatures and relative humidity changes from the baseline (1950–1999) and to the mid-century 2050s (2040–2070), across the selected five Global Circulation Models (GCMs), were used for the analysis of THI in all three representative semi-arid study areas. As the baseline, the historical daily weather data items from 1950 were used to estimate means of monthly minimum and maximum temperatures, and relative humidity, and to calculate both the minimum and maximum THI for the three selected areas in regions of the Free State Province. The baseline climate data used in this study was obtained from the quaternary catchment database developed by the University of KwaZulu-Natal (Schulze et al., 2005). This database includes 50 years (1950 to 1999) of daily minimum and maximum temperatures.

This study used five GCM models (Table 3.2), namely the Earth System Model developed by the Geophysical Fluid Dynamics Laboratory (GFDL-ESM2), the Hadley Global Environmental Model2-Earth System (HADGEM2-ES), the Community Climate System Model4 (CCSM4), and the MPI Earth System Modelling running on Medium Resolution grid (MPI_ESM_MR) and MICRO5. All of these are individual simulations, considered as a possible representation of future climate. For instance, HadGEM2-ES is a coupled Earth System Model that was used by the Met Office Hadley Centre for the CMIP5 centennial simulations. It comprises an atmospheric GCM at N96 and L38 horizontal and vertical resolution, and an ocean GCM with a 1-degree horizontal resolution (increasing to 1/3 degree at the equator) and 40 vertical levels (European Network for Earth System Modelling, 2016).

These future datasets that have been suggested for creating climate change scenarios for study areas were used according to the Climate System Analysis Group (CSAG), University of Cape Town, guidelines. Thus, representative future climate data scenarios were used from the CSAG collections for Bethlehem, Bloemfontein and Bothaville. The record complies with the quality and length of the CSAG standards. For both baseline and future scenarios datasets, the relative humidity was obtained from the mean value of dew-point temperature. In considering this assumption, the method to compute THI includes variations in humidity in the diurnal cycles that are important in understanding the heat stress in dairy cows.

Table 3.2: General circulation Models used in the study

Model Name	Institution
GFDL-ESM2	NOAA Geophysical Fluid Dynamics Laboratory, USA
HADGEM2-ES	Met. Office Hadley Centre, UK
CCSM4	National Center for Atmospheric Research, USA
MPI_ESM_MR	Max Planck Institute for Meteorology, Germany
MICRO5	Atmosphere and Ocean Research Institute, the University of Tokyo

Source: Climate System Analysis Group (CSAG), University of Cape Town

The most commonly used temperature humidity index threshold (threshold above which cows become heat stressed) is the threshold index of 70 (Du Preez, 2000; St-Pierre et al., 2003; Mauger et al., 2015). This study identified a temperature humidity index of 70 as a threshold, since the average milk production in South Africa is about 22.5 litres per cow (MPO, 2015), which is a fair threshold chosen for such quantity of productions, according to studies like Berman (2005). However, a threshold of 65 was also used for comparison reasons and sensitivity tests. A daily minimum temperature humidity index (THI_{min}) was calculated from the daily minimum temperature (T_{min}) and daily maximum relative humidity (RH_{max}). A daily maximum temperature humidity index (THI_{max}) was calculated from daily maximum temperature (T_{max}) and daily minimum relative humidity (RH_{min}), applying the standard THI equation. Following the assumptions in St-Pierre et al. (2003), the THI index was taken to have a perfect sine function, with a 24 hours period. Figure 3.2 below shows the sinusoidal curve temperature humidity index, including THI_{max}; $THI_{threshold}$ which is the THI limit above which heat stress begins; THI_{mean} is the mean daily THI; D is the proportion of the day in which THI exceeds $THI_{threshold}$, and THI_{load} is the central of the THI sine curve above $THI_{threshold}$.

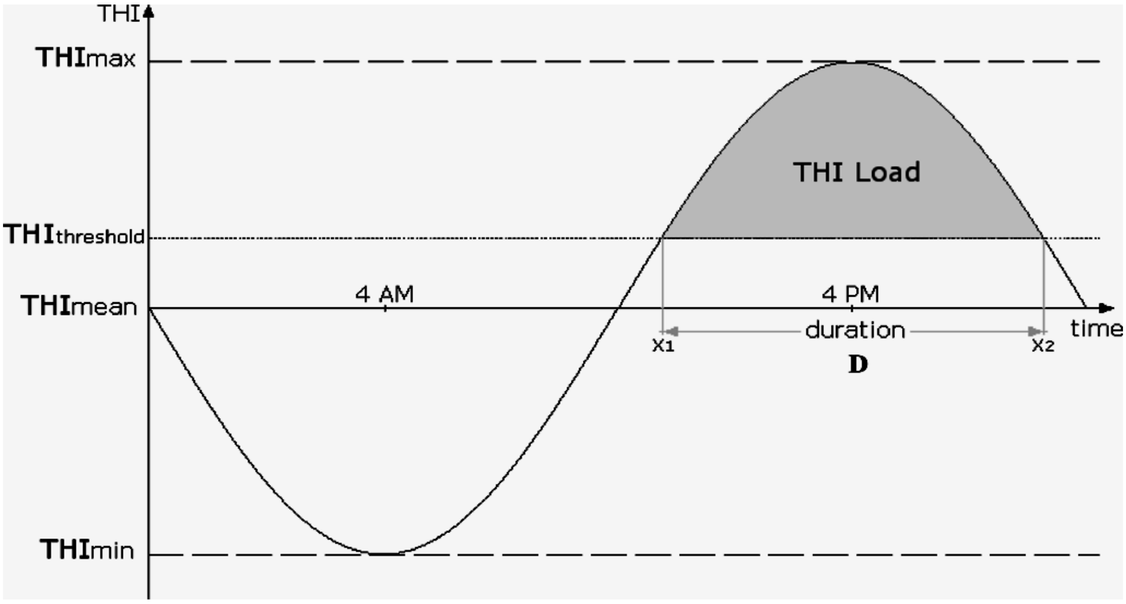

Figure 3.2: Sine model of THI

Source: St-Pierre et al.(2003)

3.4. Model Selection

To estimate milk production loss in litres per day due to heat stress, this study followed an approach used by St-Pierre et al. (2003). The numbers of cows and milk production in the absence of heat stress (baseline milk production) are implicitly assumed to be constant. The model considers daily maximum (THI_{max}), the fraction of the day that THI is above the threshold (D), and $THI_{threshold}$.

The formula for milk loss (ltr/cow/day) due to heat stress is given as:

$Loss = \alpha(THImax - THIthreshold)^2 \times D \ldots\ldots$ .... Equation 3.1

where α is taken to be = 0.065, consistentwith St-Pierreet al. (2003). THI is a single value representing the combination of air temperature and humidity associated with the level of heat stress. The THI threshold has been identified to be between 70 and 72 by many studies (Du Preez, 2000; St-Pierre et al., 2003, Mauger et al., 2015).However, modern high-producing cows (30ltr/day) experience heat stress at a THI of 65. For this study, $THI_{thresholds}$ of 70 was used, based on previous studies done in South Africa as well as other countries to estimate the point when cows become heat stressed (Du Preez et al., 1990; Du Preez et al., 1994; Du Preez 2000).

The formula for THI, according to the National Oceanic and Atmospheric Administration (NOAA, 1976), is:

$$THI = (1.8 * T + 32 - (0.55 - 0.55 * \frac{RH}{100}) * (1.8 * T - 26) \text{..................Equation 3.2}$$

Where T is the air temperature in degrees Celsius measured by a thermometer freely exposed to the air, but shielded from radiation and moisture. RH is relative humidity in percentage points.

The production loss equation is highly nonlinear in temperature, and hence this study employed daily measures, including daily maximum temperature and humidity, in preference to long-term averages. The estimates in this research study will not include the indirect impacts of heat stress, impacts of cold stress on milk production, or any changes in prices of milk throughout the study years. It is not within the scope of this study to project milk prices, and hence the ceteris paribus assumption will hold.

Following the approach in St-Pierreet al. (2003), this study estimates loss of milk production attributable to heat stress when moderate heat abatement solutions are applied. The moderate heat abatement strategy was selected due to its cost efficiency for farmers and effectiveness in reducing heat stress for dairy cows. However, the benefits of the heat abatement strategies as computed by applying a cost–benefit analysis is not within the scope of this study.

3.5. Data Analysis

The data was analysed for the historical datasets (baseline) and five future climatic scenarios, with and without applying adaptation strategies. Firstly, the daily milk loss was presented for the baseline data sets. Secondly, averages of ten years were computed for each of the 10-year steps to observe the trend of losses for the past 40 years. The coefficient of variation (CV) for THI, defined as the ratio of standard deviation to the mean, was computed over the entire time series at each study site. The percentage of CV gives a measure of the farmer's risk: low CVs indicate stable year-to-year losses, while high CVs denote high inter-annual variability. Thirdly, a seasonal analysis was employed by selecting the early summer (September–December) and late summer (January–April) milk losses, as the increase in temperatures for these months are noticed to influence heat stress in dairy cows. With regard to the future climatic scenarios data set, cumulative distribution function (CDF) probabilistic graphs were used to compare the GCMs on the effect of milk losses, with and without adaptation strategies. In this study, moderate heat stress abatement methods were used as a notional adaptation strategy for all selected study areas. The analysis was followed by taking into account the early and late summer seasonal milk losses for all future climatic scenarios, with and without adaptation strategies.

3.6. Economic Loss / Revenue Loss Estimations

The conventional way of computing income of individual farmers is:

$\mathrm{Income}_i = \sum((\mathrm{p}_j \times \mathrm{q}_j) - \mathrm{C}_j)$ .... Equation 3.3

where *i* is individual farmers, *j* is milk production, *p* is price of milk, *q* is quantity of milk produced, and c is costs incurred during milk production. The quantity of milk produced depends on different factors, and specific to this study, on heat stress. Increasing heat stress reduces the quantity of production, which adversely affects farmers' income earned. Costs involved in milk production are beyond the scope of this study and are not considered in computing economic loss. The revenue losses due to heat stress for both the baseline data (1950–1999) and the future data (2040–2070) were estimated on the basis of the following formula:

$\mathrm{Revenue\ loss} = \sum(\mathrm{p_j} \times \mathrm{q_{jloss}})$ ....Equation 3.4

Where q_{jloss} is the quantity (ltr) of milk lost due to heat stress, and p_j is the price of milk, which is assumed to remain constant during the baseline and future scenario periods.

3.7. Questionnaire Development

A semi-structured questionnaire (Appendix A) was designed, comprising open-ended and closed-ended questions, in order to account for farmers' perceptions of climate change and the adaptation strategies they follow. There are two sections in the questionnaire; section one was designed to collect information on the characteristics of the dairy farms, such as number of dairy cows and quantity of production in a day per cow, while section 2 was designed to capture information on farmers' perceptions of climate change. Information on the intensity of the impacts of climate change on the farmer's ability to produce milk from cows was also sought through the questionnaire. In addition, the indirect impacts of climate change, such as changes in production costs as well as impacts on feeds and water availability were also obtained. There were limitations in locating dairy farmers in the Free State, since they are dispersedly located and most of them were not willing to respond. Because of these limitations, a small numbers of farmers were interviewed and their responses were used to gain an understanding of the ground-level reality, and were compared with the estimations from the milk production loss model.

3.8. Conclusions

This chapter presented the research methods used for estimating milk production loss (ltr/cow/day). Models for estimating milk production loss without mitigation strategies and with moderate heat abatement strategies were also presented in this chapter. Both models were used for all the three representative study areas (Bloemfontein, Bothaville and Bethlehem). The model for milk production loss used in this study is a meta-analysis model of lost milk production, in ltr/cow/day, as applied by St-Pierre et al. (2003) in their study of the economic impacts of heat stress on livestock. The selected method of abatement strategy (moderate heat abatement), along with the respective model that was used to estimate milk production loss, was discussed in this chapter. This chapter described the questionnaire type used for the purpose of assessing farmers' understanding of climate-induced heat stress, and for comparing their responses to the estimates of the milk production loss model.

CHAPTER 4: RESULTS

4.1. Introduction

This chapter presents and discuss the results found from computing the climate data (baseline and future climate data) using the milk production loss model for the selected semi-arid regions in Free State, South Africa. Furthermore analysis of the information gathered from milk producing farmers in Bloemfontein is discussed in this chapter. The first section presents results of the baseline data analysis (1950-1999). Seasonal difference in milk loss, monthly difference in milk production loss and economic value of milk production loss are presented in the following sub-sections. The second section discusses the results of milk production loss analysed from the future climate data (2040-2070). The subsequent sub-sections discuss monthly difference in milk production loss for the future climate data and milk production loss with heat stress abatement strategies for all the projected future climate scenarios. Revenue loss estimation also computed from the future projected scenarios. The last section covers farmer's perceptions on the impact of climate change on their production analysed based on the processed information from the questionnaire designed for the study.

4.2. Baseline Data Analysis (1950–1999)

An average mean maximum daily temperature (T_{max}) and a maximum humidity index (THI_{max}) were used to compute the milk production loss (ltr/cow/day) for all the selected study regions (Bloemfontein, Bothaville and Bethlehem) for the baseline data set (Table 4.1). The mean maximum daily temperatures were found to be 27.7 °C, 24.7°C and 22.1°C for Bloemfontein, Bothaville and Bethlehem, respectively, while their THI_{max} results were approximately 73, 70 and 68, respectively. The estimated results show that for a $THI_{threshold}$ of 70, dairy cattle in Bloemfontein and Bothaville are more susceptible to heat stress, compared with Bethlehem. For a $THI_{threshold}$ of 65, dairy cows in all the three selected regions are more likely to feel the impacts of heat stress. Thus, the $THI_{threshold}$ applied in the calculation of milk production loss should determine a farmer's decision on whether to invest in heat stress abatement strategies and on which type of abatement strategy to employ. The highest loss experienced was in Bloemfontein, which experiences a THI_{max} above 70 (Appendix C). The coefficients of variation (CV) in milk production loss for the three regions were 12.5%, 13.5% and 21.9% for Bloemfontein, Bothaville and Bethlehem, respectively. For Bloemfontein and Bothaville, the CV shows smaller dispersion from the mean, while for Bethlehem the CV shows that loss in milk production is relatively more dispersed (Table 4.1). Calculating the CV will guide in gaining an understanding of whether or not there are significant differences among the average years, and if so, in identifying the possible explanations for it being high, such as highest temperature recorded in a specific year.

Table 4.1: Mean milk production loss (ltr/cow/day) for study areas Bloemfontein, Bothaville and Bethlehem

Region	Bloemfontein (BFN)			Bothaville (BOT)			Bethlehem (BTH)		
Year range	Tmax	THImax	Loss	Tmax	THImax	Loss	Tmax	THImax	Loss
1950-1959	27.52	72.67	0.03	24.56	69.23	0.02	21.87	66.41	0.003
1960-1969	27.82	73.02	0.04	24.69	69.35	0.02	22.24	66.79	0.005
1970-1979	27.62	72.77	0.03	24.61	69.24	0.01	22.14	66.70	0.003
1980-1989	27.84	73	0.03	24.95	69.65	0.02	22.23	66.78	0.004
1990-1999	27.93	73.09	0.03	24.94	69.60	0.02	22.36	66.90	0.004
Mean	27.70	72.91	0.03	24.75	69.40	0.02	22.16	66.70	0.004
Std Dev	0.16	0.18	0.004	0.18	0.19	0.002	0.18	0.18	0.000
CV%	-	-	**12.5 %**	-	-	**13.5 %**	-	-	**21.9 %**

(Temperature is measured in °C, using baseline data sets)

Figure 4.1 shows the relationship between T_{max} and milk production loss (ltr/cow/day) in the three study regions. The figure shows that after a T_{max} of 25 °C, milk production loss increases in all the three study areas. The relationship between T_{max} and milk production losses shows positive polynomial regression correlations, which indicates a sharp increase in milk loss above 25°C. The polynomial curves for Bloemfontein and Bothaville are relatively steeper than the graph for Bethlehem, which indicates that milk loss for Bethlehem is lower, compared with the other two study areas. Using the 2014–2016 milk price/litre taken from the Agricultural Research Council (ARC), a single milk producer loses 15 cents per day per cow or a loss of 0.03 litres per day per cow. Given that milk production has a very small profit margin in South Africa, and more so for medium- and small-scale dairy farmers, the observed loss attributable to heat stress is significant.

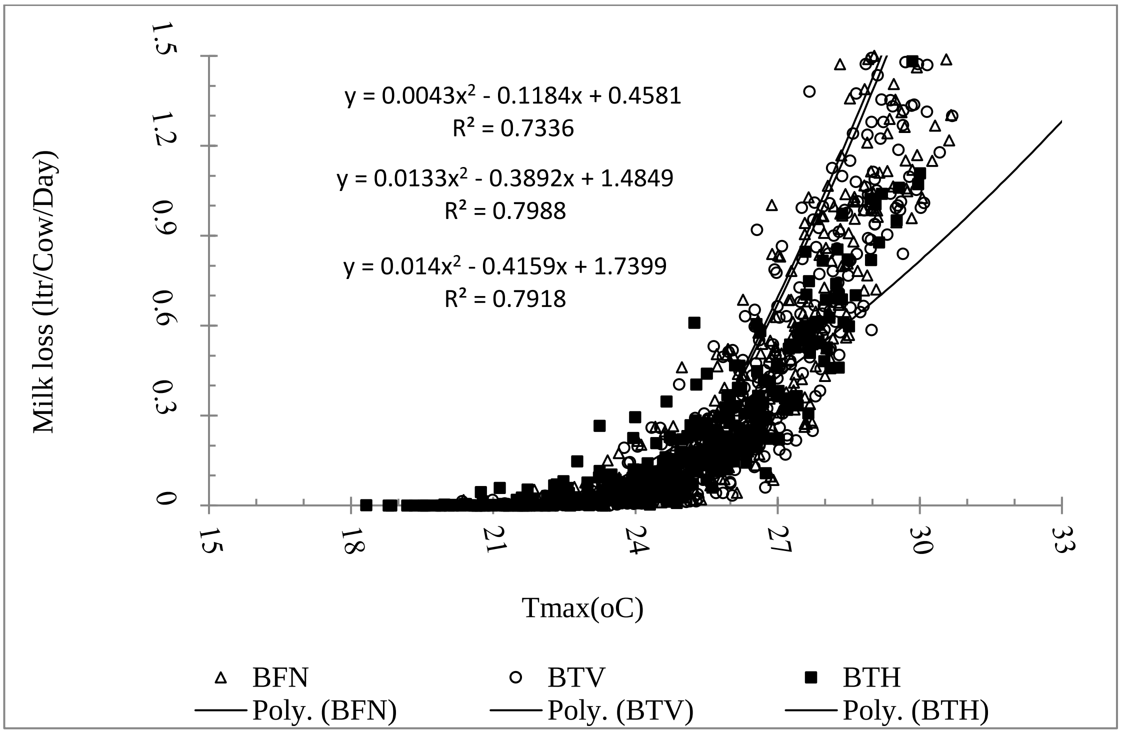

Figure 4.1: Milk production loss across maximum average daily temperature for the three study areas

(BFN=Bloemfontein; BTV=Bothaville; BTH= Bethlehem)

The daily maximum temperature, the average daily maximum THI, and the sum of milk production loss per litre/cow, from the year 1950 to the year 1999, for Bothaville are depicted in Appendix C. The highest production loss occurred in the 1980s where the maximum average daily temperatures were increasing. A single milk producer loses 10cents per day per cow, which could have been added to the revenue, according to a loss of 0.022 litres per day per cow. The slightly lower temperature experienced reduces the milk production loss in value by 5 cents.

Bethlehem, compared with the other two study areas (Bloemfontein and Bothaville), experiences lower temperatures and hence lower heat stress effects on milk production. The average daily Maximum THI shows that there are lower numbers of years when dairy cows will be outside of their zone of thermal comfort (cows will be heat stressed when

THI>70), resulting in lower milk production losses (Appendix C). This indicates that the choice of production area does influence milk production in relation to heat stress and hence plays a role in the profit margins of dairy farmers.

4.2.1. **Seasonal Milk Production Losses**

The seasonal differences in milk production losses were computed by taking the average of 10 years for September–December (early summer) and from January–April (late-summer) in the study areas (Table 4.2). A strong seasonal cycle in production loss is observed due to the non-linear dependence of the milk production loss model on daily temperature and humidity. The highest loss is recorded during the late summer season of each year in all three regions. During the years 1980–1989, the average total milk production loss is the highest for the months January–April, compared with the early summer seasons, with Bloemfontein experiencing an approximate average monthly loss of 16 ltr/cow and Bothaville losing approximately 14 ltr/cow, with the lowest loss being recorded in Bethlehem at approximately 3 ltr/cow.

Table 4.2: Average monthly total milk production loss (ltr/cow)

Study Area	BTV		BFN		BTH	
Year range	Early Summer (Sep-Dec)	Late Summer (Jan-April)	Early Summer (Sep-Dec)	Late Summer (Jan-April)	Early Summer (Sep-Dec)	Late Summer (Jan-April)
1950-1959	7.28	11.11	7.51	11.29	1.13	1.76
1960-1969	9.47	11.92	10.09	14.41	2.30	2.69
1970-1979	7.40	8.71	8.63	10.14	1.40	1.79
1980-1989	8.32	14.31	8.37	15.64	1.37	2.77
1990-1999	8.69	12.49	8.89	12.63	1.84	2.45
Average	8.23	11.70	8.69	12.82	1.60	2.29

(BFN=Bloemfontein; BTV=Bothaville; BTH= Bethlehem)

4.2.2. **Monthly Difference in Production Losses**

Seasonal changes affect dairy cows in two different ways, through either cold stress or heat stress. With a focus on heat stress and its impact on milk production, the milk production loss was calculated for each month of the year. The periods between May to August did not show milk production loss for the base year, mainly because these periods are the coldest seasons and experience lower humidity. Table 4.3 shows the quantity of milk production loss, ltr/cow, in the base year grouped on monthly bases. For January and December, the milk production losses are the highest, given that these two months are the warmest for all the three study areas.

Table 4.3: Average monthly milk production loss (ltr/cow) for the three study areas

Early Summer	Bloemfontein	Bothaville	Bethlehem
September	0.005	0.004	0.001
October	0.015	0.013	0.003
November	0.034	0.031	0.006
December	0.061	0.059	0.011
Late Summer	**	**	**
January	0.089	0.078	0.016
February	0.057	0.056	0.011
March	0.022	0.020	0.004
April	0.002	0.002	0.000

Figures 4.2 and 4.3 show the effect of heat stress during the early summer seasons and late summer seasons, respectively, for the Bloemfontein study area. In early summer, the milk loss is lower during October and showed an increase in months of November and December (Figure 4.2). January and December are the hottest months when cows experience heat stress and the highest losses of milk production. These two months are also periods where the temperature humidity index is above the comfort zone of dairy cows or above the threshold during the day. In January as the temperature rises, the milk loss reached the highest record, for example in 1967 and 1984 the highest milk losses of 7.5 and 8.1 lit/cow/day were estimated, respectively.

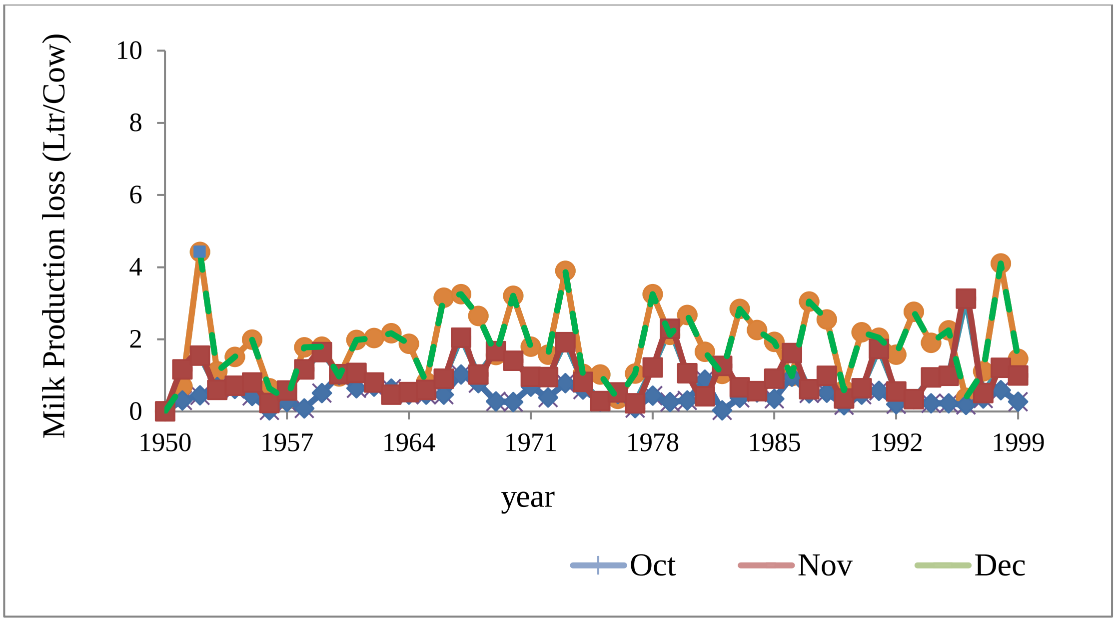

Figure 4.2: Milk production loss a function daily average temperature early summer seasons

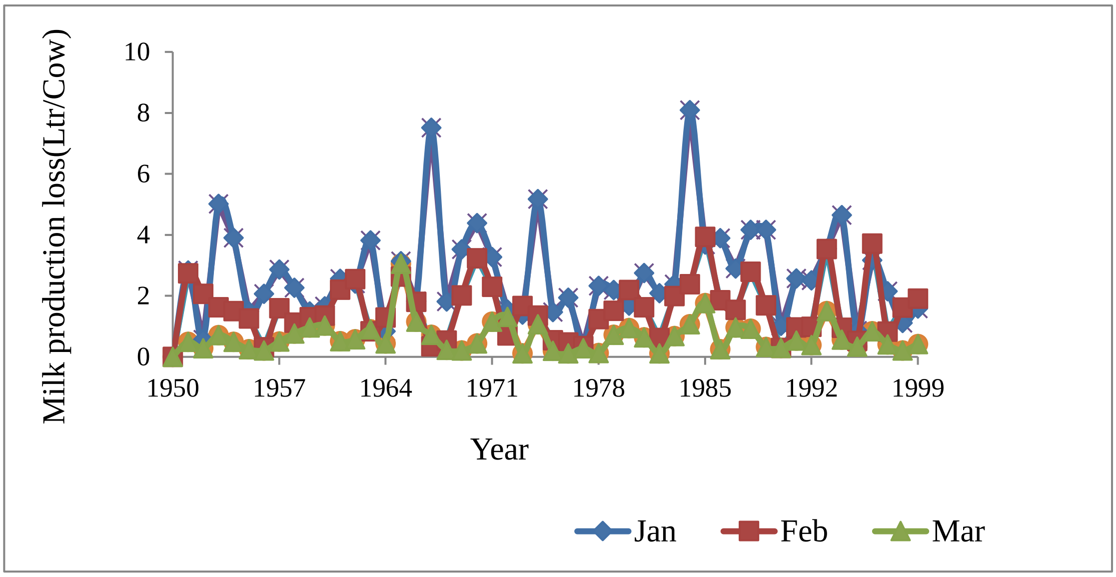

Figure 4.3: Milk production loss as a function of daily average temperature late summer seasons

4.2.3. Revenue Loss

The economic value (revenue lost) was calculated for the base years (1950–1999) using the 2014–2016milk prices per litre (ARC, 2014). With a $THI_{threshold}$ of 70, Table 4.4 shows that the loss in Bloemfontein is the highest, accruing on average to about 17cents per cow each day. A farmer owning 48 lactating cows will incur a loss of ZAR8.16per day. There is limited data in South Africa on the number of milk producing cows in total on regional basis, which is a limitation for this study in performing a conclusive calculation of economic loss. For a $THI_{threshold}$ of 65, Bloemfontein still takes the lead in production losses of about 0.12 litres of milk, on average, per cow each day, that is, each day a farmer loses 60cents worth of milk from a single cow. With 48 lactating cows, a loss of ZAR28.8 per day and ZAR10512.00 annually will be incurred. The combined average loss of milk production is 0.35litres per cow in a day, which is ZAR1.27 per cow/day.

Table 4.4: Revenue lost per cow (ZAR/day)

Region	Average total production loss(ltr/day/cow)		Average Economic loss(ZAR/day/cow)	
	70 $THI_{threshold}$	65 $THI_{threshold}$	70 $THI_{threshold}$	65 $THI_{threshold}$
BFN	-0.035	-0.12	-0.17	-0.60
BTV	-0.033	-0.11	-0.16	-0.50
BTH	-0.004	-0.33	-0.02	-0.17
Total	-0.064	-0.26	-0.35	-1.27

(BFN=Bloemfontein; BTV=Bothaville; BTH= Bethlehem; ZAR= Rand)

MPO (2014) has estimated around 140 milk-producing cows per farmer, on average, for Free State province. With the assumption that the three selected regions each has an average of 140 cows in milk, revenue losses for the base year were estimated as presented in Table 4.5. Estimates for the $THI_{threshold}$ of 70 for the three regions, all together, show a revenue loss of more than ZAR0.6 million. Milk production loss for the $THI_{threshold}$ of 65 for the three study regions was approximately ZAR5 million.

Table 4.5: Average Revenue loss (ZAR) for base year data (1950–1999)

Region	Average Revenue loss(ZAR/day/cow)		Average Revenue loss in ZAR (1950-1999)	
	70 $THI_{threshold}$	65 $THI_{threshold}$	70 $THI_{threshold}$	65 $THI_{threshold}$
BFN	-0.17	-0.60	300 976.72	1 559 488.70
BTV	-0.16	-0.50	279 316.97	2 872 019.50
BTH	-0.02	-0.17	54 739.24	442 879.90
Total	-0.35	-1.27	632 032.93	4 874 388.10

(BFN=Bloemfontein; BTV=Bothaville; BTH= Bethlehem; ZAR= Rand)

4.3. Future Scenario (2040–2070)

In the mid-century, temperatures are projected to rise, on average, for all the study areas. All the five GCMs applied show increasing temperatures alongside increasing daily maximum humidity, which in turn results in higher milk production losses. December and January are the hottest months (as observed in the baseline data, 1950–1999) where dairy cows will experience the highest heat stress for the future projected climate scenarios. These periods will also experience the highest average daily temperatures, and the estimates show the highest milk production loss on average. The three consecutive figures; 4.4 (Bothaville), 4.5 (Bloemfontein) and 4.6 (Bethlehem), show the cumulative probability function (cdf) graphs of milk production loss (ltr/Cow) with increasing temperature for all the five GCMs of the three study regions. These depict a higher probability of milk production loss with increasing temperature, with HADGEM2-ES and MPI_ESM_MR showing a higher probability of loss. With increasing temperature for Bothaville, there is an 80% probability that milk production loss will be approximately 0.3 litres per cow per day (Figure 4.4). For the HADGEM2-ES and MPI_ESM_MR climate scenario, while the other three climate scenarios show an average loss of 0.2 litres per cow per day. For Bloemfontein, the HADGEM2-ES and MPI_ESM_MR scenarios show milk production loss of 0.4 litres per cow per day, with an 80% probability as temperatures increase (Figure 4.5). The HADGEM2-ES scenario shows the highest probability milk production loss, followed by MPI_ESM_MR, for Bethlehem. There is an 80% probability of an average milk production loss of about 0.4 litres per day per cow for the HADGEM2-ES climate scenario, while there is about 0.1 litres of milk production loss for the MPI_ESM_MR climate scenario, at 80% probability. For all the five GCMs, the probability of milk production loss as temperature increases is lower for Bethlehem, compared with the other two study regions.

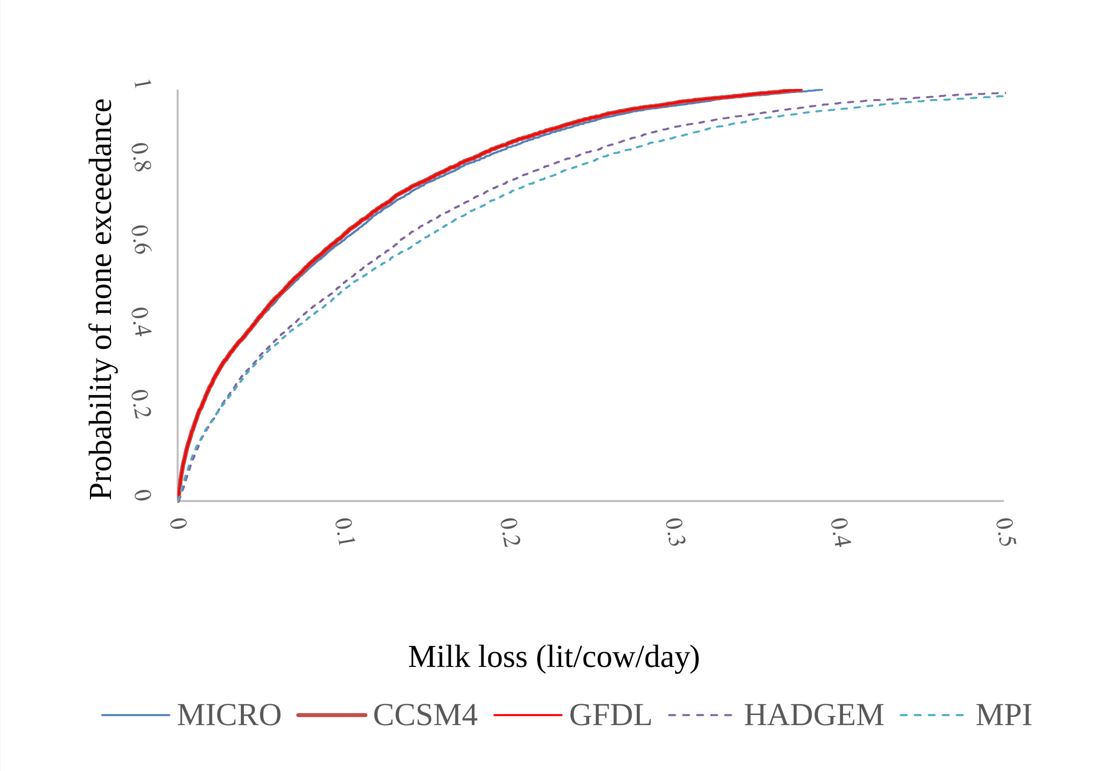

Figure 4.4: Cumulative probabilities of estimated milk production losses for five future climate scenarios – Bothaville

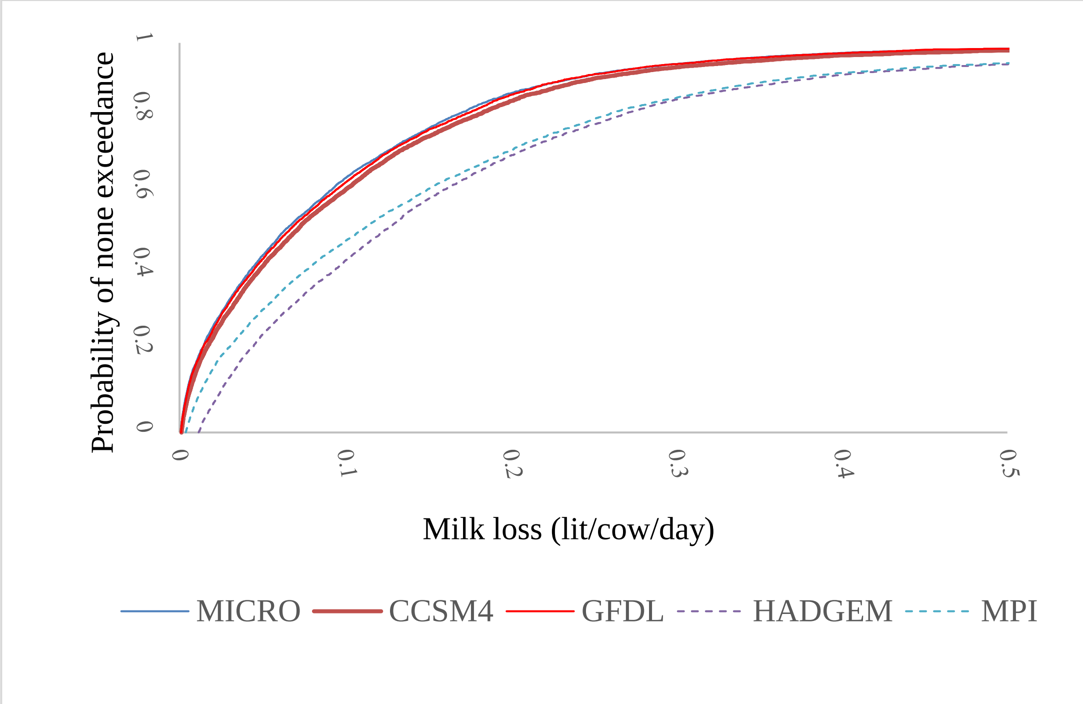

Figure 4.5: Cumulative probabilities of estimated milk production losses for five future climate scenarios – Bloemfontein

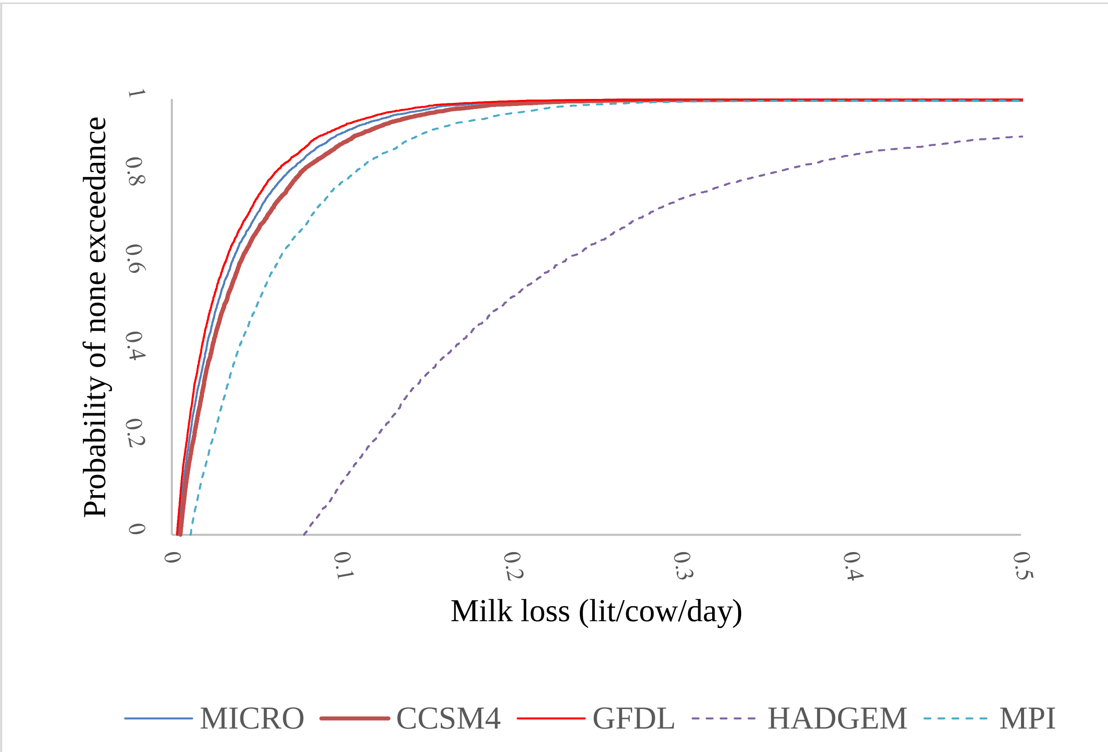

Figure 4.6: Cumulative probabilities of estimated milk production losses for five future climate scenarios – Bethlehem

4.3.1. Future Climate Scenarios without Adaptation Strategies

4.3.1.1.Seasonal milk production loss

Differences among early summer seasons (September–December) and late summer (January–April) for the future five scenarios were observed. Table 4.6 shows the average milk production losses for the three study areas and the five GCMs. Late summer seasons of the year show the highest recorded milk production losses, on average, compared to early summer seasons. For both late summer seasons and early summer seasons MPI_ESM_MR climate scenario shows the highest average milk production loss for all the three regions. Bloemfontein experiences the highest loss in late summer seasons for all the five GCMs, while Bothaville has higher milk production loss in the early summer seasons for all the five GCMs.

Table 4.6: Average seasonal milk production loss (ltr/cow)

GCMs	BFN		BTV		BTH	
	Sep-Dec	Jan-April	Sep-Dec	Jan-April	Sep-Dec	Jan-April
GFDL-ESM2	2.38	3.37	3.13	3.56	0.50	0.68
MICRO5	2.42	3.29	3.38	3.88	0.59	0.72
CCSM4	2.44	4.06	3.13	3.56	0.61	0.90
HADGEM2-ES	3.62	4.01	5.06	6.16	0.90	1.05
MPI_ESM_MR	3.97	7.16	5.06	7.03	0.92	1.36

4.3.1.2. Monthly difference in production losses (2040–2070)

Table 4.7 shows the results from the milk production loss model, analysed on a monthly basis, using all the five GCMs (GFDL-ESM2, CCSM4, MICRO5, HADGEM2-ES, and MPI_ESM_MR). Milk production losses for Bloemfontein increased more than double, resulting in the highest loss of approximately 15 litres per cow for the MPI_ESM_MR projections, compared to the base year average loss. This increase in milk production loss is evident for all study areas and all the five GCMs. January and December show the highest average milk production losses in all the three study areas (also observed in the base year). Bethlehem has lower loss, compared with the other two study areas (Bloemfontein and Bothaville), experiencing a maximum loss of about 4 litres per cow for the projected temperatures and humidity.

Table 4.7: Average monthly milk production loss (ltr/cow) for early and late summer for three study areas

month	GFDL-ESM2			CCSM4			MICRO5			MPI_ESM_MR			HADGEM2-ES		
	BTV	BTH	BFN	BTV	BTH	BFN	BTV	BTH	BFN	BTV	BTH	BFN	BTV	BTH	BFN
Sep	0.93	3.50	0.33	1.09	0.13	0.43	1.09	0.16	0.45	1.30	0.25	0.76	1.84	0.38	0.76
Oct	4.31	0.48	1.80	2.56	0.46	1.41	2.56	0.46	1.32	3.52	0.57	1.86	4.63	0.91	1.86
Nov	3.41	0.73	2.91	3.87	0.91	3.20	3.87	0.78	2.83	5.96	1.17	4.57	5.55	0.97	4.57
Dec	3.88	0.68	4.47	6.02	0.95	4.71	6.02	0.96	5.08	9.48	1.68	8.70	8.24	1.32	8.70
Jan	7.24	1.40	7.76	7.24	1.87	9.30	7.24	1.46	6.84	14.0	2.48	15.1	9.83	1.78	15.1
Feb	3.81	0.80	3.84	4.60	1.00	4.45	4.60	0.89	4.19	8.04	1.75	9.55	7.57	1.37	9.55
Mar	2.56	0.46	1.64	3.03	0.60	2.14	3.03	0.48	1.90	4.99	1.04	3.46	6.17	0.90	3.46
Apr	0.64	0.06	0.26	0.67	0.10	0.35	0.67	0.06	0.27	1.07	0.17	0.56	1.09	0.15	0.56

(BFN=Bloemfontein, BTV=Bothaville and BTH=Bethlehem)

4.3.2. Future Scenario with Abatement Strategies

The five GCMs (GFDL-ESM2, CCSM4, MICRO5, HADGEM2-ES, and MPI_ESM_MR) were applied in the calculation of the moderate heat abatement equation. The result from the analysis of the moderate abatement model, which includes employing strategies such as fans, showed a reduction in the total milk production loss of more than 50 %. Table 4.8below shows the average total production loss (ltr/cow) before the application of moderate heat abatement strategies for the projected climate scenarios in all the three study areas. The highest average loss was found to be in Bothaville (1098.4ltr/cow) by the end of the mid-century. This is different from the baseline results, where Bloemfontein experienced the highest milk production loss. The average milk production loss for Bloemfontein, before heat abatement strategy, is 913.3 ltr/cow, while after strategies, such as fans or forced ventilation, are employed, the average loss reduced to 316 ltr/cow, as shown in Table 4.9.

Table 4.8: Total production loss before abatement strategies

Region	GFDL-ESM2	CCSM4	MICRO5	HADGEM2-ES	MPI_ESM_MR	Average
BFN	715.6	808.2	710.5	950.0	1382.6	913.3
BTH	146.9	187.5	163.8	243.3	283.7	205.0
BTV	838.4	838.4	908.3	1402.7	1508.3	1098.4

(BFN=Bloemfontein; BTV=Bothaville; BTH= Bethlehem)

Without any heat abatement strategy, a farmer in Bothaville owning 50 dairy cows will experience a loss of 54 920 litres due to heat stress. By employing a moderate heat abatement strategy (wetting and forced ventilation), dairy farmers will set a limit to the duration of time during which dairy cows could be heat stressed, and hence reduce production losses.

Table 4.9: Total production loss after heat abatement strategies

Region	GFDL-ESM2	CCSM4	MICRO5	HADGEM2-ES	MPI_ESM_MR	Average
BFN	264.8	284.6	251.2	302.9	476.7	316
BTH	28.3	40.0	33.5	56.0	73.5	46.26
BTV	316.3	316.3	324.5	435.3	508.6	380.2

(BFN=Bloemfontein; BTV=Bothaville; BTH= Bethlehem)

4.3.2.1.Seasonal milk production loss

The use of moderate heat abatement strategies reduced seasonal milk production losses (Table 4.10 below). Late summer seasons (January–April) for the future five scenarios convey higher losses, compared with early summer seasons (September–December). Table 4.10 shows the average seasonal milk production losses for the three study areas and the five GCMs.

Table 4.10: Average milk production loss (ltr/cow) for late summer seasons (January–April) and early summer seasons (September–December)

GCMs	BFN		BTV		BTH	
	Sep-Dec	Jan-April	Sep-Dec	Jan-April	Sep-Dec	Jan-April
GFDL-ESM2	0.91	1.22	1.24	1.30	0.09	0.13
MICRO5	0.88	1.14	1.27	1.40	0.11	0.15
CCSM4	0.91	1.38	125	1.30	0.12	0.19
HADGEM2-ES	1.22	1.22	1.74	1.75	0.21	0.23
MPI_ESM_MR	1.47	2.36	1.86	2.23	0.23	0.35

4.3.2.2.Monthly Difference in Production Loss

Milk production losses for the Future Scenarios with abatement were computed on monthly bases (Table 4.11). The use of an abatement strategy reduced production losses by more than 50% for all the five scenarios. January and December are the two warmest months and estimates from the milk production loss model shows that during these months, production loss is the highest.

There are various ways of mitigating the impacts of heat stress on milk production (loss of milk production and hence lowered revenue). For instance, producers can use cooling mechanisms, such as sprinklers or shade installation; they can increase the use of electricity for cooling, or even increase the quantity of feed and variety of dry matter intake. However, all of these methods are costly, and producers do need to first work on the benefit and cost analysis of revenues earned from mitigation and costs of applying mitigation strategies. Table 4.11 portrays the benefits of applying moderate heat abatement strategies, such as forced ventilation and wetting of cows, using the climate forecasts from five GCMs

Table 4.11: Average monthly milk production loss (ltr/cow) for the Study Areas

Month	GFDL-ESM2			CCSM4			MICRO5			MPI_ESM_MR			HADGEM2-ES		
	BTV	BTH	BFN	BTV	BTH	BFN	BTV	BTH	BFN	BTV	BTH	BFN	BTV	BTH	BFN
Sep	0.30	0.01	0.08	0.30	0.30	0.11	0.40	0.02	0.11	0.50	0.03	0.22	0.70	0.07	0.32
Oct	1.80	0.10	0.68	1.80	1.80	0.47	1.00	0.10	0.42	1.40	0.13	0.64	1.90	0.24	1.00
Nov	1.40	0.14	1.13	1.40	1.40	1.25	1.50	0.15	1.03	2.20	0.35	1.67	1.80	0.27	1.28
Dec	1.60	0.13	1.80	1.60	1.60	1.80	2.20	0.20	2.00	3.30	0.42	3.40	2.60	0.29	2.30
Jan	2.80	0.3	3.00	2.80	2.70	3.22	2.70	0.30	2.50	4.20	0.70	5.06	3.00	0.43	2.43
Feb	1.60	0.16	1.46	1.50	1.50	1.53	1.60	0.20	1.50	2.80	0.50	3.12	2.20	0.33	1.60
Mar	0.90	0.06	0.48	0.83	0.80	0.72	1.00	0.07	0.57	1.60	0.21	1.17	1.60	0.15	0.80
Apr	0.10	0.02	0.03	0.14	0.10	0.05	0.15	0.02	0.03	0.30	0.01	0.10	0.30	0.01	0.06

(BFN=Bloemfontein; BTV=Bothaville; BTH= Bethlehem)

4.3.3. Revenue Loss

Milk production losses attributable to heat stress increased when estimated for the five future scenarios. These increases in production loss mean an increase in revenue loss for dairy farmers. Table 4.12 shows revenue losses due to heat stress for the future five climate scenarios, applying the formula described in Chapter 3 of this study. The estimate for the MPI_ESM_MR climate scenario shows the highest revenue loss, amounting to ZAR2.2 million by the end of the mid-century for the three study areas. Bothaville experienced the highest revenue loss, amounting to ZAR1.1 million, followed by Bloemfontein with a revenue loss of about ZAR1 million, while the lowest loss was incurred by Bethlehem, amounting to ZAR200000.

Table 4.12: Revenue losses (ZAR) due to heat stress for the five future scenarios before heat abatement

GCMS	BFN	BTV	BTH	Total
GFDL-ESM2	500,900.48	586,892.62	102,837.98	1, 190, 631.08
MICRO5	497,335.82	635,835.99	114,671.25	1, 247, 843.06
CCSM4	565,771.6	586,810.09	131,214.64	1, 283, 796.33
HADGEM2-ES	665,001.74	981,897.74	170,305.15	1, 817, 204.63
MPI_ESM_MR	967,851.05	1,055,867.03	198,649.67	2, 222 ,367.75

Revenue losses reduced after the employment of the heat abatement strategy by more than 50% (Table 4.13). The highest revenue loss was recorded in the MPI_ESM_MR climate scenario, with Bothaville experiencing the highest among the three study regions. Bothaville incurred a revenue loss of approximately ZAR400000, followed by Bloemfontein with a loss of about ZAR334000. Bethlehem incurred the lowest revenue loss, amounting to about ZAR60000.

Table 4.13: Revenue loss (ZAR) due to heat stress for the five future scenarios after heat abatement

GCMs	BFN	BTV	BTH	Total
GFDL-ESM2	185,366.86	221,448.09	20,000.00	426,814.95
MICRO5	175,865.94	227,199.23	22,748.46	425,813.63
CCSM4	199,254.24	221,448.09	28,026.71	448,729.04
HADGEM2-ES	212,040.60	304,767.08	39,230.24	556,037.92
MPI_ESM_MR	333,685.21	356,048.75	51,432.90	741,166.86

Farmers' Perceptions

The findings from the milk production loss (ltr/cow/day) model revealed that increasing temperature couple with increasing humidity will result in increased milk production loss per cow. Given that dairy farmers earn little profit margins, the revenue lost due to heat stress will have an impact on their ability to produce more (if the average variable cost is greater than the revenue earned, they will be operating at a loss). A semi-structured questionnaire was developed to account for farmers' understanding of heat stress/climate change and their impacts on their production. It was a plausible step to take in order to ascertain whether the findings of the milk production loss model relate to the realities of the farmers. Dairy farmers were selected from the Bloemfontein study area and were given a questionnaire aimed at their perception of heat stress and its impact on milk production. Holstein dairy cows are known to be ideally the most productive among other dairy cow breeds and all respondent farmers in this study have Holstein Friesians, one of the dominant dairy cow breeds in South Africa (Lacto Data, 2015). However, due to various challenging factors, dairy farmers produce less than their potential. Table 4.14 describes the characteristics of farms interviewed for the study. The farms have an average of 86 dairy cows and produce on average 14 litters per cow/day. A total of seven farmers were interviewed in order to validate the estimates from the milk production loss model.

Table 4. 14: Farm Characteristics

Label	Number of dairy cows	Feed types produced	Source of water	Production per ltr/cow/day
Farm 1	90	wheat	Dam and Borehole	7
Farm 2	92	wheat	Dam and Borehole	10
Farm 3	170	Maize, Sorghum & wheat	Bore holes	24
Farm 4	120	Maize, Sorghum & wheat	Bore holes	26
Farm 5	40	yellow maize, rye grass	Bore holes	3
Farm 6	47	Maize, Sorghum & wheat	Bore holes	20
Farm 7	45	None	Bore holes	16
Average	86	****	****	14

Source: Author’s computation

Increasing feed costs, such as the feed price, coupled with reduced milk production, have lowered the profit margins of dairy farmers. One farmer’s response to the first open-ended question, asking if they had noticed any long-term change in the temperature, and the last closed-ended question, asking what the main effects of increased heat and low rainfall on their production were, is presented as follows

> “Yes there is a change in temperature and rainfall – higher temperature for longer periods and no spring rain anymore and lower rainfall late in summer. Increased heat and lower rainfall affects cows directly and increase production cost because of droughts.”

Some farmers also stated that dams, where they used to get water for their cows, are now drying up owing to lower rainfall and increased temperatures, and some are no longer in use. Table 4.15 shows the perception of farmers and adjustments they made to adapt to changes in temperature and rainfall. All the respondents indicated that they have observed increasing temperature and variability of rainfall. They stated that increasing temperature is one of the reasons for their lower milk production. Although the farmers were aware of the impact of heat stress, most of them did not take any measure against it (Table 4.15). Implementing mechanised cooling, or even ventilation systems, to cool their cows is expensive for most farmers. The respondent farmers mentioned their wish to change to crop production, such as planting drought-resistant crops or moving on to piggery production, for cash flows. According to Lacto Data (2015), the number of dairy farmers in Free State region declined by 64 % from January 2008 to January 2015. Lacto Data (2015) has shown that the number of milk producers reduced by 14 % from January 2015 to August 2015. For example, when asked about what additional measures to consider in the future, one respondent answered a move to beef production. Another one responded as follows:

> "I would like to improve the dairy from a tandem to a fish grate….
> Pave the income and exit."

The results from the questionnaires show that heat stress reduces farmers' milk production significantly in summer times, and for most of the respondents, measures that should be taken are too costly to apply. For example, one respondent stated that:

> "Production becomes 50 % lower in summers …increase prices of
> feeds and have a great influence on calve percentages."

Table 4.15 1:Farmer's Perception

Label	Increased Temperature	Reduced Rainfall	Adjustments made	Constraints for adjustments	Future planes
Farm 1	Yes	Yes	None	Finance	Build Shelter
Farm 2	Yes	Yes	None	Finance	Plant trees, change to smaller cows
Farm 3	Yes	Yes	None	Finance	Shift to Beef sales
Farm 4	Yes	Yes	Use minimum labour	Finance	None
Farm 5	Yes	Yes	Move to piggery	None	Diversification into other farming enterprises
Farm 6	Yes	Yes	Shade	Finance	Diversification into other farming enterprises
Farm 7	Yes	Yes	None	Finance	None

Source: Author's computation

From the survey conducted among a few selected Bloemfontein dairy farmers, the following points can be summarised:

i. Farmers are aware of increasing heat stress:
    - For example, ponds that served as sources of water for their cows have dried up
ii. Farmers had to reduce the numbers of their milking cows because of:
    - Reduced dry matter intake due to heat stress, which is unhealthy for the cows and affects their reproductively
    - Some farmers decided to sell their dairy cows and move out of the market
iii. The farmers employed no abatement strategies.

The low-profit margin of dairy farming is a concern for small-scale and medium-scale farmers. Therefore, in order to bring about awareness of the impact of heat stress on milk production for dairy farmers, it is very important to compute revenue lost and estimate a cost–benefit analysis of applying any abatement strategy. If the cost of implementing a mitigation strategy is higher than the revenue lost due to heat stress, then it is not economically smart to consider that mitigation strategy for the farmer. However, it is worth knowing that with increasing temperatures, dairy farmers will incur a revenue loss due to the impact of heat stress on the dairy cows. Climate change is surely a challenge for milk producers, especially for small- and medium-scale farmers who are unable to cope with the associated costs. In addition, if revenue earned is not sufficient to cover their variable plus their fixed costs, they will search for alternative ways of earning revenue by getting out of the dairy production.

4.4. Conclusion

In this chapter, results from the milk production loss (ltr/cow/day) model for the baseline (1950–1999) and mid-century (2040–2070) climate data was presented. The estimates from the model show that with increased temperature, milk production losses will increase for all the three representative regions (Bloemfontein, Bothaville and Bethlehem). This is consistent with studies which show that dairy cows become less productive with increased heat stress, mainly due to changes in feed intake and reproductive systems. It is evident that without using any mitigation strategies, milk production losses due to heat stress will increase. This chapter also discussed milk production loss (ltr/cow/day) after moderate mitigation strategies (wetting of cows and forced ventilation) were employed, and the results show a reduction in milk production loss. It is worth mentioning that this paper has not considered the costs of moderate heat abatement strategies and that it was not within the scope of the study to compute a cost–benefit analysis; hence, further studies in these areas are recommended.

This chapter also discussed dairy farmers' perceptions of climate change-induced heat stress on their production. Although heat stress reduces milk production and respondent farmers are facing the negative consequences from heat stress, strategies to combat the problem were not being followed by the farmers. Climate change affects their production, both indirectly and directly: indirectly through its impact on the different feed types for the dairy cows, and directly through its consequences for the cows themselves. It was seen that over time, local ponds from where the cows used to get their water intake have dried up and feed costs have risen, while prices of milk have remained more or less the same, leaving dairy farmers with even smaller profit margins. These constraints will put financial pressure on small-scale and medium-scale dairy farmers, leading them to leave the market eventually.

CHAPTER 5: SUMMARY CONCLUSION AND POLICY RECOMMENDATION

4.5. Summary and Conclusion

Household food insecurity is a major challenge which South Africa has yet to overcome (Altman et al., 2009; Abdu-Raheem &Worth, 2011). One viable solution that should not be overlooked is dairy farming, which is an agricultural activity with vital potential of providing nutrition for households and is a good source of household income. Therefore, it is imperative to look at the challenges faced by this particular economic activity to reach beneficial decisions, both on household and national levels. Amid the other challenges faced by dairy farmers, the aim of this research is to evaluate the economic impact of heat stress on milk production in three selected semi-arid regions of the Free State, in South Africa. Increasing temperature puts pressure on dairy cows, resulting in lowered production and revenue for farmers. The results from the model of milk production loss show that with increasing temperatures, production losses rise, assuming that the farmers take no adaptation strategies. Geographical location and humidity were also found to affect milk production. From the three regions of study, Bloemfontein has the highest loss of production as a result of its high temperature.

The 2014–2016 price of milk per litre was used in the computation of the economic value of production loss for the base year, as well as for the mid-year data. Production loss, with a $THI_{threshold}$ of 70, in Bloemfontein was on average about 17cents per cow each day. Thus, the farmer, aside from all other costs, loses 17cents worth of milk production from each cow every day. Thus, taking the average number of cows in the Free State (MPO, 2015) as an example, in a year a farmer would lose about ZAR8 687.00, on average. With a $THI_{threshold}$ of 65, the three regions lose about ZAR1.27 per cow/day, with an annual loss of ZAR64, 897.00, assuming 140 as the average numbers of cows.

The future production losses are calculated based on estimated future mid-century temperatures taken from three Global Climate Models. With the estimated temperatures, milk production loss increased by more than 50% in the mid-century

(2050–2070). However, with the adoption of moderate heat abatement strategies, such as forced ventilations and wetting, dairy farmers would reduce the impact of heat stress on milk production. Climate change will likely alter the price and variability of feed types and the productivity of dairy cows in South Africa. It is worth mentioning that this study did not include other provinces in South Africa, and so including an economic analysis, such as a cost–benefit analysis, is an important for future studies.

The sub-objective of this study was to assess dairy farmers' perceptions of climate change and the adaptation strategies they use. Most of the farmers interviewed did not use any adaptation strategy because of the financial costs they would incur. Some dairy farmers applied certain adaptation strategies, such as growing drought-resistant feed types, which, however, will not render dairy cows less heat stressed. It was observed that farmers are very aware of the change in climate (rising temperatures and reduced levels of rainfall) and some do plan to plant trees so that their cows could get shade. It is, however, crucial that farmers should employ at least wetting and forced ventilation as adaptation strategies, as was observed from the moderate heat abatement model.

From the qualitative data collected, farmers who were interviewed stated that it is very costly for them to apply forced ventilation, especially given the fact that their profit margin is too small. Lacto Data (2015) showed that more and more milk producers are getting out of the market, and as the results from the qualitative data and from the milk production loss model indicate, it is more likely that if solutions are not taken, more dairy farmers will also shift to a new, more rewarding activity. This loss of dairy farmers may leave the milk market open to monopolies and will give very little solution, if any, in combating household food insecurity.

Out of the three regions under study, Bloemfontein, experienced the highest loss, while Bethlehem experienced the least, due to geographical, humidity and temperature variations. Given the importance of the dairy industry in South Africa, it is imperative to study production losses across all milk-producing provinces and to assess the economic impact of climate change on dairy farms in the country, as a whole. Of the many factors which affect dairy cows, heat stress was studied in this paper and was found to be significant, and hence further research and studies on milk production in South Africa should also consider climate change-induced heat stress in their analyses.

4.6. Policy Recommendations

Climate change is a global issue, affecting all sectors of a country's economy. The dairy sector is no exception and producers are likely to suffer from it in South Africa. It is recommended that farmers should keep their cows cool in summer seasons by planting trees for shade or building shade areas for their cows. It is also highly recommended that dairy farmers should employ moderate heat abatement strategies, such as forced ventilation and wetting. This is because it is imperative for farmers to keep their dairy cows cool in order to minimise loss.

Milk production loss was found to be influenced by geographical location variations. Hence, when selecting an area of production, farmers should identify those areas where production losses are at the minimum by considering climatic factors that influence milk production. It is also suggested that a further study should be done on the cost–benefit analysis of the use of abatement strategies versus the loss of milk production due to climate change. It is recommended that further studies should be done on the South African dairy sector as it is an important sector for alleviating the household food insecurity faced by the country. Exhaustive analyses of the economic impacts of climate change on milk production should be conducted in order to support the growth of the sector. It is also important in making a decision on which adaptation strategies to follow and so minimise losses. It is also imperative for the government to support dairy farmers by providing subsidies for implementing mitigation strategies. Extension agents should also play a role in giving their professional advices as well as information on how the dairy farmers can adapt to climate change given the financial limitations of farmers. As adaption is assumed to be an important aspect of any policy response to climate change (Gbetibouo, 2009), it is vital that dairy farmers should be encouraged to employ some of the strategies.

Milk production is very sensitive to heat stress, and the stress levels depend on breed types. Hence studies on the different effects of climate change on various dairy breeds will also contribute to the existing knowledge. When making decisions, policy makers should concern themselves with the impacts of climate change on agriculture in general, and its impact on milk production in particular. As an important sector that contributes to household food security, to the means of income and the means of employment generation, the dairy sector should be given attention in agricultural policy designs.

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APPENDIX A: QUESTIONNAIRES

DEPARTMENT OF AGRICULTURAL ECONOMICS
UNIVERSITY OF FREE STATE

"**Impact of climate change on milk production in Free State, South Africa**"

This is a survey conducted for the fulfilment of a master's thesis. The study aims to assess the impact of climate change on milk production in Free State, South Africa. The information collected will be employed for the analysis of milk production loss due to heat stress and adaptation strategies followed by dairy farmers and data collected will be on the adaptation strategies used by dairy farmers, milk production loss due to heat stress and impact of heat stress on farmer's operation costs.

The researcher would like to thank you for your cooperation in answering the questions forwarded.

Name of interviewer…………………………………

Date of interview……………………………........

Name of respondent…………………………………

Region name………………………………………....

Questionnaire number………………………………

Section A: Farm Characteristics

1. Number of dairy cows………………….
2. Feed types Produced ………………………….
3. Source of water for the dairy cows ………………………………………………
4. Production per day (Kgs or L)…………………………………………………

Section B: Farmers Perception of Climate Change

1. Have you noticed any long-term changes in the temperature since you have been working on this farm? (Please explain).

2. Have you noticed any long-term changes in the rainfall since you have been working on this farm? (Please explain).

3. What adjustments have you made in your farming practices as a result of the changes in temperature and rainfall? (Please list below).

4. What are the main constraints/ difficulties experienced in making these adjustments? (Please list below).

5. What additional measures would you consider in the future? (Please list below).

6. Since you started working have you increased or reduced the number of milk producing cows?

   Yes [ ]   No [ ]

7. If your answer to the question above is 'Yes' will you please explain you reasons?

8. Have production remained more or less the same throughout your production years?

   Yes [   ]   No [   ]

9. If milk production has decreased, do you think increasing heat and low rainfall could be part of the reason?

10. What are the main effects of heat and low rainfall on your enterprise?
    a. By affecting the cows directly
    b. By increasing prices of water and feeds for the cows
    c. By increasing your cost of production
    d. Others ____

APPENDIX B: Milk production Loss Model

Duration of heat stress (D)

```
If THIThreshold>THIMax then duration:=0
Else if THIThreshold<THIMin then duration: =24
 Else begin
THIMean:=(THIMax+THIMin)/2;
If THIThreshold>THIMeanthen
duration:=(PI-2*ArcSin((THIThreshold-THIMean)/(THIMax-THIMean)))/(2*PI)*24
else duration:=(PI+2*ArcSin((THIMean-THIThreshold)/(THIMax-THIMean)))/(2*PI)*24;
end;
```

Calculation of THIload

```
PERIOD = 24;   // 24 hours
 PI   = 3.141…
x1,x2,P,Amplitude = auxilary variables
ifTHIThreshold>=THIMax
thenTHILoad:=0
else begin
THIMean:=(THIMax+THIMin)/2;
ifTHIThreshold<THIMin then
THIResult:=PERIOD*(THIMean-THIThreshold)
else begin
Amplitude:=(THIMax-THIMin)/2;
ifTHIThreshold>=THImean then begin
x1:=ArcSin((THIThreshold-THIMean)/Amplitude);x2:=PI-x1;
THILoad:=(Cos(x1)-Cos(x2))*Amplitude*PERIOD/2/PI-(x2-
x1)*PERIOD/2/PI*(THIThreshold-THImean);
end
else begin
x1:=PI; x2:=PI+ArcSin((THIMean-THIThreshold)/Amplitude);
P:=(Cos(x2)-Cos(x1))*Amplitude*PERIOD/PI;
THILoad:=Amplitude*PERIOD/PI+(THIMean-
THIThreshold)*PERIOD/2+(THImean-THIThreshold)*((x2-PI)*PERIOD/PI)-P;
end;
```

APPENDIX C: Average milk production loss (1950-1999)

Milk production loss (ltr/cow) for Bloemfontein, Bothaville, Bethlehem

Years	Bloemfontein	Bothaville	Bethlehem
1950	0.03424223	0.022159572	0. 004386013
1951	0.038888438	0.025218284	0.004129797
1952	0.040239075	0.030085604	0.004680738
1953	0.0366794	0.023176457	0.004050488
1954	0.026084631	0.017206273	0.001745395
1955	0.014647739	0.009283408	0.000969837
1956	0.025716055	0.016305731	0.003336283
1957	0.029755265	0.018362616	0.001865436
1958	0.033429198	0.0208096	0.003202115
1959	0.031062301	0.018967384	0.003390491
1960	0.037392325	0.023225126	0.003156201
1961	0.038511138	0.022760596	0.004074382
1962	0.03728	0.022192107	0.005205279
1963	0.023644576	0.014205014	0.003266144
1964	0.04509263	0.023371777	0.004836396
1965	0.039357362	0.023077126	0.006146619
1966	0.061678183	0.032111523	0.007491848
1967	0.029351172	0.017923698	0.003359921
1968	0.038494599	0.023083511	0.007970299
1969	0.05383243	0.032415369	0.009242931
1970	0.044703324	0.026822576	0.005959448
1971	0.027483181	0.015226556	0.002465421
1972	0.040569779	0.023394265	0.005691005
1973	0.041987154	0.027422854	0.006637724
1974	0.01658159	0.00822892	0.001483102
1975	0.016534105	0.007792405	0.001125083
1976	0.010740694	0.006289488	0.001193846
1977	0.036025768	0.019813146	0.004126547
1978	0.037935548	0.02016953	0.002907793

1979	0.037756921	0.021631664	0.003454212
1980	0.033094304	0.020009718	0.003647918
1981	0.021778601	0.012632211	0.00293153
1982	0.038048131	0.022117219	0.00588317
1983	0.064423954	0.034541669	0.007490139
1984	0.053850512	0.035292612	0.004619185
1985	0.040708092	0.030386957	0.005165412
1986	0.040050412	0.025814962	0.003601598
1987	0.050365312	0.033978003	0.006282007
1988	0.030293467	0.019519374	0.003849292
1989	0.020981877	0.013684229	0.001982068
1990	0.035584066	0.022757903	0.006186879
1991	0.025886159	0.017084709	0.004063734
1992	0.051862584	0.034581696	0.008701775
1993	0.038678837	0.027876721	0.003734102
1994	0.022745733	0.016758013	0.004212644
1995	0.048286094	0.030518816	0.006486659
1996	0.023032452	0.013316836	0.001914774
1997	0.037678346	0.023867134	0.00385049
1998	0.028034038	0.017038055	0.003767262
1999	0.043863925	0.028318805	0.004175335

APPENDIX D: Farmers Perception

The regulation sceptic– high level of scepticism towards regulation related to the environment and dairy farming generally. This tends to indicate that their approach to production is perceived as being constrained by these regulations. With respect to the specific outlook of this type towards climate change, it seems that they do not expect this issue to affect their future production decisions.

The commercial ecologist– members of this cluster agree with statements related to production, profit and resource maximisation. They also have a markedly strong level of agreement with statements related to ecological values. Farmers within this type expect the impact of climate change to be predominantly negative. When coupled with their underlying openness towards the environment it would be expected that members of this group would be more pro-active. However, farmers within this cluster do not see climate change as a large enough threat to change their business approach.

The innovator– members of this cluster display a strong propensity to embrace innovative behavior. Naturally, the adoption of new techniques and methods can be coupled with their agreement with profit motives as a means of enhancing efficiency for reducing costs. When considered against their negative outlook towards the impact of climate change, members would be more likely to adopt the innovative practices and technologies proposed to negate these effects. These technologies though must satisfy their requirements for profit and resource maximisation. Hence, this group provides a stronger argument for focusing on 'win win' technology, for example adoption of best practice guidance levels for nitrogen application.

The negativist– members of this cluster are mostly typified by their negative outlook towards the impacts of climate change. A number of other studies have found 'passive' types within land use decision makers.

The disengaged– this group expresses no strong opinion towards climate change and therefore are the most disengaged of the six clusters presented here. This also presents problems for information providers to create any type of behavioral change. This type has not been directly explored per se but have usually provided a counterfactual or referent group for measuring levels of participation within environmental and conservation management programmes. The low level of belief that conservation was a legitimate use for land was identified as a main reason for this disengagement.

The positivist– members of this cluster are distinguished by their agreement that climate change will impact positively in the future. Their expectations rely on the future improvements in yield and income and may explain their equally strong response to their lack of proactively managing climate change impacts. Members of this group are skeptical towards regulation but have no agreement with other statements related to innovation, profit or ecological improvement.