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The impact of heat stress on milk production, conception percentage, temperature humidity index and maximum temperature of dairy cattle in South Africa

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The impact of heat stress on milk production, conception percentage, temperature humidity index and maximum temperature of dairy cattle in South Africa.
Heat stress has a significant negative effect on the immune function and health of dairy cattle at all stages of their life cycles and has the greatest negative impact as a stress factor in dairy cattle because all functions of the dairy cattle suffer from it. It is clear that heat stress in dairy cattle suppresses their immune system and is part of the animals continuous effort to maintain a state of homeostasis. The consequences of the increased heat stress impact on milk production, conception percentage (CP), maximum temperatures (MT) and temperature humidity index (THI) of the dairy cattle of South Africa are the following: The average reduction in CP over the period 1960 to 2020 (60 years) is 4.9% which is a formidable negative impact on South Africa's dairy cattle. The average increase in the MT over the period 1933 to 2020 (87 years) was 0.9 °C which has a frightening impact on South Africa's dairy cattle. The average milk production loss over the period 1960 to 2020 (60 years) has been 0.26kg/cow/day. The average THI values have increased by one (1) THI value for the period 1960 to 2020 (60 years). This increase stands to exacerbate the negative heat stress impact on the performance of South Africa's dairy cattle. It is estimated that the loss due to heat stress in the dairy industry in South Africa is more than one billion Rand per year. Prevention and control of heat stress in dairy cattle is therefor extremely relevant and a priority.

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KEYWORDS: Heat stress; immune system; conception percentages; maximum temperature; milk production; temperature humidity index; dairy industry; climate change; South Africa.

INTRODUCTION

Global warming is mainly caused by the build-up of greenhouse gases since the industrial revolution, with carbon dioxide (CO_2) the main contributor. Since the beginning of the 20th century, the average atmospheric temperature has risen by about 0.74 °C. In South Africa the average rate of warming is in the region of 0.16°C per decade, measured over the last 70 years (https://www.weathersa.co.za/home/annualstateoftheclimate). Global warming is already causing visible changes for humans, animals and the environment, and these are international environmental issues affecting people worldwide (Johnston, 2018; Engelbrecht, 2019). The above-mentioned greenhouse effect is set to continue, and Southern Africa's temperatures could rise by up to eight degrees Celsius within the next century. Carbon dioxide emissions into the atmosphere must be reduced by 45% within the next eleven years if disaster is to be averted (Engelbrecht, 2019). The symbolic carbon dioxide reference level of 400 ppm in the atmosphere was reached in 2015 and has risen every year since. In 2020, greenhouse gas concentrations reached new highs. Levels of carbon dioxide (CO2) were 413.2 parts per million (ppm), methane (CH4) at 1889 parts per billion (ppb) and nitrous oxide (N2O) at 333.2 ppb, respectively, 149%, 262% and 123% of pre-industrial (1750) levels. The increase has continued in 2021 (https://public.wmo.int/en/media/press-release/state-of-climate-2021-extreme-events-and-major-impacts). The increase in CO2 concentration implies a year-on-year average increase of 0.6 ppm since pre-industrial levels, although according to the latest WMO State of the Climate report it is clear that the rate of increase since 1985 is about 2 ppm per year.
This means that the annual increase of greenhouse gases in the atmosphere will most probably continue in the

foreseeable future with serious consequences of climate change.

Climate change is a change in the statistical distribution of weather patterns when that change continues for an extended period, for example for decades or millions of years. Climate change can refer to a change in average weather conditions, or to the time variation of weather within the context of longer-term average conditions. Climate change is caused by factors such as biotic processes, variations in solar radiation impacting the earth, plate tectonic movements and volcanic eruptions. Certain human activities have been identified as primary causes of continuous climate change, commonly referred to as global warming. There is no agreement in scientific media or policy documents on exactly what term should be used to refer to man-made climate change; both “global warming” and “climate change” are used (WikipediaA, the free encyclopaedia, Climate Change, 2019). The trends of South Africa's surface temperatures during 1931 to 2015 inland have shown increased and decreased tendencies for certain coastal areas (Kruger and Nxumalo, 2016). Climate change will certainly affect farming methods and the lives of the people in Southern Africa.

The sensitivity of the animals to weather conditions has been well proven and their performance and survival are severely affected by the direct effects of the weather. As a result, the weather often limits the efficiency of livestock production systems, especially in the case of dairy cattle with a high milk yield for which sufficient nutritional needs must be provided. The effects of adverse weather conditions have a detrimental effect on the quantity and quality of human food supplies, no matter how extensive or intensive the production is (Hahn, 1985). An excessively warm climate impedes food intake, milk production and the reproductive capacity of dairy cattle (e.g. reduced conception rates), while metabolic heat production also increases (Johnson, 1985; Yousef, 1985b; Flamenbaum, *et al*., 1986; Gantner *et al*., 2011; Habeeb *et al*., 2018) and this has serious economic consequences for dairy farming. Especially under hot conditions, abiotic (non-living components) or physical environmental factors such as an observable excessive high temperature of the air, humidity, rain, low altitude, solar radiation and wind have an important influence on the productivity of livestock (Yousef, 1985b; Du Preez, 1994a; Habeeb, *et al*., 2018). Dairy cattle are homothermic animals and their homeostasis is maintained by a sensitive balance between heat production and heat loss (Yousef, 1985c).

Ambient temperature fluctuations lead to significant variations in the temperature of the peripheral body parts; therefore the deep body temperature or core temperature is used as a control parameter for changes in body temperature (Yousef, 1985a). Environmental factors such as sunlight, thermal radiation and air temperature, animal characteristics (rate of metabolism, moisture loss and geometric structure) and thermoregulatory mechanisms such as conduction, radiation, convection and evaporation influence the energy exchange between the dairy cow and her environment. This in turn affects the body temperature of the animal, which in turn leads to changes in the metabolism and behaviour of the animal (Gebremedhin, 1985). Farm animals need better management and housing in hot and humid environments to meet their expected level of performance and well-being. Rationally planned housing and management strategies, as well as tactical practices such as reducing ambient heat, are essential for short-term protection aimed at increased long-term performance and well-being (Yousef, 1982; Hahn, 1985; Wolfenson, *et al.,* 1988). Considering the above, it is imperative to assess how climate changes, primarily through the gradual increase in the mean surface temperature, has adversely impacted on the prevalence of unfavourable conditions of heat stress, with consequent negative impacts on milk production and conception rate in dairy cattle. This is done through the historical analysis of relevant long-term climate data, measured at weather stations within the regions where the dairy industry is prevalent in South Africa. The aim of the study were to determine the effects and consequences of heat stress on temperature humidity index (THI values), milk production (MP), conception percentage (CP) and maximum temperature (MT) on dairy cattle in South Africa.

RESEARCH METHODS, DESIGN, DATA AND METHODOLOGY

Acquisition of meteorological data from South African Weather Service

Figure 1 presents Map 1 of all the regions in South Africa which contribute significantly to the dairy industry. Meteorological time series of the relevant weather parameters to calculate the required indices were selected in the vicinity of these regions. The meteorological data (maximum daily temperature (Tdb) and dew point temperature (tdp) at 14:00) of 18 weather stations with long-term data deemed sufficient (26 to 87 years) to estimate long-term trends were selected for analysis. The recording periods vary between stations and are presented in Table 1.

Calculation of temperature humidity index (THI values) as an index of warm weather stress (heat stress)

Mathematical calculation of the actual THI values as an index of heat stress, using the formula below. The temperature humidity index (THI) is still one of the best, simplest and most practical index parameters for measuring the environment's temperature with its effect on dairy cattle as well as the most effective indicators for heat stress potential (Du Preez, 1994a; Du Preez, 2000; Dikmen & Hansen, 2009; Dahl, *et al.,* 2020) The formula for calculating the THI index for dairy cattle is:
THI = Tdb + 0.36tdp + 41.2 (Bosen, 1959; Kibler, 1964) where Tdb = dry bulb temperature in °C (maximum temperature at 14:00), and tdp = dew point temperature in °C, also at 14:00. The dew point is the temperature to which a given amount of air must be cooled at a constant air pressure to condense water vapour.

Calculation of milk production of lactating cattle per cow per day in South Africa

The estimation of milk production **(kg / cow / day) = 47,722 - 0,2725 x THI.** This formula has been compiled from relevant information obtained from scientists. (Du Preez, 1994a; Bouraoui, *et al*., 2002, West, *et al.,* 2003; Nardone, *et al.,* 2010; Das, *et al.,* 2016; Santana, *et al.,* 2016; Gunn, *et al.,* 2019). This regression equation in general shows that for every one unit value of the THI value that is above 69, there is a 0.2725 kg decrease in milk production per cow per day (Bouraoui, *et al*., 2002). The general scientific consensus regarding the effect of heat stress in dairy cattle is that there is a decrease in milk production, as well as the milk quality and milk composition in accordance with the increase in temperature-humidity index (THI) values. (Prangna, *et al*., 2017).

Calculation of conception percentage (CP) of dairy cattle in South Africa

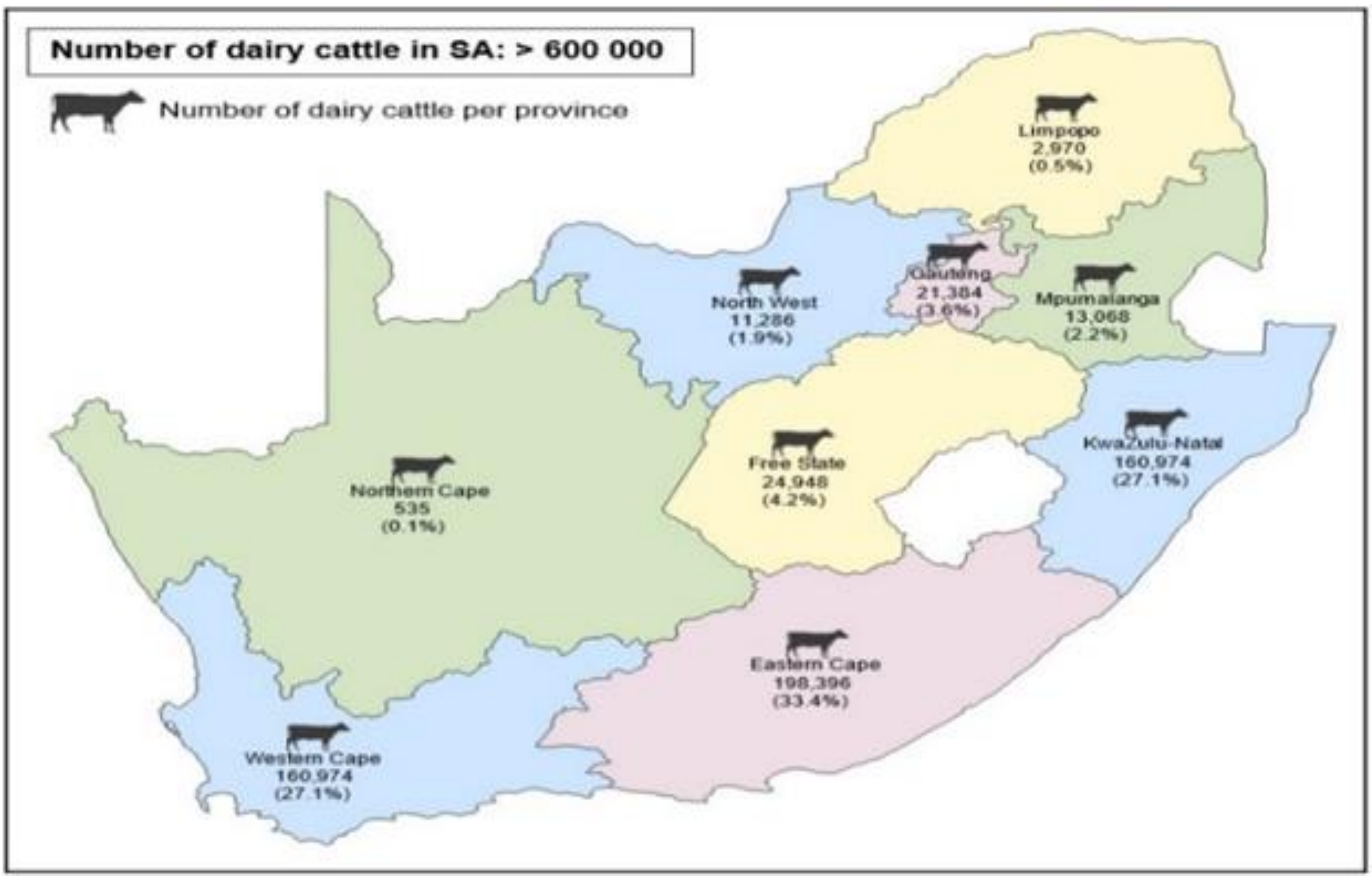
To predict the effect of heat stress on reproduction in dairy cattle under South African conditions. The following regression model THI values were calculated by:

$CP = -890.2 + 31.15\ THI - 0.253\ THI^2$ (Du Preez, 1994a).

Calculation of the maximum temperature (MT) of the day (14:00) from eighteen weather stations data in South Africa

Acquisition of the MT data of the day from South African Weather Service.

Map 1: Number of dairy cattle per Province in South Africa (Swart, 2020)



RESULTS

Weather stations are listed in Table 1, eighteen graphs were drawn from weather stations data of South Africa in seven provinces for temperature humidity index (THI values), milk production, conception percentage and maximum temperatures of the day (14:00) and were individually constructed, to obtain the long-term trend values. The long-term calculations varied between 26 and 87 years, depending on data availability.

Table 1: Weather stations, years, graphs and provinces

Weather station no.	Weather stations	Years	Graphs	Provinces
1.	Lichtenburg	1994-2020	1	North West
2.	Potchefstroom	1958-2020	2	North West
3.	Vereeniging	1986-2020	3	Gauteng
4.	Pretoria University	1991-2020	4	Gauteng
5.	Ermelo	1994-2020	5	Mpumalanga
6.	Bethlehem	1981-2020	6	Free State
7.	Bloemfontein	1962-2020	7	Free State
8.	Malmesbury	1987-2020	8	Western Cape
9.	Worcester	1989-2020	9	Western Cape
10.	George	1977-2020	10	Western Cape
11.	Mosselbay	1933-2020	11	Western Cape
12.	Riversdale	1986-2020	12	Western Cape
13.	Tygerhoek	1966-2020	13	Western Cape
14.	Cape St. Francis	1933-2020	14	Eastern Cape
15.	Patensie	1991-2020	15	Eastern Cape
16.	Cradock	1986-2020	16	Eastern Cape
17.	Estcourt	1994-2020	17	KwaZulu-Natal
18.	Cedara	1952-2020	18	KwaZulu-Natal

From the 19 graphs with long-term calculations, we show only three graphs (Potchefstroom, Worcester and Cradock weather stations) with the impact of heat stress on THI values, milk production, conception percentage and maximum temperatures of dairy cattle. The total data from 18 weather stations were captured (Table 1).

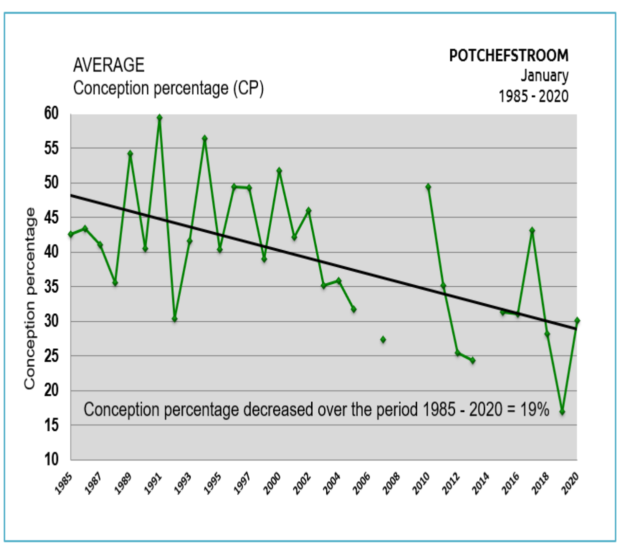
Graph 1: Conception percentage (CP), Milk production (MP), Maximum temperature (MT) and temperature humidity index (THI) values as well as for graph 9 and 16

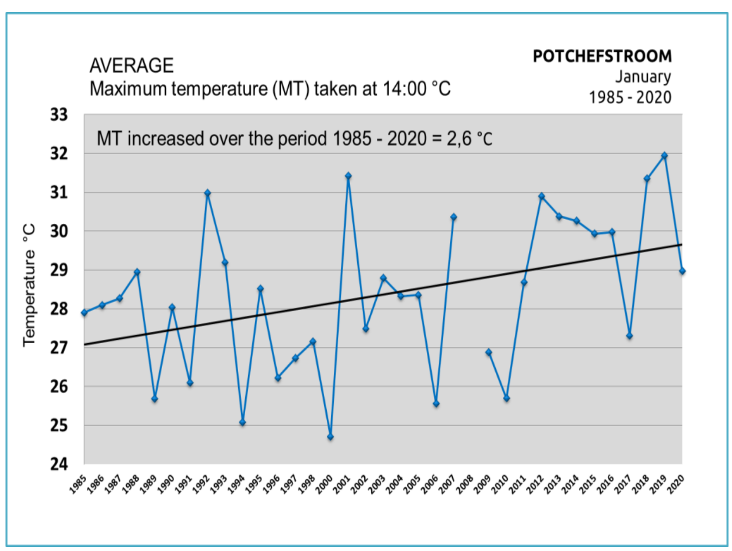
POTCHEFSTROOM

Conception percentage (CP)

Maximum temperature (MT)

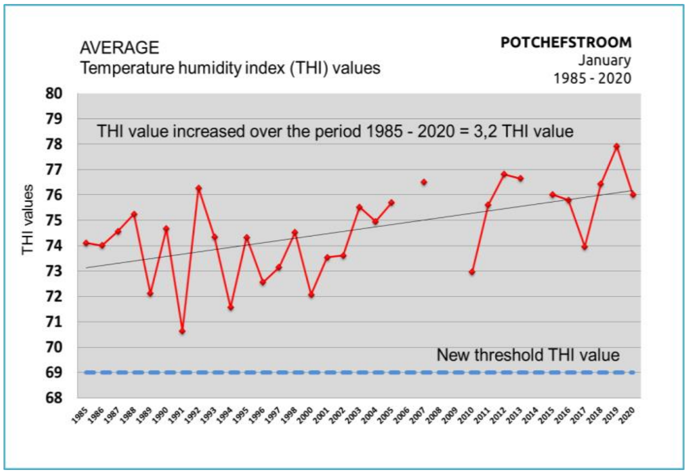
North West Province



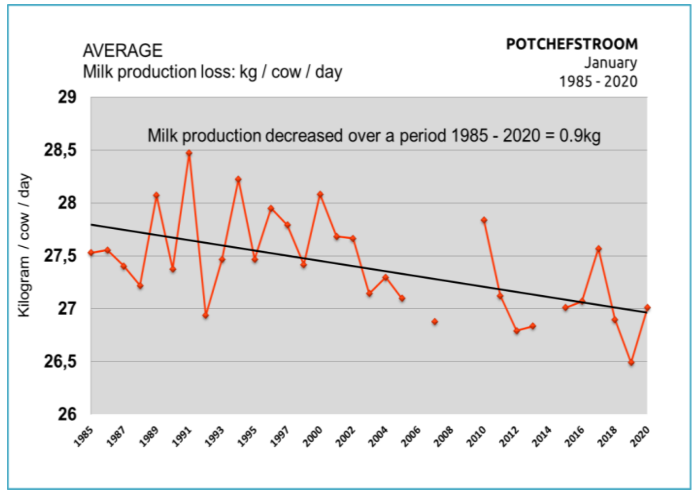


Graph 1. Continued.

THI values



Milk production (MP)

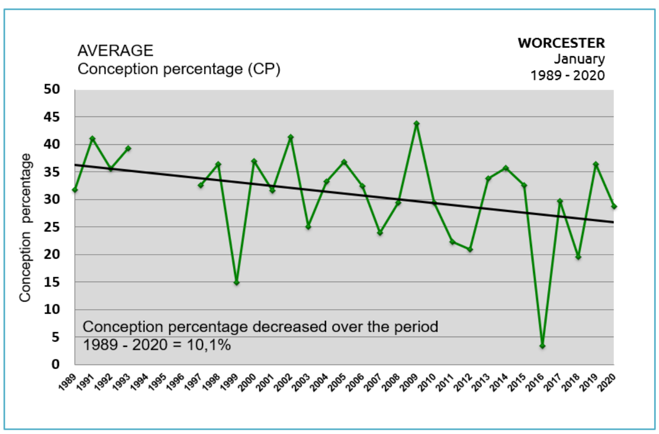


Graph 2

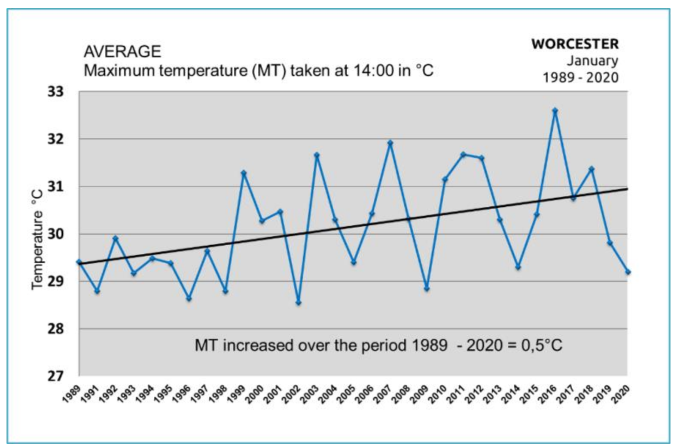
WORCESTER

Western Cape Province

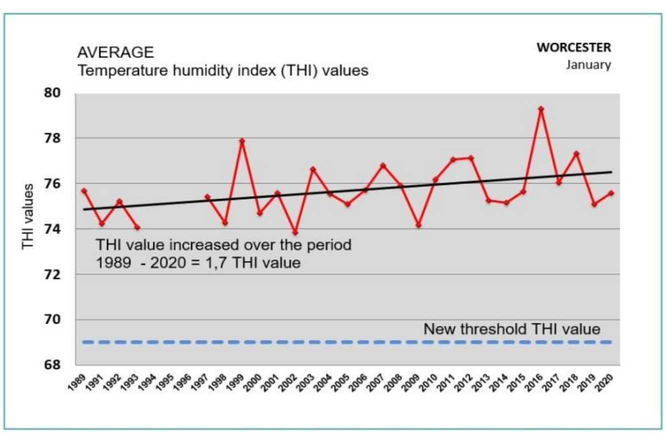
Conception percentage (CP)



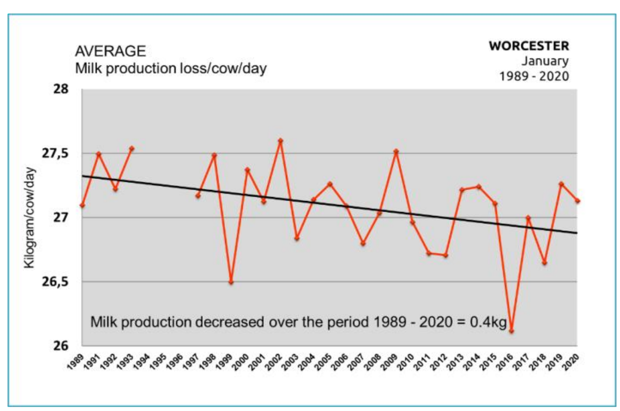
Maximum temperature (MT)



THI values



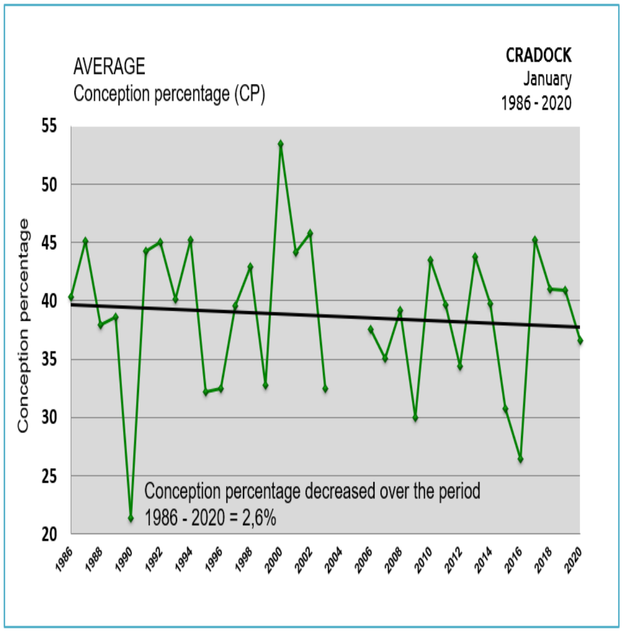
Milk production (MP)



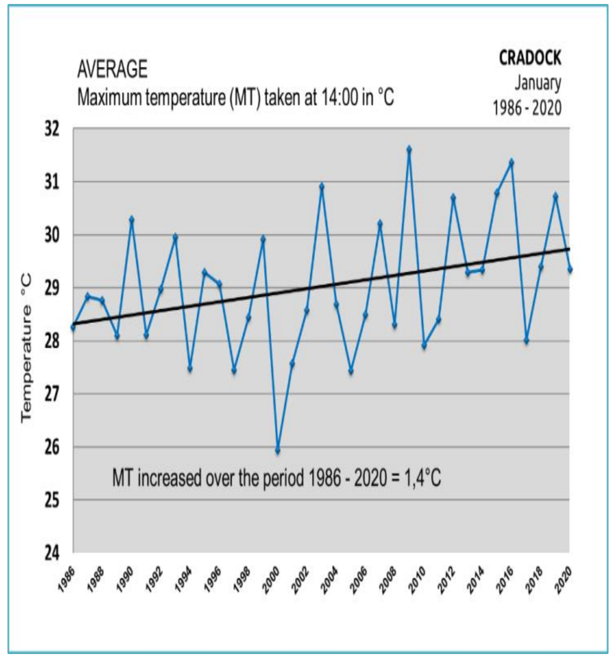
Graph 3

CRADOCK
Eastern Cape Province

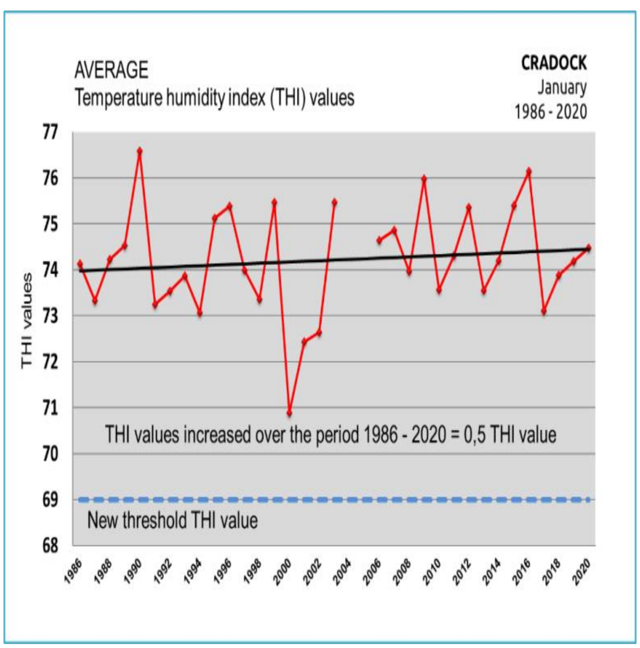
Conception percentage (CP)



Maximum temperature (MT)



THI values



Milk production (MP)

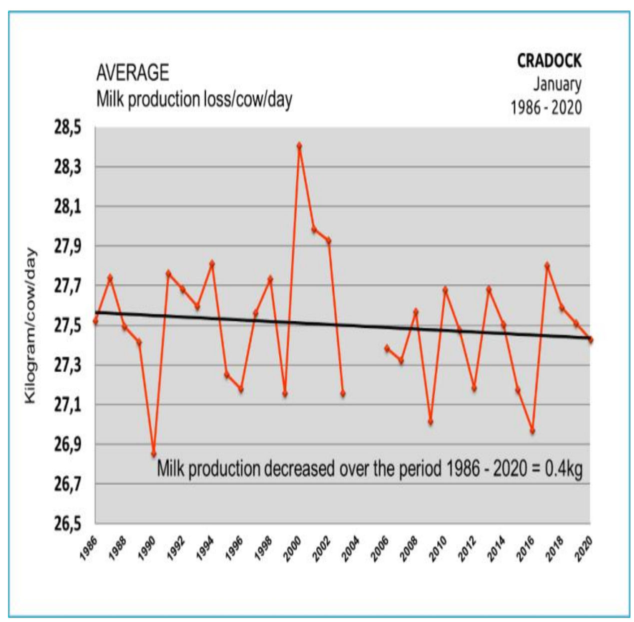


Table 2: Names and numbers of graphs (1 to 18, total graphs are 72) and weather stations (1 to 18). All the data and information of the graphs are summarised in this table.

Weather station Numbers	NAME	THI value *	MT °C **	Conception % +	Milk production kg / cow / day ++	Graphs
1	Lichtenburg	2,4	3,3	12,1 ↓	0,6 ↓	1
2	Potchefstroom	3,2	2.6	19 ↓	0,9 ↓	2
3	Vereeniging	1	0,5	1 ↓	0,5 ↓	3
4	Pretoria University	0,2	0,6	2 ↓	0,1 ↓	4
5	Ermelo	0,3	1,4	0,2 ↑	0,1 ↓	5
6	Bethlehem	-0,8	-1,4	1,3 ↑	0,2 ↑	6
7	Bloemfontein	0,5	0,5	2 ↑	0,1 ↑	7
8	Malmesbury	1	1,7	5 ↓	0,3 ↓	8
9	Worcester	1,7	0,5	10,1 ↓	0,4 ↓	9
10	George	1	0,2	3 ↓	0,1 ↓	10
11	Mosselbay	1	0,5	3,6 ↓	0,3 ↓	11
12	Riversdale	1	0,9	5 ↓	0,4 ↓	12
13	Tygerhoek	1,2	1	10,1 ↓	0,2 ↓	13
14	Cape St. Francis	0,5	0,4	2 ↓	0,1 ↓	14
15	Patensie	0,3	0,6	10,1 ↓	0,2 ↓	15
16	Cradock	1,7	1,4	2,6 ↓	0,4 ↓	16
17	Estcourt	0,2	0,3	0,7 ↓	0,1 ↓	17
18	Cedara	1,5	1	4,7 ↓	0,3 ↓	18
	Total	**17.9 ↑**	**16 ↑**	**87.5 ↓**	**4,70 ↓**	
	Average	**1.0 ↑**	**0.9 ↑**	**4.9 ↓**	**0.26 ↓**	

Temperature humidity index values (THI), maximum temperature (MT), concept percentages (CP) and milk production (MP) decrease or increase of THI values, MT, CP and MP at weather stations over a period of 26 to 87 years

***** = All THI values increase, except Bethlehem's THI value
****** = All MT °C increases except Bethlehem's MT °C.
+ = All the conception percentages decrease except for Ermelo, Bethlehem and Bloemfontein
++ = Milk production at all locations is reduced except at Bethlehem and Bloemfontein

Figure 2: Summary of important effects and consequences of heat stress impact on the performance of dairy cattle (Thatcher, 1974; Wolfenson, *et al.,* 1988; Du Preez, *et al.,* 1990a,b&c; Du Preez, *et al.,* 1991; Du Preez. *et al.,* 1992; Du Preez, 1994 a&b; Bouraoui, *et al.,* 2002; Bonmanova, *et al.,* 2007; Gantner, *et al.,* 2011; Thompson-Crispi, *et al.,* 2016; Santana, *et al.,* 2016; Das, *et al.,* 2016; Pragna, *et al.,* 2017; Habeeb, *et al.,* 2018; Dahl, *et al.,* 2020)

Heat stress has a significant negative effect on the immune function and health of dairy cattle at all stages of their life cycles. It also dominates as a negative influence on the health and production performance of dairy cattle worldwide. Heat stress has the greatest negative impact as a stress factor in dairy cattle because all functions of the dairy cattle suffer from it.

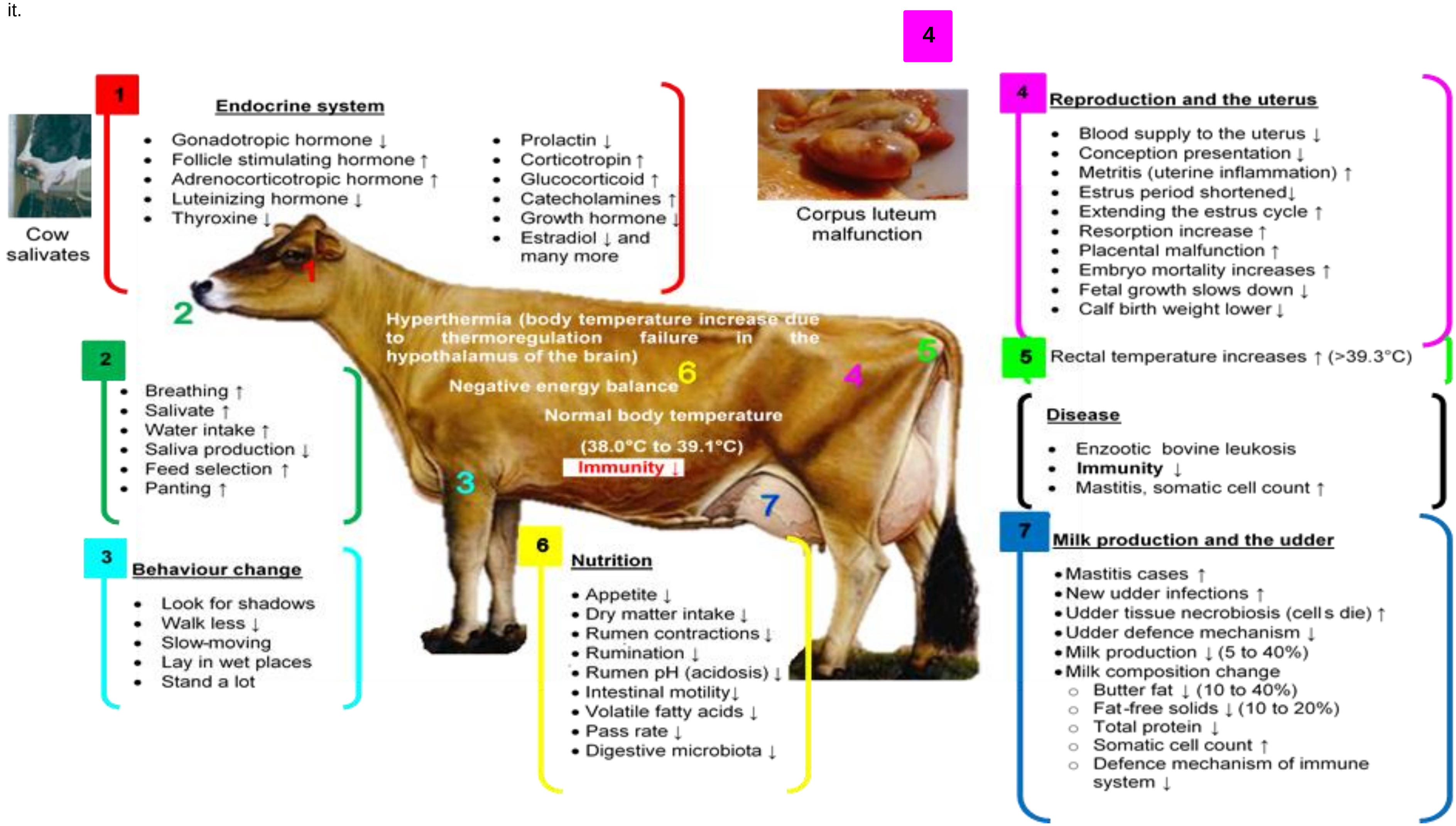


Table 3: Milk production loss due to increased THI values

Table 3 shows two calculation examples (2021) of THI values 74 and 77 with a negative impact on milk production which occur frequently in South Africa (Du Preez, *et al.,* 1992). We use two dairy herds with 500 and 1500 lactating dairy cattle. The critical THI value for milk production is 69. If the THI value increases from 68 to 78, the milk production decreases by 21%, the milk loss/day/cow is 0.41kg. (Bouraoui, *et al.,* 2002).

Milk loss/cow/day for every one (1) THI value above 69 = 0.2725 kilograms.
The density of milk is approximately 1.03kg per litre. One litre of milk weighs very close to 1kg.

Number of dairy cattle	**500 dairy cows**	**1 500 dairy cows**
Average milk production /day	**18 litres / cow / day**	
Dairy herd total milk production / day	9,000 litres / day	27,000 litres/day

THI value is **74** Increase of 5 THI value above the THI value of 69	1.3625kg / cow / day milk loss **1.3625 x 500 cows = 681ℓ litre milk loss / herd / day**	1.3625kg / cow / day milk loss **1.3625 x 1 500 cows = 2 044ℓ litre milk loss / herd / day**
	Farm gate milk price / litre R5-00 R5.00 x 681ℓ = R3 405.00	Farm gate milk price / litre R5-00 R5.00 x 2 044ℓ = R10 220.00
	Total loss / day in Rand **R 3 405.00**	Total loss / day in Rand **R10 220.00**

THI value is **77** Increase of 8 THI values above THI value 69	2.18kg / cow / day milk loss **2.18 x 500 cows = 1,090ℓ litre milk loss / herd / day**	2.18kg / cow / day milk loss **2.18 x 1,500 cows = 3,270ℓ litre milk loss / herd / day**
	Farm gate price / litre R5-00 R5.00 x 1 090ℓ = R5 450.00	Farm gate price / litre R5-00 R5.00 x 3 270ℓ = R16 350.00
	Total loss / day in Rand **R 5 450.00**	Total loss / day in Rand **R16 350.00**

All the other information mentioned under data and methodology indicates that heat stress has an enormous negative effect on milk production in South Africa as well as worldwide and it also has a negative impact on the dairy industries' profitability of South Africa. It is estimated that the loss due to heat stress in the dairy industry in South Africa is more than one billion Rand per year (Swart & Du Preez, 2021). The prevention and control of heat stress in dairy cattle in South Africa is therefore extremely relevant and a priority.

DISCUSSION

From 18 selected weather stations with reliable meteorological data, graphs were drawn with long-term calculations (period of 1933 to 2020, 87 years) of the THI values, maximum temperature (14:00 °C), conception percentages and milk production of dairy cattle. Most South African dairy cattle, which are of northern European origin, are typical animals from cool weather conditions. The hot and sometimes humid conditions can therefore pose considerable danger to the dairy industry during the hot months between October and March. South Africa's commercial dairy farmers (plus-minus 1 000) have more than 600 000 dairy cattle and more than 400 000 heifers. These dairy farmers produce more than 3.43 million tons of milk per year. (Swart, 2020).

Temperature Humidity Index Values (THI values) (Graphs 1 - 18)

Calculations were conducted in order to determine whether the THI values of the 18 weather stations increased or decreased in the period from 1960 to 2020. Seventeen weather stations' average THI values increased and one decreased (Bethlehem). For the 18 weather stations the average THI values increased by 1 THI value for the period 1960 to 2020 (60 years). This increase has a negative impact on the performance of South Africa's dairy cattle. The temperature humidity index (THI) is still one of the best, simplest and most practical index parameters of measuring the environment's temperature with its effect on dairy cattle as well as the most effective indicators for heat stress potential (Dahl, *et al.,* 2020; Dikmen & Hansen, 2009). The highest average monthly THI value to date (Oct. 2019) ever recorded in South Africa was 83.43 (emergency category) at Lichtenburg weather station, which until fairly recently did not experience excessively high temperatures. Heat stress caused a loss of more than 80 lactating (more than 80% were first calved heifers) dairy cattle (Du Preez, 2019).

Maximum temperature (14:00 °C) (Graphs 1 - 18)

Seventeen of the weather stations' maximum temperature for 1933 to 2020 (87 years) increased and one weather station's maximum temperature (Bethlehem) decreased. The average increase in the maximum temperature over the period is 0.9 °C which has a unfavourable negative impact on South Africa's dairy cattle. Meteorologists have been predicting that in the eastern parts of South Africa the average annual rainfall would increase and the average temperatures would decrease while the western parts of the country would become drier and hotter (Johnston, P., 2018).

Conception percentage (CP) of dairy cattle (Graphs 1 - 18)

Fifteen of the 18 weather stations' graphs show a decrease in the CP and three weather stations (Ermelo, Bethlehem and Bloemfontein) show a slight increase for the period 1960 to 2020 (60 years). The average reduction of the 18 weather stations' CP over the period is 4.9% which has a worrying negative impact on South Africa's dairy cattle.
Indications are that the effect of heat stress on the reproduction of South Africa's dairy cattle is very negative. Thatcher (1974) proved that dairy cattle breed throughout the year, but at ambient temperatures above the critical temperature of 21°C, the conception percentage decreases. Heat stress prolongs the oestrus cycle and shortens the oestrus period, conception percentage decrease and there is an increase in embryo deaths with a corresponding decrease in fertility and placental dysfunction. Conception percentages were shown to have dropped from 66% to 35% as the THI index rose from 68 to 78 (Ingraham, *et al*., 1976). The critical THI value for CP in dairy cattle is 65 (Du Preez, 1994a). The gestation period and birth weight of the calf indirectly affect the neonatal health due to high temperatures. For dairy cattle in a tropical area, the gestation period is shortened by about 2 weeks for summer calving (Ansell, 1976). Fetal growth is delayed, the gestation period is reduced and the viability of the calf is reduced (Brody, *et al*., 1948; Fuquay, 1981; Thatcher, 1974). Gwazdauskas, *et al.,* (1975) report that the maximum temperature on the day after insemination has the greatest influence on conception. In general, the critical period for fertility is a few days after estrus and insemination (Johnson, 1985). Ulberg & Burfening (1967) proved that an increase of 1°C in the rectal temperature in cows within 12 hours after insemination reduced the conception percentages from 61% to 45%. If the uterine temperature rose by 0.5 °C on the day or the day after insemination, the conception percentage decreased by 13% and 7%, respectively. The critical period for the embryo's survival with respect to heat stress is between day 4 and 6 days after fertilization (Gwazdauskas, *et al.,* 1973). Malayer, *et al.,* (1990) showed that elevated temperature causes the secretion of prostaglandin F from the uterine endometrium collected on day 17 after oestrus and it may have an effect on conception rates. Available data (Du Preez, *et al*., 1991; Du Preez, *et al.,* 1992) indicate that the higher the THI values for an area, the lower the conception percentages and vice versa. All the above data indicate that the protection of dairy cattle against heat stress in South Africa, where the THI values are higher than 70, is essential to improve their reproduction. In order to reduce heat stress, good management should be practiced in a hot climate at all times. It is clear that heat stress in dairy cattle suppresses the immune system, as in other species and is part of the animals' continuous effort to maintain a state of homeostasis (Das, *et al.,* 2016; Habeeb, *et al.,* 2018; Dahl, *et al.,* 2020).

Milk production of dairy cattle per kg per cow per day (Graphs 1 - 18)

Sixteen of the 18 weather stations' graphs show that the milk production of dairy cattle decreased and two graphs show that the milk production increased over the period 1960 to 2020 (60 years). The average milk production loss over the period was 0.26 kg/cow/day. A adverse negative impact of heat stress on the dairy cattle of South Africa for milk production is experienced.
The prediction is that the effect of heat stress on dairy cattle will cause a decrease in feed and roughage intake and will increase the concentrate requirements. The serious consequences of heat stress in dairy cattle in South Africa, are enormous milk losses and decreased conception percentage (Du Preez, 1994b; Habeeb, *et al.,* 2018). Older, heavier and high-producing dairy cattle are most susceptible to heat stress (Bucklin, *et al.,* 1991). Dairy cattle sometimes reduce their dry matter intake to 25% during heat stress (Hansen, 1994; Jacobsen, 1996). In general, high-producing dairy cattle have higher feed intake per body weight and the result is more metabolic heat and more heat stress in the dairy cattle. The decrease in the consumption of roughage is possibly responsible for the decrease in the butterfat percentage in the milk. Normally the concentrate-to-roughage ratio is from 40:60 to 60:40, but if it increases to an 80:20 ratio it will lead to an increased energy intake. Providing a higher energy ration for dairy cattle in a warm environment is recommended. There is also decreased rumination. Heat stress tends to increase the rumen's lactic acid levels and this causes the rumen's pH to drop, leading to rumen acidosis, sometimes with the possibility of laminitis in the dairy cattle (Christopherson, 1985). Dairy cattle that feed at a high ambient temperature show heat increases. It also seems that dairy cattle need more potassium in their rations under hot conditions (Conrad, 1985; Johnson, 1985). The provision of sufficient feed and water

for lactating cows during hot summer months in Florida lowered respiration and rectal temperature and improved milk yield by 10%, also increasing reproduction from a low 25.3% to 44.4% (Roman-Ponche *et al*., 1977). Dairy cattle sometimes increase their water intake to 150 litres per cow per day (Du Preez, 1994a) and evaporation loss due to sweating during heat stress (Drost & Thatcher, 1987). In order to maintain homeostasis behavioural changes occur in dairy cattle. These include postural adjustments, wetting of the skin surface by licking where possible, lying in wet places, standing in water (trough, pond, etc.) and shorter feeding periods during peak temperatures. Under South African heat stress conditions, behavioural changes occur in lactating as well as non-lactating dairy cattle such as reduced feeding times during peak temperatures, reduced feed intake, reduced activity, sub-optimal performance, search for shade and increased respiration rate to reduce the effect of heat stress (Curtis, 1983).

CONCLUSION

Heat stress has the greatest negative impact as a stress factor in dairy cattle because all functions of dairy cattle suffer from it. Not all parameters are trustworthy and practical to use as parameters to determine heat stress in dairy cattle. The temperature-humidity index (THI) is still the best, simplest and most practical index (parameter) for measurements of environmental warmth which cause heat stress in dairy cattle. The holistic impact of heat stress on dairy cattle is devastating. The average reduction of CP in South Africa over the period 1960 to 2020 (60 years) was 4.9% which has a formidable negative impact on dairy cattle. The critical THI value for CP in 65 in dairy cattle. The average milk production loss over the period 1960 to 2020 (60 years) was 0.26kg/cow/day. The critical value for THI is 69. An adverse negative impact of heat stress on the dairy cattle of South Africa for milk production is experienced. The average values of the THI increased by one (1) THI value for the period 1960 to 2020 (60 years). This increase also has a negative impact on the performance of South Africa's dairy cattle. The greatest short-term improvement in performance during heat stress within a dairy herd would come from proper attention being given to environmental factors, such as management, disease control, shade provision, air movement, wetting by showering, activities (handling of dairy cattle during the hottest time of the day should be limited), nutrition (the first and primary nutrition management strategy is to protect the dairy cattle from a heat stress environment), area where dairy farming, water supply (adequate clean fresh water [*ad libitum]* of which temperature does not exceed 21°C, if possible) and milk breeds (Jersey cows and cross breeds can tolerate heat stress somewhat better than Holsteins). It is estimated that the loss due to heat stress in the dairy industry in South Africa is more that one billion Rand per year. Veterinarians and animal scientists can predict the effect of heat stress on the performance, comfort and well-being of dairy cattle in South Africa by using the THI values. During the research of this investigation, it has again been confirmed that most of the South African dairy farmers are not sufficiently aware of the potential effects and consequences of heat stress impact of the most important factors on their dairy production. Neither is the government aware of those effects and no noteworthy contribution in being made to improve commercial dairy production. However, certain of the private veterinary practitioners attempt to make commercial dairy farmers aware of the effects of heat stress on milk production and conception percentage. The most important site of impact of the respective determinants is unmistakably the inherent immune system of the dairy cattle. Drastic and relevant steps in South Africa during heat stress is necessary, especially in summer, to protect dairy cattle as much as possible.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS CONTRIBUTIONS

JH prepared the initial version of the manuscripts. JH, AK and LJ assisted in literature collection. JH, AK and LJ drafted and revised the manuscript for critical scientific corrections. All authors read and approved the manuscript.

REFERENCES

ANSELL, R.H., 1976. Maintaining European dairy cattle in the Near East. World Animal Review, 20: 1 - 7.

BONMANOVA, J., MISZTAL, I., COLE, J.B., 2007. Temperature-humidity indices as indicators of milk production losses due to heat stress. Journal of Dairy Science, 90: 1947 – 1956.

BOSEN, J.F., 1959. Discomfort index. Reference Data Section. Air conditioning, heating and ventilation. American Society of Heating

and Ventilating Engineers, Atlanta.
BOURAOUI, R., LAHMAR, M., MAJDOUB, A., DJEMALI, M., BELYEA, R., 2002. The relationship of temperature-humidity index with milk production of dairy cows in Mediterranean climate. Anim. Res; 51: 479 – 491.
BRODY, S., WORSTELL, D.M., RAGSDALE, A.C. & KIBLER, H.H., 1948. Heat production and cardiorespiratory activities, gestation and lactation in Holstein cattle. Research Bulletin, Missouri Agricultural Experiment Station: 424.
BUCKLIN, R.A., TURNER, L.W., BEEDE, D.K., 1991. Methods to relieve heat stress for dairy cows in hot humid climates. Appl Engineering Agriculture (2): 241 – 247.
CHRISTOPHERSON, R.J., 1985. The thermal environmental and the ruminant digestive system, in Stress Physiology in Livestock. Vol. 1. Bocca Raton: CRC Press: 163 – 177.
CONRAD, J.H., 1985. Feeding of farm animals in hot and cold environments. In: YOUSEF, M.K., (ed). Stress physiology in livestock, Ungulates, Volume 2, Boca Raton. Florida, CRC Press: 205 - 226.
CURTIS, S.E., 1983. Environmental management in animal agriculture. Ames, IA, The Iowa State University Press.
DAHL, G.E., TAO, S., LAPORTA, J., 2020. Heat stress impacts immune status in cows across the life cycle. Front. Vet. Sci., https://doi.org/10.3389/fvets.2020. 00116 (https://www.frontiersin.org/people/u/847062).
DAS, R., SAILO, L., VERMA, N., BHARTI, P., SAIKIA, I., IMTIWATI, KUMAR, R., 2016. Impact of heat stress on health and performance of dairy animals: A review. Vet. World. 9: 260 – 268. doi: 10.14202/vetworld.2016.260-268.
DIKMEN, S. & HANSEN, P.J., 2009. Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in subtropical environment? Journal of Dairy Science; 92 (1): 109 – 116. doi: 10.3168/jds.2008-1370.
DROST, M. & THATCHER. W.W., 1987. Heat stress in dairy cows. Its effect on reproduction. Veterinary Clinics of North America, Food Animal Practice, 3: 609 – 618.
DU PREEZ, J.H., 1994a. The role of heat stress in the performance of dairy cattle in Southern Africa. PhD Thesis. University of Pretoria.
DU PREEZ, J.H., 2000. Parameters for the determination and evaluation of heat stress in dairy cattle in South Africa. Onderstepoort Journal of Veterinary Research, 67: 263 – 271.
DU PREEZ, J.H., 2019. Personal communication.
DU PREEZ, J.H., GIESECKE, W.H. & HATTINGH, P.J. 1990a. Heat stress in dairy cattle under Southern African conditions. I. Temperature-humidity index mean values during the four main seasons. Onderstepoort Journal of Veterinary Research, 57: 7 - 87.
DU PREEZ, J.H., GIESECKE, W.H., BARNARD, M.L., ERASMUS, A.G., HATTINGH, P.J., EISENBERG, B.E., WILLEMSE, J.J.C. & KRUGER, R., 1992. Heat stress in dairy cattle and other livestock under Southern African conditions. Technical communication No. 234, Department of Agricultural Development. Republic of South Africa: 1 - 43.
DU PREEZ, J.H., GIESECKE, W.H., HATTINGH, P.J. & EISENBERG, B.E., 1990b. Heat stress in dairy cattle under Southern African conditions. II. Identification of areas of potential heat stress during summer by means of observed true and predicted temperature-humidity index values. Onderstepoort Journal of Veterinary Research, 57: 183 - 187.
DU PREEZ, J.H., HATTINGH. P.J., GIESECKE, W.H. & EISENBERG, B.E., 1990c. Heat stress in dairy cattle under Southern African conditions. III. Monthly temperature-humidity index mean values and their significance in the performance of dairy cattle. Onderstepoort Journal of Veterinary Research, 57: 243 – 248.
DU PREEZ, J.H., TERBLANCHE, S.J., GIESECKE, W.H., MAREE, C. & WELDING, M.C., 1991. Effect of heat stress on conception in a dairy herd model under South African conditions. Theriologenology, 35: 1039 - 1049.
DU PREEZ, J.H., WILLEMSE, J.J.C. & VAN ARK, H., 1994b. Effect of heat stress on conception in dairy-herd model in the Natal highlands of South Africa. Onderstepoort Journal of Veterinary Research, 61: 1 – 6.
ENGELBRECHT, F., 2019. Kan ons aardverwarming omkeer? RSG Plus: https://www.rsgplus.org>Natuur.
FLAMENBAUM, I., WOLFENSON, D., MAMEN, M. & BERMAN, A., 1986. Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system. Journal of Dairy Science, 69: 3140 - 3147.
FUQUAY, J.W., 1981. Heat stress as it affects animal production. Journal of Animal Science, 52: 164 - 174.
GANTNER, V., MIJIC, P., KUTEROVAC, K., SOLIC, D., GANTNER, R., 2011. Temperature-humidity index values and their significance on the daily production of dairy cattle. Original scientific paper – Izvorni Znastveni rad. Mljekastvo 61 (1): 56 – 63.
GEBREMEDHIN, K.G., 1985. Heat exchange between livestock and the environment. In: YOUSEF, M.K. (ed.). Stress physiology in livestock. Basic principles. Volume 1, Boca Raton, Florida: CRC Press: 16 - 33.
GUNN, K.M., HOLLY, M.A., VEITH, T.L., BUDA, A, R., PRASAD, R., ROTZ, C.A., SODER, K.J., STONER, A.M., 2019. Projected heat stress challenge abatement opportunities for U.S. milk production. Plos ONE. 14: e0214665. doi: 10.1371/journal.pone.0214665.
GWAZDAUSKAS, F.C., THATCHER, W.W. & WILCOX, C.J., 1973. Physiological environmental and hormonal factors at insemination which may effect conception. Journal of Dairy Science, 56: 873 - 877.
GWAZDAUSKAS, F.C., WILCOX, C.J. & THATCHER, W.W., 1975. Environmental and managemental factors affecting conception rate in a subtropical climate. Journal of Dairy Science, 58: 88 - 92.
HABEEB, A.A.M., GAD. A.E., EL-TARABANY, A.A., ATTA, M,A,A., 2018. Negative effects of heat stress on growth and milk production of farm animals. Journal of animal husbandry and dairy science. Volume 2, Issue 1: 1 – 12.
HAHN, G.L., 1985. Management and housing of farm animals in hot environments. In: YOUSEF, M.K. (ed.). Stress physiology on livestock. Ungulates Volume 2,. Boca Raton, Florida, CRC Press: 151 - 174.
HANSEN, P.J., 1994. Causes and possible solutions to the problem of heat stress in reproductive management of dairy cows. Proceedings of the National Reproductive Symposium. Pittsburgh, P.A.
INGRAHAM, R.H., STANLEY, R.W. & WAGNER, W.C., 1976. Relationship of temperature and humidity to conception rate of Holstein cows in Hawaii. Journal of Dairy Science, 59: 2086 - 2090.
JACOBSEN, K.L., 1996. Dairy production management update: The wellbeing of dairy cows in hot and humid climates. Part 1. Housing and effects of heat stress. Compend Contin Edu Prac Vet, Volume 18, No 4, April 1996 (Food Animal Medicine): 137 – 142.
JOHNSON, H.D., 1985. Physiology responses and productivity of cattle. In: YOUSEF, M.K., (ed.). Stress physiology in livestock. Ungulates Volume 2, Boca Raton, Florida, CRC Press: 3 - 19.
JOHNSTON, P., 2018. Aardverwarming is 'n feit! Lesing, Agri Wes-Kaapkongres.

KIBLER, H.H., 1964. Environmental physiology and shelter engineering. LXVII. Thermal effects of various temperature humidity combinations of Holstein cattle as measured by eight physiological responses. Research Bulletin Missouri Agricultural Experiment Station: 862.
KRUGER, A.C. & NXUMALO, M., 2016. Surface temperature trends from homogenized time series in South Africa: 1931 – 2015. International Journal of Climatology. Published online in Wiley Online Library. DOI: 10.1002/joc.4851.
MALAYER., J.R., HANSEN, P.J., GROSS, T.S. & THATCHER, W.W., 1990. Regulation of heat shock-induced alterations in the release of prostaglandins by the uterine endometrium of cows. Theriogenology, 34: 219 - 226.
NARDONE, A., RONCHI, B., LACETERA, N., RANIERI, M.S., BERNABUCCI, U., 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Sci. 130: 57 – 69. doi: 10.1016/j.livsci.2010.02.011.
PRAGNA, P., ARCHANA, P.R., ALEENA, J., SEJIAN, V., KRISHNAN, G., BAGATH, M., MANIMARAN, A., BEENA, V., KURIEN, E.K., VARMA, G., BHATTA, R., 2017. Heat stress and dairy cow: Impact on both milk yield and composition. International Journal of Dairy Science; 12: 1 – 11.
ROMAN-PONCE, H., THATCHER, W.W., BUFFINGTON, D.E., WILCOX, C.J. & VAN HORN, H.H., 1977. Physiological and production responses of dairy cattle to shade structure in a subtropical environment. Journal of Dairy Science, 60 (3): 424 - 430.
SANTANA, Jr. M.L., BIGNARDI, A.B., PEREIRA, R.J., MENÉNDEZ-BUXADERA., ALBERTO., FORA, L.E., 2016. Random regression models to account for the effect of genotype by environment interaction due to heat stress on the milk yield of Holstein cows under tropical conditions. J. Applied Genet. 57: 119 – 127. doi: 10.1007/S13353-015-0301-x.
SWART, P. & Du Preez, J.H., 2021. Personal communication.
SWART, P., 2020. Milk Producers' Organisation (MPO). Personal communication.
THATCHER, W.W., 1974. Effects of season, climate and temperature on reproduction and lactation. Journal of Dairy Science, 57: 360 - 368.
THOMPSON – CRISPI, K., ATALLA, H., MIGLIOR, F., 2016. The role of nutrition in mastitis prevention is reviewed relative to its impact on immune response of dairy cows. Nutrition, immunity and mastitis – Penn State Extension: extension.psu.edu.
ULBERG, L.C. & BURFENING, P.J., 1967. Embryo death resulting from adverse environment on spermatozoae or ova. Journal of Animal Science, 26: 571 - 577.
WEST, J.W., MULLINIX, B.G., BERNARD, J.K., 2003. Effects of hot, humid weather on milk temperature, dry matter intake, and milk yield of lactating dairy cows. J. Dairy Sci. 86: 232 – 242. doi: 10.3168/jds.S0022-0302(03)73602-9.
WikipediaA, the free encylopaedia, Climate change, 2019. https://af.wikipedia.org/wiki/Klimaatverandering.
WOLFENSON, D., FLAMENBAUM, I., BERMAN, A., 1988. Hyperthermia and body energy store effects on estrus behaviour, conception rate, and corpus luteum function in dairy cows. Journal of Dairy Science, 71; 3497 - 3504.
YOUSEF, M.K., (ed)., 1982. Animal production in the tropics. Praeger Special Studies. Praeger Scientific, New York, Praeger Publishers.
YOUSEF, M.K., (ed)., 1985a, Stress physiology in livestock. Basic principles. Volume 1. Boca Raton, Florida, CRC Press.
YOUSEF, M.K., 1985b. Thermal environment. In: YOUSEF, M.K., (ed.). Stress physiology in livestock. Basic principles. Volume 1, Boca Raton, Florida, CRC Press: 10 - 13.
YOUSEF, M.K., 1985c. Measurement of heat production and heat loss. In: YOUSEF, M.K., (ed). Stress physiology in livestock. Basic principles. Volume 1, Boca Raton, Florida, CRC Press: 36 - 44.