



Research article

Influence of heat stress on milk production and its financial implications in semi-arid areas of South Africa

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ABSTRACT

Heat stress affects dairy cows' feed intake, reproductive system and milk production. This study analysed the financial implications of heat stress for small scale milk producers. The semi-arid regions of the Free State – Bloemfontein, Bothaville, and Bethlehem were selected for the study. To estimate the impact of heat stress on milk production, baseline (1950–1999) and mid-century (2040–2070) climate data and Temperature Humidity Index thresholds ($THI_{\text{threshold}}$) of 70 and 65 were used. Mid-century data with no adaptation strategy resulted in a doubled loss, while moderate heat-mitigation strategies (wetting and forced ventilation) resulted in positive improvements in milk production and income of farmers. Results show strong polynomial correlations (R^2 of 0.73–0.79) between the T_{max} and milk-production losses where above T_{max} of 25°C, milk-production loss increased sharply. The combined average loss of milk production during the hot summer was estimated at 0.35 liters per cow in a day, which is equivalent to ZAR1.27 per cow per day. With changing climate, the highest revenue loss was recorded in the MPI_ESM_MR future climate scenario. Moreover, results from the questionnaires show that heat stress reduces farmers' milk production significantly in the summertime, and for most of the respondents, measures that should be taken are too costly to apply. Exhaustive analysis of the economic impacts of heat stress on milk production is recommended for future studies, as it is an important sector in alleviating household food insecurity in South Africa.

1. Introduction

Dairy farming contributes to the cultural and economic values of society. According to the Food and Agriculture Organization (FAO, 2015), the value of milk, on a global scale, represents 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 to these, millions of jobs linked with transporting, processing, and marketing the milk can be added. The FAO estimated that in East Africa and the Near East, for every 100 L 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 countries' economic growth and economic development.

Dairy is the fifth largest agricultural industry sector and one of the highest employing sectors in South Africa. It caters for about 1.2 million

dairy cattle, employs around 60000 farmworkers, and provides 40 000 people with indirect jobs within the value chain, such as in the milk processing and milling industries (Milk SA, 2014; Department of Agriculture, Forestry and Fisheries (DAFF), 2015). Based on the production systems currently prevalent in the regions, milk-producing areas in South Africa are divided into six, namely KwaZulu-Natal, Southern Cape, Western Cape, Central Highveld and Free State, Central-Eastern Cape and Southern Eastern Cape. South Africa contributes only around 0.5% to the world market, with the European Union and New Zealand contributing 31% and 30% respectively (Milk SA, 2014). South Africa, on average, imported dairy products in value amounting to over ZAR440 million (over 28 million kg) between 2004 and 2014 (Milk SA, 2014). One possible reason for these figures could be increasing domestic demand.

There is growing concern over the impact of climate change-induced heat stress on dairy cows. In addition to the direct effects of heat stress on animal productivity, climate change will also have impact on soil fertility, water availability and pasture growth (Thornton et al., 2009; Nardone et al., 2010). Existing literature on dairy cows points out their

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sensitivity to high temperatures and humidity, which affect their feed intake, reproductive system, and milk production. Above their zone of thermal comfort (range of temperatures in which dairy cows can maintain normal body temperature without becoming stressed), dairy cows will reduce their dry matter intake (DMI) and experience reduced reproductive performance and declined overall productivity (St-Pierre et al., 2003; Key et al., 2014; Mauger et al., 2015). According to Mauger et al. (2015), the annual loss attributable to heat stress in the United States of America could more than triple and be over and above US\$2 billion by the end of the 21st century. Dairy farmers have slim profit margins and are also vulnerable to fluctuations in production and milk prices (Calil et al., 2012), hence heat stress will have a significant economic impact on milk production. In the case of dairy cows, climate change has an important effect on milk organic and inorganic composition (Mariani et al., 1998).

Moreki and Tsopito (2013) studied climate change effects on dairy production in Botswana and suggested certain mitigation strategies, such as using smaller dairy breeds such as Jersey, growing fodder crops, and the utilization 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, maximizing shade, and improving ventilation, while high-cost measures include designing and installing thermo-air conditioning.

Semi-arid areas of the Free State region are prone to increase temperatures and heat stress during summertime. This study was conducted in the Free State province of South Africa. Three locations were selected that represent major dairy-production areas across the Free State. The three selected areas are Bloemfontein (29°06'S, 26°18'E, 1351 m), Bethlehem (28°01'S, 18°09'E, 1585m), and Bothaville (27°05'S, 27°23'E, 1425 m). These semi-arid areas are characterized by 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 1 presents the milk producer numbers per province from 2007 to 2020. 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 2000–2001, and then again in 2008, while the Northern Free State District Municipality had a share of 11.05 % only in 2009. The number of milk producers in the Free State Province declined drastically from 987 producers in January 2007 to 145 producers in January 2020 (approximately a 85% decline). This decline could be attributed to many factors including the evident change in climate and financial challenges small holder farmers' face to compare to large scale producers. The

production loss, without adaptation strategies, is the highest due to the sensitivity of dairy cows to excessive climatic variables such as temperature and humidity. Given the predicted Global Circulation Models (GCMs), production losses are expected to increase if adaptation strategies are not implemented by producers.

Given the aforementioned problems, it is important to conduct an economic analysis on the effect climate change induced heat stress on dairy production in South Africa. The economic losses due to heat stress were estimated by St-Pierre et al. (2003) for the major livestock industries in the United States. A review of the literature also shows that there is limited literature on the economic impact of heat stress on milk production. The effects of increasing temperatures on livestock will be different worldwide, based on latitude and farming systems. Therefore, this article focuses on the main aspects linked to the effects of heat stress on dairy in semi-arid region. In addition, we examined farmers' perception of the impact of climate change-induced heat stress and their preferred adaptation strategies. We found no studies on the relationship between heat stress, milk production, farmers perception and adaptation making this study a unique one. Without any adaptation strategies, heat stress increases the cost of milk production, however, by applying moderate to large scale adaptation and mitigation strategies, farmers can reduce production losses. The findings from the study contribute immensely to a better understanding of climate change in South Africa as it relates to the dairy industry and advances climate change and adaptation policies. The subsequent sections of the paper present data and methodology, results, discussion as well as conclusion.

2. Data and methodology

2.1. Rationale

Exposure to the combination of high temperature and humidity overcomes the capacity of cattle to disperse heat and leads to an increase in body temperature that surpasses the physiological limits (Das et al., 2016). Such condition is called heat stress and impairs the welfare and productive performance of dairy cattle. Heat stress in dairy cows is associated with high temperature and humidity. The endurance and performance of animals during heat-stress months is highly dependent on several weather factors, especially temperature and humidity (Du Preez, 2000). To evaluate the simultaneous effect of temperature and humidity factors and to assess the risk of heat stress in cattle, the temperature–humidity index (THI) is used. THI accounts for the combined effects of environmental (air) temperature and relative humidity; lower temperatures at high humidity cause similar heat stress to higher temperatures at lower humidity (Dunn et al., 2014).

Studies measuring the impacts of climate change on dairy cows use THI to measure heat stress and commonly apply a THI threshold between 70 and 72. Some researchers have, however, shown that developments in genetics and increases in milk production have lowered the heat-stress

Table 1. Milk Producer numbers per Province.

Province	2007	2008	2009	2011	2012	2014	2015	2016	2017	2018	2019	2020
Western cape	827	815	795	683	647	526	533	502	481	419	402	379
Eastern Cape	420	407	387	314	283	264	262	251	244	212	201	206
Northern Cape	37	34	37	28	21	25	14	14	7	7	6	4
KwaZulu-Natal	385	373	373	323	322	281	267	253	247	221	212	208
Free State	987	919	884	601	535	389	328	280	249	206	165	145
North West	596	549	540	386	352	233	222	181	165	135	117	100
Gauteng	245	228	217	127	126	109	100	97	98	84	83	65
Mpumalanga	357	302	286	201	164	117	94	93	87	69	56	50
Limpopo	45	38	32	23	24	14	14	12	15	12	11	7
Total	3899	3665	3551	2686	2474	1961	1834	1683	1593	1365	1253	1164

Source: Milk SA (2020)

threshold to 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 THI as an indicator of heat stress.

Calculations of THI do not include wind speed and solar radiation; however, wind speed is more dependent on topography than humidity and temperature (Dunn et al., 2014). The THI is still the commonly used method and most practical index (parameter) for quantifying temperatures that cause heat stress in dairy cattle (Du Preez, 2000). According to Du Preez (2000), the THI can be computed from air temperature and relative humidity as follows:

$$THI = \left(0.18 \times T_{air} + 32 - \left(0.55 - 0.55 \times \frac{RH}{100} \right) \times (T_{air} - 26) \right) \quad (1)$$

where T_{air} is the air temperature in degrees Celsius, measured by a thermometer freely exposed to the air, and RH is the relative humidity in percentage points.

2.2. Methodology and data sources

This study identified a THI of 70 as a threshold, since the average milk production in South Africa is about 22.5 L per cow (Milk SA, 2015), which is a fair threshold chosen for such a quantity of production (Beriman, 2005; St-Pierre et al., 2003; Mauger et al., 2015; Du Preez, 2000; DuPreez et al., 1994; Du Preez et al., 1990). A threshold of 65 was used for comparison reasons and sensitivity tests. A daily minimum THI (THI_{min}) was calculated from the daily minimum temperature (T_{min}) and daily maximum RH (RH_{max}). A daily maximum THI (THI_{max}) was calculated from the daily maximum temperature (T_{max}) and daily minimum RH (RH_{min}), applying the standard THI equation. Following the assumptions in St-Pierre et al. (2003), the THI was taken to have a perfect sine function, with a 24-hour period.

Daily averages of maximum and minimum temperatures and RH changes from the baseline and mid-century (2040–2070) data, across the selected five GCMs, were used for the analysis of THI in all three representative semi-arid study areas. A time series daily weather data from 1950 was used to estimate means of monthly minimum and maximum temperatures, and RH, and to calculate both the minimum and maximum THI for the three selected areas in semi-arid 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 (1950–1999) of daily minimum and maximum temperatures.

This study used five GCMs, 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 Model 4 (CCSM4), the MPI Earth System Modelling running on Medium Resolution grid (MPI_ESM_MR), and MICRO5. All these are individual simulations, considered as possible scenarios 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 one-degree horizontal resolution (increasing to $1/3^\circ$ at the equator) and 40 vertical levels (Eyring et al., 2016).

These future datasets that have been suggested for creating climate change scenarios for study areas were used according to the guidelines of the Climate System Analysis Group (CSAG), University of Cape Town. 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 heat stress in dairy cows.

To estimate the impact of climate change, this study followed the approach in St-Pierre et al. (2003) for its malleability and extensive literature review. 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 (L/cow/day) due to heat stress is given as:

$$Loss = \alpha (THI_{max} - THI_{threshold})^2 \times D \quad (2)$$

where α is taken to be = 0.065, consistent with St-Pierre et al. (2003); THI is a single value that represents the combination of air temperature and humidity associated with the level of heat stress.

To compute the income of individual farmer we used:

$$Income_i = \sum (P_j \times q_j) - C_j \quad (3)$$

where i is individual farmers, j is milk production, p is the price of milk, q is the quantity of milk produced, and c is the cost 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. 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 based on the following formula:

$$RevenueLoss = \sum (P_j \times q_{jloss}) \quad (4)$$

where q_{jloss} is the quantity (L) 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. Results

3.1. Baseline data analysis (1950–1999)

Average mean T_{max} and THI_{max} were used to compute milk-production loss (L/cow/day) for the selected study regions (Bloemfontein, Bothaville, and Bethlehem) in the baseline dataset. 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 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 which type of abatement strategy to employ. The highest loss experienced was in Bloemfontein, which had a THI_{max} above 70.

The coefficients of variation (CV) in the milk-production loss for the three regions were 12.5%, 13.5%, and 21.9% for Bloemfontein, Bothaville, and Bethlehem respectively. The CV for Bloemfontein and Bothaville showed smaller dispersion from the mean, while for Bethlehem the CV showed that loss in milk production was relatively more dispersed. Calculating the CV will assist in understanding whether there are significant differences among the average years and if so, to identify the possible explanations for it being high, such as the highest temperature recorded in a specific year. Seasonal cycles in production loss exist due to the non-linear dependence of the milk-production loss model on daily temperature and humidity (Table 2). The highest loss was recorded during the late summer months of each year in all three regions.

In early summer, milk loss was lower during October and showed an increase in the months of November and December. In January, as the temperature rises, milk loss reaches the highest records; for example, in 1967 and 1984 the highest milk losses of 7.5 and 8.1 L/cow/day were estimated, respectively.

Table 2. Average seasonal total milk-production loss (L/cow) for Bothaville (BTV); Bloemfontein (BFN) and Bethlehem (BTH) for each 10 years range from 1950–1999.

Year range	BTV		BFN		BTH	
	Early summer (Sep.–Dec.)	Late summer (Jan.–Apr.)	Early summer (Sep.–Dec.)	Late summer (Jan.–Apr.)	Early summer (Sep.–Dec.)	Late summer (Jan.–Apr.)
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

The relationship between T_{\max} and milk-production losses shows positive polynomial regression correlations, where above T_{\max} of 25°C, milk-production loss increased in all three study areas (Figure 1). The polynomial curves for Bloemfontein and Bothaville are relatively steeper than the graph for Bethlehem, which indicates that milk loss for Bethlehem was lower, compared with the other two study areas.

The economic value (revenue lost) was calculated for the base years (1950–1999) using 2014–2016 milk prices per liter (Agricultural Research Council, 2014). With a $THI_{\text{threshold}}$ of 70, revenue loss in Bloemfontein was the highest, accruing on average to about 17 cents per cow/day. Limited data are available in South Africa on the number of milk-producing cows in total on a regional basis, which is a limitation for this study in performing a conclusive calculation of economic loss. For a $THI_{\text{threshold}}$ of 65, Bloemfontein still takes the lead in production losses of about 0.12 L of milk; that is, a farmer loses 60 cents worth of milk from a single cow each day. The combined average loss of milk production is 0.35 liters per cow in a day, which is ZAR1.27 per cow per day.

3.2. Future scenario (2040–2070)

In the mid-century, temperatures are projected to rise, on average, for all the study areas. All five GCMs estimated increasing temperatures, alongside increasing daily maximum humidity, which in turn will result in higher milk-production losses. December and January are the hottest months (as observed in the baseline data of 1950–1999) when dairy cows will experience the highest heat stress for the future projected climate scenarios. Differences among the early summer months (September to December) and late summer months (January to April) for the five future scenarios were observed. Table 3 shows the average milk-production losses for the three study areas and the five GCMs. Late summer months of the year show the highest recorded milk-production losses, on average, compared to the early summer months. For both late summer

months and early summer months, the MPI_ESM_MR climate scenario shows the highest average milk-production loss for all three regions. Bloemfontein experiences the highest loss in late summer months for all five GCMs, while Bothaville indicates a higher milk-production loss in the early summer months for all five GCMs.

3.2.1. Future scenario with adaptation strategies

The five GCMs (GFDL-ESM2, CCSM4, MICRO5, HadGEM2-ES, and MPI_ESM_MR) were applied in the calculation of the moderate heat abatement/adaptation equation. The results from the moderate abatement model, which included employing strategies such as fans, showed a reduction in the total milk-production loss of more than 50%. The highest average loss was recorded in Bothaville (1098.4 L/cow) by the end of the mid-century. This differs from the baseline results, where Bloemfontein experienced the highest milk-production loss. The average milk-production loss for Bloemfontein, before a heat-abatement strategy, was 913.3 L/cow, while after such strategies, such as fans or forced ventilation, are employed, the average loss reduced to 316.0 L/cow (Table 4).

Without any heat-abatement strategy, a farmer in Bothaville who owns 50 dairy cows will experience a monthly average loss of 54920 L 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. The use of adaptation strategies reduced production losses by more than 50% for all five scenarios. January and December are the warmest months and estimates have shown production loss to be the highest during these months. There are various ways to adapt to heat stress; 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 and variety of feed and DMI.

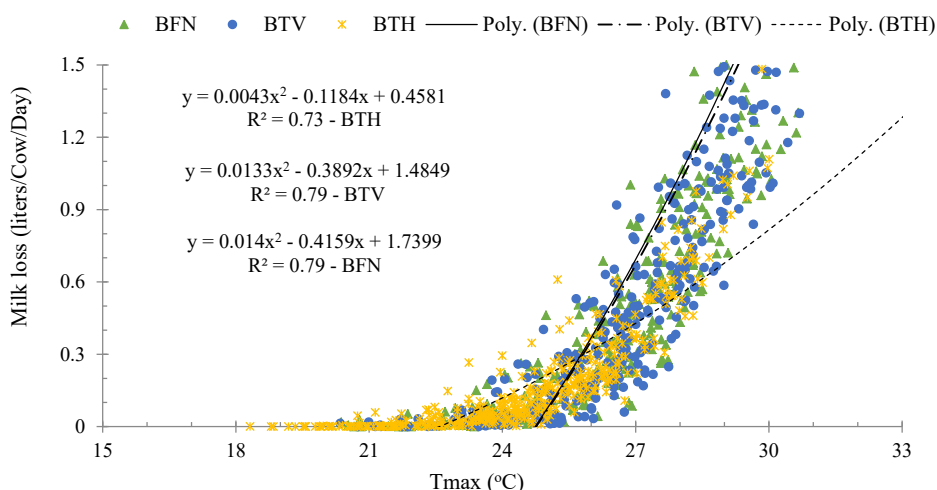


Figure 1. Fitted polynomial regression between milk-production loss and maximum average daily temperature for all three study areas (Bothaville [BTV]; Bloemfontein [BFN]; Bethlehem [BTH]).

Table 3. Average seasonal milk-production loss (liters/cow) for all three study areas (Bothaville [BTV]; Bloemfontein [BFN]; Bethlehem [BTH]).

GCMs	BFN		BTV		BTH	
	Early-summer (Sep.–Dec.)	Late summer (Jan.–Apr.)	Early summer (Sep.–Dec.)	Late summer (Jan.–Apr.)	Early summer (Sep.–Dec.)	Late summer (Jan.–Apr.)
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

Table 4. Total production loss (liters/cow) a) before and b) after adaptation strategies for all three study areas (Bothaville [BTV]; Bloemfontein [BFN]; Bethlehem [BTH]).

Regions	GFDL-ESM2	CCSM4	MICRO5	HadGEM2-ES	MPI_ESM_MR	Average
a)						
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
b)						
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

3.2.2. Revenue loss

Milk-production losses attributable to heat stress increased when estimated for the five future scenarios. The estimate for the MPI_ESM_MR climate scenario was the highest in 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 approximately ZAR1-million, while the lowest loss was incurred by Bethlehem, amounting to ZAR200 000.

Revenue losses reduced by more than 50% after the employment of a heat-abatement strategy (see Figure 2). 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 ZAR400 000, followed by Bloemfontein with a loss of around ZAR334 000. Bethlehem incurred the lowest revenue loss, amounting to approximately ZAR60 000.

3.2.3. Farmers' perceptions

The findings of the milk-production loss (liters/cow/day) model revealed that increasing temperature coupled with increasing humidity will result in increased milk-production loss per cow. Given that dairy farmers earn small profit margins, the revenue lost due to heat stress will have an impact on their ability to produce more (i.e. if the average

variable cost is greater than the revenue earned, they will operate at a loss). A semi-structured questionnaire was developed to account for farmers' understanding of heat stress and climate change and the impacts thereof on their production. It was a plausible step to take to ascertain whether the findings of the milk-production loss model relate to the realities of the farmers. Dairy farmers were selected (convenient sampling) from the Bloemfontein study area and were given a questionnaire aimed at determining their perception of heat stress and its impact on milk production. Holstein dairy cows are known as the most productive among the dairy cow breeds and all respondent farmers in this study owned Holstein Friesians, one of the dominant dairy cow breeds in South Africa (Milk SA, 2015). Due to various challenging factors, however, dairy farmers produce less than their potential. Table 5 describes the characteristics of farms selected for the study. The farms have an average of 86 dairy cows and produce on average 14 L per cow/day. A total of seven farmers were interviewed to validate the estimates from the milk-production loss model.

Table 6 shows the perceptions of farmers and the adjustments they made to adapt to changes in temperature and rainfall. All the respondents indicated that they have observed increasing temperatures and variability of rainfall. They stated that increasing temperatures are 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

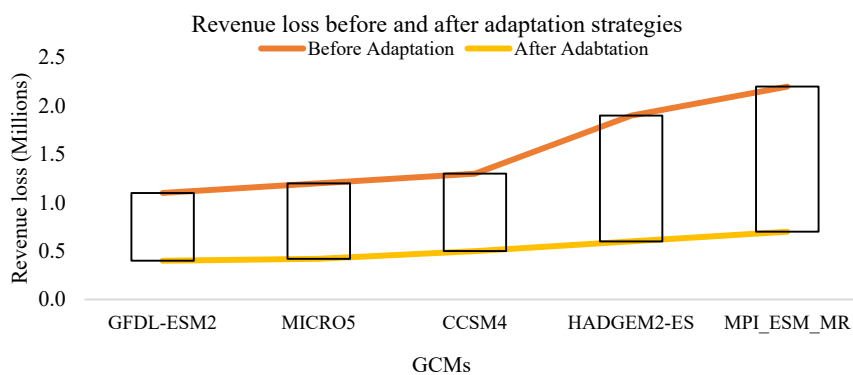
**Figure 2.** Revenue loss before and after adaptation strategies using 5 future scenarios (GCMs).

Table 5. Different farm-scale characteristics of selected dairy farmers visited and interviewed in Bloemfontein to understand their perception's on the impact of climate change on milk production.

Label	Number of dairy cows	Feed types produced	Source of water	Production per L/cow/day
Farm 1	90	Wheat	Dam and borehole	7
Farm 2	92	Wheat	Dam and borehole	10
Farm 3	170	Maize, sorghum & wheat	Boreholes	24
Farm 4	120	Maize, sorghum & wheat	Boreholes	26
Farm 5	40	Yellow maize& ryegrass	Boreholes	3
Farm 6	47	Maize, sorghum & wheat	Boreholes	20
Farm 7	45	None	Boreholes	16
Average	86 (47)*	-	-	15 (8)*

* std for the number of dairy cows owned and production level.

Source: Authors compilation from the questionnaire.

Table 6. Farmers' perceptions for the effect of climate change-induced heat stress in dairy cows.

Label	Increased temperature	Reduced/fluctuating rainfall	Adjustments made	Constraints for adjustments	Future plans
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 labor	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: Authors compilation from the questionnaire

measures against it (Table 6). Implementing mechanized 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 to pig-gery production, for improved cash flow. According to Milk SA (2015), the number of dairy farmers in the Free State region declined by 64% from January 2008 to January 2015. Milk SA (2015) has shown that the number of milk producers reduced by 14% from January 2015 to August 2015.

The results from the questionnaires show that heat stress reduces farmers' milk production significantly in the summertime, and for most of the respondents, measures that should be taken are too costly to apply. For example, one respondent stated: "Production becomes 50% lower in summers ...increase prices of feeds and have a great influence on calving percentages."

From the survey conducted among selected dairy farmers, the following points were summarized:

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

The low-profit margin of dairy farming is a concern for small- and medium-scale farmers. Therefore, to create awareness of the impact of heat stress on milk production for dairy farmers, it is very important to compute revenue loss 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 revenue loss due to the impact of heat stress on 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 moving out of dairy production.

4. Conclusion

Climate change is a global phenomenon which poses a challenge to 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 months by planting trees for shade or building shaded areas for their cows. It is also highly recommended that dairy farmers 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 to minimize loss.

The 2014–2016 price of milk per liter 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 17 cents per cow each day. The farmer, aside from all other costs, loses 17 cents worth of milk production from each cow every day. Thus, taking the average number of cows in the Free State (Milk SA, 2020) as an example, in a year a farmer would lose about ZAR 8 687.00, on average. With a THI threshold of 65, the three regions lost about ZAR1.27 per cow/day, with an annual loss of ZAR 64, 897.00, assuming 140 as the average numbers of cows.

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. In addition, further research should be conducted 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 conducted on the South African dairy sector as it is an important sector for alleviating household food insecurity faced by the country. Exhaustive analyses of the economic impacts of climate change on milk production could be an important step to support the growth of the sector. This is essential in deciding which adaptation strategies to utilize to minimize losses. It is also imperative for concerned parties to support dairy farmers by providing subsidies for implementing mitigation strategies. As adaptation is assumed to be an important aspect of any policy response to climate change, it is vital that dairy farmers be encouraged to employ some adaptation strategies.

Milk production is very sensitive to heat stress, and the stress levels depend on breed types. Hence studies on the effects of climate change on various dairy breeds will contribute to existing knowledge. When making decisions, policymakers 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, means of income, and employment generation, the dairy sector should be paid attention to agricultural policy designs. This study provides an insight into how =====+<http://www.scialert.net/asci/result.php?search-in=Keywords&cat=&ascicat=ALL&Submit=Search&keyword=heat+stress+heat+stress+affects+milk+production+in+semi-arid+areas+of+South+Africa> and elucidates the mechanisms through which the reduced milk production affects financial stability for small-to medium-scale farmers. Besides, heat stress not only reduces milk production but also affects the quality of milk by altering various components of milk with changing climatic conditions. Further, extensive studies are required to determine the exact loss of milk production incurred due to the effect of climate change to equip farmers with cost-effective mitigation strategies.

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Author contribution statement

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Data will be made available on request.

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The authors declare no conflict of interest.

Additional information

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