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

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ABSTRACT

DU PREEZ, J. H., GIESECKE, W. H., HATTINGH, P. J. & EISENBERG, B. E., 1990. Heat stress in dairy cattle under southern African conditions. II. Observed true and predicted temperature-humidity index values to indicate areas of potential heat stress during the five hottest months of the year. *Onderstepoort Journal of Veterinary Research*, 57, 183–187 (1990).

November–March are the hottest months of the year with the highest monthly mean "temperature-humidity index" (THI) in South Africa and Namibia. These 5 months are associated with severe heat stress in dairy cattle, are of critical importance for their performance and may have great economic implications for the owner as well as for the dairy industry. Firstly, compared with the existing Livestock Weather Safety index (LWSI), more relevant meteorological data can be generated when mapping South Africa and Namibia according to the LWSI modified for lactating dairy cattle (LDC). Secondly, compared with the observed true THI values alone, more relevant data on heat stress and its deleterious effects on dairy cattle performance, become available when mapping South Africa and Namibia according to the combined observed true and predicted THI values. Minimum precautions against heat stress in dairy cattle are recommended depending on THI values as classified by the LWSI for LDC.

INTRODUCTION

An animal is never independent of the environment in which it lives. In other words, the animal and its environment form a system in which both act and react upon each other (Yousef, 1985a). The vulnerability of animals to weather is well established; their performance and even their survival are strongly influenced by direct effects of weather. Consequently, weather is generally a constraint on efficient livestock production systems, particularly for high producing animals whose nutritional needs have been met. Under warm to hot climatic conditions such adverse effects of weather are further aggravated where dairy cattle are not bred for elevated heat tolerance and/or are not protected carefully from highly stressful environmental factors. Irrespective of whether the production system is extensive or intensive, penalties resulting from adverse weather affect the quantity and quality of human food supplies (Hahn, 1985). Warm climates depress feed intake, milk production and reproductive performance in dairy cows, while metabolic heat production also declines (Flamenbaum, Wolfenson, Mamen & Berman, 1986; Johnson, 1985; Yousef, 1985b) and thus have major implications for dairy farming economics.

Homeothermy of the dairy cow is maintained as a result of a sensitive balance between heat production and heat dissipation (Yousef, 1985b). Environmental factors, animal characteristics and thermoregulatory mechanisms, such as conduction, radiation, convection and evaporation, affect the exchange of energy between the dairy cow and its environment. This, in turn, affects the body temperature of the animal which again leads to changes in the animal's metabolism and behaviour (Gebremedhin, 1985). Especially under warm conditions, the abiotic environmental factors including air temperature, humidity, solar radiation and wind are important to the productivity of livestock (Yousef, 1985b).

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All livestock need protection from climatic extremes even in temperate climatic regions, primarily to insure survival of animals for continued production and reproduction (Hahn, 1981). Dairy cows can benefit from modifications of microclimates to improve their comfort and performance (Fuquay, Zook, Daniel, Brown & Poe, 1979). For example, natural shade has been shown to have a highly significant effect on Friesian crosses, increasing the milk yield by 18,4 % (MacFarlane & Stevens, 1972). Partially or totally enclosed shelters can reduce the thermal radiation received by animals (Hahn, Bond & Kelly, 1963; Hahn, 1985) and improve their performance (Hahn, 1985). Wiersma & Armstrong (1983) demonstrated the benefits of a sprinkling and fan cooling system on milk production in Arizona. Hahn (1985) found that usage of water (as a cooling agent) through direct sprinkling (not fogging) on the animals' skin or through indirect evaporative cooling of the animals' housing is an excellent technique for reducing heat stress. He also pointed out that effects of heat stress can be reduced, where nighttime temperatures are lowered by evaporative cooling or other techniques and correspondingly permit more rapid recovery through increased dissipation of accumulated body heat. Cooling of cows in hot climatic conditions by a combination of wetting the coat and forced ventilation reduces heat stress (Flamenbaum *et al.*, 1986).

To reduce heat stress, good management in warm climates must at all times include the provision of adequate feed and water (Hahn, 1981). Correct space allocation for animals in intensive production systems and avoiding or restricting handling during hot weather to limit heat stress, are important managemental aspects (Hahn, 1985).

No appropriate South African data are available on heat tolerance and related genetic, physiological, health, reproductive, productive, engineering, economic and other aspects of dairy cattle. Therefore, scientific and practical information on, among others, the artificial cooling of dairy and feedlot cattle for optimal performance in areas where the cattle suffer from heat stress in South Africa and Namibia seem of utmost importance (Du Preez, Giesecke & Hattingh, 1990).

To identify in a general way the areas of importance to heat stress in food-producing animals, especially dairy cattle, Du Preez *et al.* (1990) have mapped South Africa and Namibia for winter, spring, summer and autumn according to the "temperature-humidity index" (THI) for cattle.

The aim of this report is to provide more specific meteorological data which are relevant to heat stress in dairy cattle during those months of the year that have the highest temperature and mean THI and to map South Africa and Namibia according to observed true as well as the combined observed true and predicted THI values.

Materials and Methods

Acquisition of meteorological data

The meteorogical data were obtained from the South African Weather Bureau publication WB 40 (Weather Bureau, Department of Environmental Affairs, 1988) as described by Du Preez *et al.* (1990).

Calculation of THI values as an index of heat stress

The THI index (Bősen, 1959; Kibler, 1964) for cattle was calculated as described by Du Preez *et al.* (1990).

Classification of THI values

The Livestock Weather Safety Index (LWSI) of the Livestock Conservation Institute (Anonymous, 1970) as changed by Du Preez *et al.* (1990) for practical and computer contouring/mapping purposes was used as a basis to classify the various categories of the THI values.

The original LWSI categories of the THI values, with a critical THI value of 72 for milk production (Johnson, 1985), were changed to the following:

THI value	*LWSI category*
70 or less	Normal
70–78 (original 71–78)	Alert
78–82 (original 79–83)	Danger
82 or above (original 83 or above)	Emergency

The LWSI (LDC) categories (Du Preez *et al.*, 1990) of the THI values with due consideration of the critical THI value of 72 for milk production (Johnson, 1985), were classified as follows:

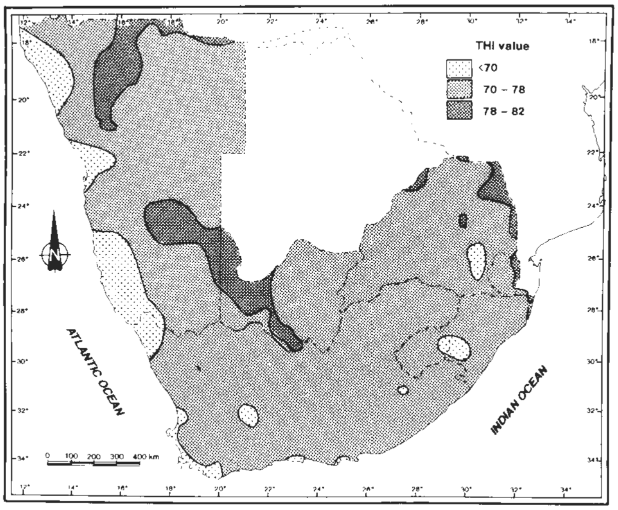

FIG. 1 Mapping of South Africa and Namibia according to the LWSI categories of the mean observed true THI values for the 5 hottest months (November–March) of the year with the greatest heat stress potential for dairy cattle.

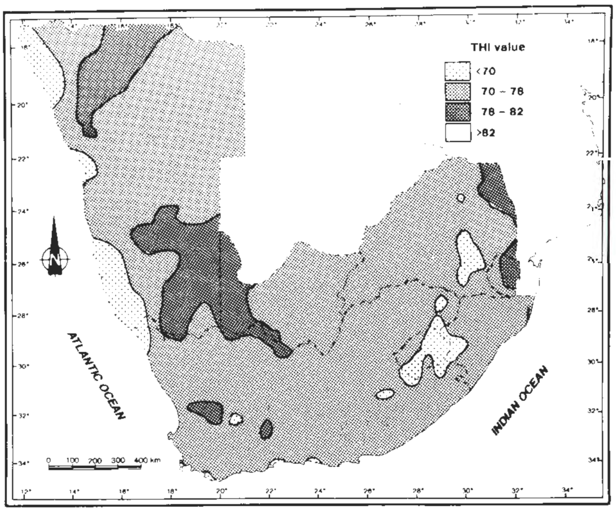

FIG. 2 Mapping of South Africa and Namibia according to the LWSI categories of the combined mean observed true and predicted THI values for the 5 hottest months (November–March) of the year with the greatest heat stress potential for dairy cattle.

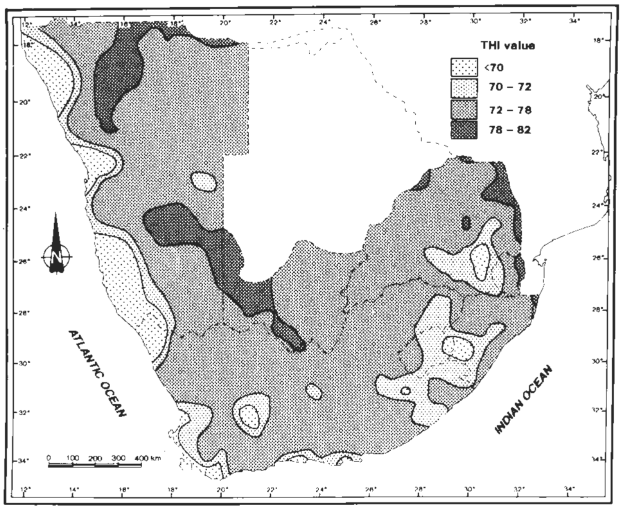

FIG. 3 Mapping of South Africa and Namibia according to the LWSI(LDC) categories of the mean observed true THI values for the 5 hottest months (November–March) of the year with the greatest heat stress potential for dairy cattle.

THI values	*LWSI (LDC) Category*	*Colour codes* (Fig. 4)
70 or less	Normal	Blue
70,0–72,0	Alert to critical index for milk production	Green
72,0–78,0	Alert and above critical index for milk production	Orange
78,0–82,0	Danger	Red
82,0 or above	Emergency	Not existing

Mapping of THI values

Mapping of South Africa and Namibia according to the changed LWSI and LWSI(LDC) categories of the THI values was done as described by Du Preez *et al.* (1990).

Contouring for mapping

Contouring for mapping was done as described by Du Preez *et al.* (1990), for weather stations with the observed true and the combined observed true and predicted THI values to indicate regions with different LWSI and LWSI(LDC) zones. Mapping of

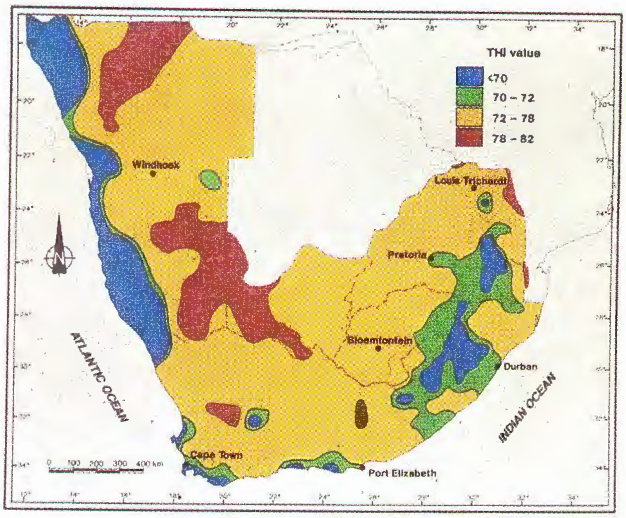

FIG. 4 Mapping of South Africa and Namibia according to the LWSI(LDC) categories of the combined mean observed true and predicted THI values for the 5 hottest months (November–March) of the year with the greatest heat stress potential for dairy cattle.

South Africa and Namibia, using the mean observed true LWSI (Fig. 1) and the LWSI(LDC) (Fig. 3) categories of the THI values as well as the combined mean observed true and predicted LWSI (Fig. 2) and the LWSI(LDC) (Fig. 4) categories of the THI values (Table 1), was completed for the 5 months (November–March) of the year with the highest mean THI values. For the interpretation of the results described, the mapped LWSI and LWSI(LDC) zones for the observed true as well as the combined observed true and predicted THI values, should be visualized as superimposed on a map of South African dairy cattle distribution (Du Preez *et al.*, 1990).

Results

Calculation of predicted THI values

Only the 5-monthly averages (November to March) were considered here. Altitude (A) and maximum temperature (MT) are available for 563 South African and Namibian weather stations (Weather Bureau, Department of Environmental Affairs, 1988), but observed true THI values are only available for 226 weather stations. Closer "grid values" are obviously more desirable for mapping. The use of a multiple regression model was therefore investigated in an attempt to obtain estimates of the 337 missing THI values. A and MT values were used to predict these THI values fased on the observed true THI values at the 226 stations (Table 1). The following model provided the most accurate prediction of the observed THI values (Alvey, Galway & Lane, 1982; Draper & Smith, 1981):

	Coefficients	*Standard error (SE)*	*t-values*
Constant	= 33,22	SE = 3,87	t = 8,59
A	= −0,001409	SE = 0,000135	t = −10,4
MT	= 2,114	SE = 0,286	t = 7,38
(MT)2	= − 0,02157	SE = 0,00523	t = −4,13

The low SE and consequently high t-values indicate that the coefficients are estimated with a high degree of accuracy. The model, which is based on A, $MT + MT^2$ accounts for 89 % of the variation in the observed THI values, the rest (i.e. 11 %) being attributable to residual variation.

The following equation was therefore derived for the prediction of THI:

$$THI\ (predicted) = 33,22 - 0,001409\,A + 2,114\,MT - 0,02157(MT)^2.$$

Table 1 The mean observed true (226) and predicted (337) arithmetical THI values of the various weather bureau stations for the 5 hottest months (November–March) of the year with the greatest heat stress potential for cattle in South Africa and Namibia. This Table is obtainable from the main author because it is too lengthy to publish.

The THI values observed, predicted and mapped suggest that certain minimum precautions against heat stress in food-producing animals, especially dairy cattle, should be considered as further discussed below.

Discussion

As regression models are increasingly inaccurate when predictions are made beyond the range of values of the independent variables, it is important to note that only 3 altitude values and 2 maximum temperature values were outside the range of values used for the development of the model. The predicted THI values will certainly be subject to error (11 %). However, they do provide an estimate of the THI values in the gaps between the observed THI values, allowing more complete and smoother contour lines. Unfortunately, there does not appear to be any promise of an increase in the number of stations that can provide THI values in the future, so that a real test of the predictions, as well as a refinement of the regression function, is not imminent.

Protection includes trees, shade nets or adequate solid-roofed shades in hot weather (1,8 to 2,5 m^2/head for large species). The most effective shades are trees, as they provide protection from sunlight, combined with beneficial cooling as moisture evaporates from the leaves (Bond, Kelly, Garrett & Hahn, 1961). Farmers must be encouraged to plant proper trees for shade. However, trees are not always available for livestock shades. In the absence of trees, hay or straw shades are the most effective. Solid shade provided by sheet metal and painted white on top, is next in effectiveness (Bond *et al.*, 1961).

Good management includes the provision of adequate feed and water at all times, reduction of the ratio of roughages to concentrates in hot-weather rations and recognition of the need for increased feed at the end of a heat wave to permit production recovery (Hahn, 1981). Johnson (1985) said that during heat stress hormones associated with heat loss functions and water regulation tend to increase whereas calorigenic pituitary and target organ hormones decrease and are related to concurrent declines of the growth rate, reproductive and milk production performance. These responses depend on the cattle genotype, heat intensive factors and presence or absence of adequate pastures, nutrition, disease and care, which can be limiting factors in the animal's physiology and performance.

It is of the utmost importance for the performance of dairy cows in areas of South Africa and Namibia where extreme heat stress occurs to protect the animals against heat stress. In most of the areas of South Africa and Namibia where dairy cattle occur (Du Preez *et al.*, 1990), the THI values are above 70, and the cattle experience heat stress (Fig. 1–4).

More data relevant to meteorological animal husbandry and management data can be derived by mapping South Africa and Namibia according to the modified LWSI(LDC) (Fig. 3 and 4) rather than the LWSI (Fig. 1 and 2). When the THI zones as mapped in Fig. 1–4 for the hottest months of the year, are compared with those of the cooler months (Du Preez *et al.*, 1990) dynamic changes caused by monthly and seasonal meteorological differences are revealed. The meteorological data shown in Fig. 4 has the greatest significance from a practical point of view. Dairy and beef farmers in the higher THI zones as well as in the transitional areas at the borders between consecutive THI zones should apply measures aimed at controlling heat stress.

From data available at present it seems justifiable to propose the following practical and economical minimum precautions against heat stress in animals, especially dairy cattle, in areas of South Africa and Namibia where the THI values are above 70:

THI values	*LWSI(LDC) category*	*Proposed minimum precautions*
70,0 or less	Normal (Fig. 4, blue)	Natural or artificial (permanent or portable = PP) shade
70,0–72	Alert to critical index for milk production (Fig. 4, green)	The former or well-ventilated, open-sided barn; *ad lib.* drinking* water at shaded troughs.
72,0–78,0	Alert and above critical index for milk production (Fig. 4, orange)	The former plus overhead sprinklers and large fans in the holding area adjacent to the milking palour; diet alterations**; consider breed of dairy cow***; animal husbandry and management alterations†.
78,0–82,0	Danger (Fig. 4, red)	The former plus shade covering over feed bunks and sprinklers with fans at feed bunks.
82,0 or above	Emergency	Not occuring during the 5 month period of mean THI values, but on individual days. The former precautions are applicable.

* Provision of cooled drinking water (± 20 °C) is the ideal.

** Depending on the THI value, the proportion of higher-energy concentrates in the diet as compared to roughage should be increased. Normally, the concentrate-to-roughage ratio ranges from 40:60 to 60:40, but increasing this to a 80:20 ratio will result in increased energy intake. A combination of feeding higher energy diets and providing some protection by the use of shade, are a recommended practice in hot environments. Potassium requirement of lactating dairy cattle appears to be higher during heat stress. Cows should be allowed to consume most of the ration during the cooler hours and be provided with feeds which have a low heat increment. Fats have the lowest heat increment, followed by carbohydrates, then protein; however, carbohydrates, such as cellulose have higher heat increments than the more soluble carbohydrates, for example, sugar and starch (Conrad, 1985).

*** Distinct differences exist between breeds of cattle and in their physiological response and adaptation to thermal environments (McDowell, 1972). The *Bos indicus* cattle generally have a short, glossy coat of low density and are well adapted to heat, but poorly to cold. They can tolerate more heat stress than *Bos taurus* cattle. Among the *Bos taurus* breeds, Jerseys can tolerate higher environmental temperatures than Friesians (McDowell, 1972; Young, 1985).

† Any stressful handling during the hottest time of the day should be restricted. Appropriate timing of the milking routine (especially with 3 milkings per day), vaccination, dipping, etc., during the cooler time of the day or at night is essential.

The thermoneutral zone for milk production ranges from approximately −5–21 °C for Holsteins. Warm climates depress feed intake (Conrad, 1985), milk production (Johnson, 1980) and reproductive performance (Wolfenson, Flamenbaum & Berman, 1988) in dairy cattle. When environmental temperatures rise above 21–25 °C, milk production declines because cows consume less feed. Eating less is the homeothermic cow's (37,5–38,5 °C) major strategy to try to maintain normal body temperature (Fuquay, 1981; Johnson, 1985). Thus, the upper critical temperature for milk production for the Holstein is 21 °C, but slightly higher (24 °C) for Jerseys and Brown Swiss. The average recovery time of milk production to the initial values at thermoneutrality preceding a 3-day heat exposure was 7 to 8 days (Johnson, 1985).

Thatcher (1974) showed that cattle breed throughout the year, but, at environmental temperatures above the critical temperature of 21 °C, conception rates are depressed. Other reproduction disadvantages of heat stress are prolonged oestrus cycle, shortened oestrus period, retained placentas (Fuquay, 1981; Hall, Branton & Stone, 1959; Madan & Johnson, 1973; McDowell, 1972; Stott, 1961; Ulberg & Burfening, 1967). Gwazdauskas, Wilcox & Thatcher (1975) reported that the maximum temperature on the day after insemination has the greatest effect on conception. In general, the most critical period for fertility appears to extent to several days following oestrus and insemination (Johnson, 1985). Ulberg & Burfening (1967) showed that 1 °C increase in rectal temperature in cows within 12 h after insemination reduced the pregnancy rate from 61 to 45 %. If uterine temperature increased 0,5 °C on the day of, or day after, insemination, conception rates decreased 13 and 7 %, respectively (Gwazdauskas, Thatcher & Wilcox, 1973). All the above data indicate that protection of dairy cows against heat stress in South Africa and Namibia in areas where the THI values are above 70, is essential to improve their general performance.

Temperature and humidity are 2 important factors which influence the economy of the dairy industry in various parts of the United States and in other countries (Kibler, 1964). The biometeorological data in this report imply that dairy farmers and industry in South Africa and Namibia suffer significant economic losses, because of poor performance of dairy cattle which are not adequately protected against heat stress in the areas as indicated (Fig. 1–4). Hot, humid environmental conditions along with solar radiation, animal crowding, stressful handling, insect pests and poor ventilation add to reproduction and production stress and are associated with an increased incidence of mastitis and a reduction in milk yield (Nickerson, 1987). Johnson (1980) found that the average decline in milk production was approximately 15 % during the period in which THI was above 72. Conception rates declined from 66–35 %, as the THI index increased from 68 to 78 (Ingraham, Staley & Wagner, 1976). Length of gestation and masses at birth, which indirectly affect neonatal health, are reduced in hot weather. For dairy cows in a tropical area, gestation periods were shortened by approximately 2 weeks for summer calvings (Ansell, 1976).

Further research in South Africa on the detrimental effects of heat stress on dairy cattle is essential if the South African dairy industry is to achieve more cost-effective milk production, improved herd and udder health and adequate supplies of high-quality raw milk.

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