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HEAT STRESS IN DAIRY CATTLE AND OTHER LIVESTOCK UNDER SOUTHERN AFRICAN CONDITIONS. I. TEMPERATURE-HUMIDITY INDEX MEAN VALUES DURING THE FOUR MAIN SEASONS

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ABSTRACT

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The Livestock Weather Safety Index (LWSI) indicates that in large areas of South Africa and South West Africa/Namibia and for prolonged periods of the year warm conditions are causing heat stress in food-producing animals, especially dairy cattle, thereby hampering their performance. South Africa and South West Africa/Namibia have been mapped according to a modified LWSI, which includes the critical "temperature-humidity index" value for milk production. The importance of heat stress in dairy cattle is discussed relative to such areas.

INTRODUCTION

Life, health, reproduction and production of an animal always depend on the enivronment in which it lives. The animal and its environment form a system in which both act and react upon each other (Yousef, 1985a). The concepts of stress and the general adaptation syndrome (Selye, 1948) are widely accepted in the veterinary context (Hillman, 1982; Lamb, 1976; Moberg, 1976). Selye (1976) proposed that stress, from the medical-biological point of view, may be defined as the non-specific response of the body to any demand, including efforts to cope with the wear and tear in the body caused by the state of stress, general adaptation syndrome, as well as pregnancy, lactation and stress of life at any one time. According to modern concepts of stress in dairy cattle as well as the definition of stress proposed by Fraser, Ritchie & Fraser (1975) and amended by Giesecke (1985), hot, humid environmental conditions along with solar radiation, animal crowding, insect pests, and poor ventilation add to these "physiological" stress conditions, affect udder health (Giesecke, 1985) and are associated with an increased prevalence of mastitis (Nickerson, 1987). The animals are forced to readjustments (compensatory reactions) which depend on their magnitude and nature as well as on secondary complications (e.g. infections), lead to undesirable/abnormal conditions (abortions, increased susceptibility, etc.), changes in reproduction, production, health and behaviour (Giesecke, Van Staden, Barnard & Petzer, 1988; Wolfenson, Flamenbaum & Berman, 1988; Yousef, 1985a).

Especially under warm conditions the abiotic or physical environmental factors are important to productivity of livestock and include sensible air temperature, humidity, solar radiation and wind (Yousef, 1985b). Homeothermy of the dairy cow is maintained as a result of a sensitive balance between heat production and heat loss (Yousef, 1985c). Temperatures of the peripheral body regions vary considerably with environmental temperature, there fore the deep body (core) temperature is used as a controlled parameter for changes in body temperature (Yousef, 1985a). Environmental factors (sunlight, thermal radiation, air temperature, etc.), animal properties (rates of metabolism and moisture loss, geometric structure of fur properties, etc.) and thermoregulatory mechanisms, such as conductioı radiation, convection and evaporation, affect th exchange of energy between the dairy cow and it environment. This, in turn, affects the body tem perature of the animal which again leads to changes of the animal's metabolism and behaviour (Gebremedhin, 1985).

On the general body surface of cattle there are no eccrine glands that are analogous to the thermoregulatory structures of man. The glands are apocrine in nature (Robertshaw, 1971). Allen, Bennett, Donegan & Hutchinson (1970) demonstrated in sweating cattle that, as the site of evaporation is at the skin surface, the fur provides little impediment to cutaneous evaporative cooling. By means of this and other mechanisms (convection and radiation), the animal endeavours to maintain homeothermy within the physiological limits of its body temperature (Bligh, 1985).

The productivity, efficiency and performance of cattle is optimum within the optimum zone of the thermoneutral zone (comfort zone, zone of thermopreferendum) (Yousef, 1985d) which is bound at its lower end by the lower critical temperature and upper end by the upper critical temperature (Bligh & Johnson, 1973). At thermoneutrality, metabolism of the animal can maintain homeostasis without excessive use of energy for thermoregulation, hence energy is available for maintaining optimum conditions of health and performance (Yousef, 1985a).

Bianca (1970) stated that the thermoneutral zone of the cow varies between 0 and 16 °C in terms of ambient temperature. The thermoneutral zone for milk production has been estimated from the literature to be between −5 and 21 °C for Holsteins (Johnson, 1986). The comfort zone for milk production is the optimum zone for maximum milk production, a zone in which the animal is within a normal range of body temperature (Brody, Worstell, Ragsdale & Kibler, 1948; Ragsdale, Brody, Thompson & Worstell, 1948). Where ambient temperatures rise above 23,8 °C at a relative humidity of 80 %, cows begin to experience stress (Nickerson, 1987). Hahn (1976) stated that the "acceptable temperature range" for lactating dairy cattle within 2 weeks of breeding was between 4 and 24 °C. Dairy cattle with their high metabolism are notorious for their sensitivity to heat and even slight differences in core temperatures indicate heat stress which is related to major performance changes (Bligh, 1985; Giesecke *et al.*, 1988; Johnson, 1985; Yousef, 1985a). Because of their sensitivity to heat, dairy cattle usually respond favourably to artificial cooling (Hahn, 1985; Wolfenson *et at.*, 1988).

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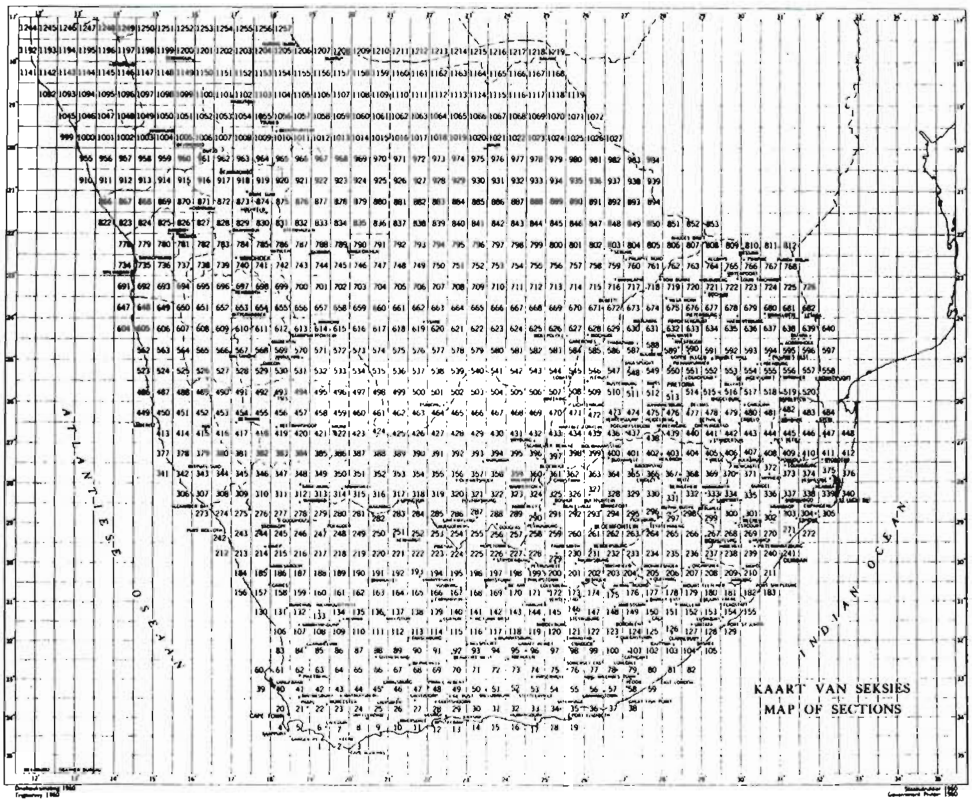

FIG. 1 Map of numbered sections of the Weather Bureau (Government Printer, 1960)

Any exposure to an environmental temperature beyond the thermoneutral zone stimulates an animal to a response which aims at maintaining deep body temperature within set limits. As the environmental temperature and relative humidity rise, heat losses from the cow via radiation, conduction and convection decrease, whereas body temperature rises (Nickerson, 1987). A small departure from thermal neutrality would perhaps not normally be regarded as "stressful"; severe cold or heat is almost always regarded as "stress" (Ingram & Dauncey, 1985).

It is evident that stress in dairy cattle, as in other species, is part of the continuous effort by the animals to maintain themselves in a state of homeostasis (Selye, 1948; Guyton, 1971; Hails, 1978; Stephens, 1980; Hillman, 1982). Glucocorticoids, mineralocorticoids and catecholamines of the adrenal cortex and medulla control vital physiological and biochemical events to maintain homeostasis under different environmental stresses (Yousef & Johnson, 1985). In these attempts the animals may respond by means of short-term and medium/long-term reactions. The former are initially accompanied by increased sympathetic-adrenomedullar activity. This emergency response is normally followed by a more medium/long-term adaptive response, involving the hypophyseal-adrenocortical system and corresponding secretions of ACTH and corticosteroids (Giesecke, 1985).

The severity of the decline in performance relative to the animal's state above the thermoneutral zone is dependent on the humidity, which reduces evaporative heat loss by the animal. This results in an increase of body temperature that inhibits feed intake and thus lowers milk yields (Johnson, 1980a). When the body temperature is significantly elevated, a myriad of homeothermic events are initiated which can, among other things, be used to diagnose heat stress. These events include increased water intake, respiration and urinary excretion which may aid in conductive and convective cooling. However, radiation of the animal is lessened and, to help alleviate the heat imbalance, feed intake, body mass, and milk yield decrease. As environmental temperature increases, metabolism decreases and respiratory rates, rectal temperature and surface vaporization increase (Johnson, 1980a & b). Reproduction disadvantages of heat stress are: depressed conception rates (Thatcher, 1974), lengthened oestrus cycle, shortened oestrus period, retained placentas (Fuquay, 1981; Hall, Branton & Stone, 1959; Madan & Johnson, 1973), reduced and seasonally decreased fertility (Bond & McDowell, 1972; Stott, 1961; Ulberg & Burfening, 1967).

Farm animals often require improved management and housing in hot environments to meet expected levels of performance and well-being. Rationally planned housing and management strategies and tactical practices (e.g. shades, shelters, animal wetting, air cooling, space allocations, dietary alterations, handling, etc.) are essential for short-term protection or long-term increased performance and well-being (Hahn, 1985; Wolfenson *et al.,* 1988; Yousef, 1982).

Under climatic conditions in South Africa (Du Preez, 1987) and in other world regions (Yousef, 1985 a & e; Yousef, 1982; Wolfenson *et al.*, 1988) cattle are frequently subject to heat stress with all its disadvantages. Most of the South African and South West Africa/Namibian dairy cows, being of northern European origin, are cool-weather animals. Thus the hot and sometimes humid conditions could pose a real hazard to the dairy industry during the warm months between October and March.

However, no practical information is available at

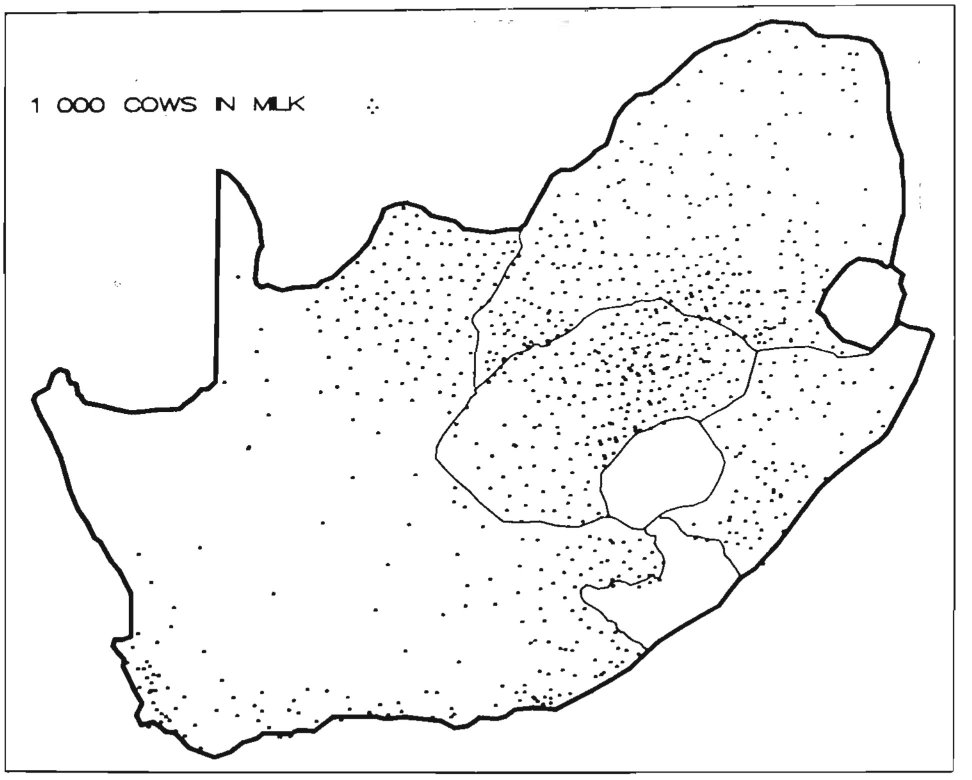

FIG. 2 Cows in milk in South Africa (From Animal Husbandry and Dairy Science Research Institute)

present to indicate South African and South West African/Namibian regions with warm climatic conditions which are stressful to food-producing animals, especially dairy cattle, and which require particular zootechnological precautions in order to protect the cattle and facilitate improved udder and general health, production and reproduction.

The aim of this investigation is to provide such information by mapping South Africa and South West Africa/Namibia according to the "temperature-humidity index" (THI) for cattle (Bosen, 1959; Kibler, 1964) and to illustrate the importance of heat stress to food-producing animals, especially dairy cattle.

MATERIALS AND METHODS

Acquisition of meteorological data

The meteorological data were obtained from the South African Weather Bureau publication WB 40 (Weather Bureau, Department of Environmental Affairs, 1988) which contains "long-term" averages as well as extreme values of weather conditions for periods from 1881 up to the end of 1984.

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

The THI index for cattle was calculated as follows: THI = t_{db} + 0,36t_{dp} + 41,2 (Bosen, 1959; Kibler, 1964), where t_{db} = dry-bulb temperature in °C (maximum temperature at 14:00), and t_{dp} = dew-point temperature in °C. The dew-point temperature is the temperature where condensation first occurs when an air-water vapour mixture is cooled at constant pressure.

The t_{db} and t_{dp} data was obtained from the publi-
7 cation WB 40. The dew-point (t_{dp}) was calculated as follows: t_{dp} = dry-bulb temperature at 14:00 (T) minus wet-bulb temperature at 14:00 (T^1). This value is used in the hygrometric tables (Weather Bureau, Department of Transport), to arrive at the correct atmospheric pressure (mb) for the corresponding t_{dp}.

RESULTS

Classification of THI values

The livestock weather safety index (LWSI) of the Livestock Conservation Institute (Anonymous, 1970) was used as a basis for classifying the various categories of the THI values:

THI value	LWSI category
70 or less	Normal
71–78	Alert
79–83	Danger
83 or above	Emergency

With due consideration to the THI value of 72 which is regarded by Johnson (1985) as being critical for milk production, and the LWSI categories referred to above, we combined these values in a modified LWSI for lactating dairy cattle (LDC). We also changed the LWSI(LDC) parameters and criteria slightly for practical and computer contouring for mapping purposes as listed below:

THI values	LWSI(LDC) category	Colour codes (Fig. 3–6)
70 or less	Normal	Blue
70–72	Alert, approaching critical index for milk production	Green
72–82	Alert, and above critical index for milk production	Orange
78–82	Danger	Red
82 or above	Emergency	Not existing

Mapping according to THI values

Mean arithmetical THI values were computed for summer, autumn, winter and spring for the various Weather Bureau stations in South Africa and South-West Africa/Namibia, and compiled in Table 1. THI

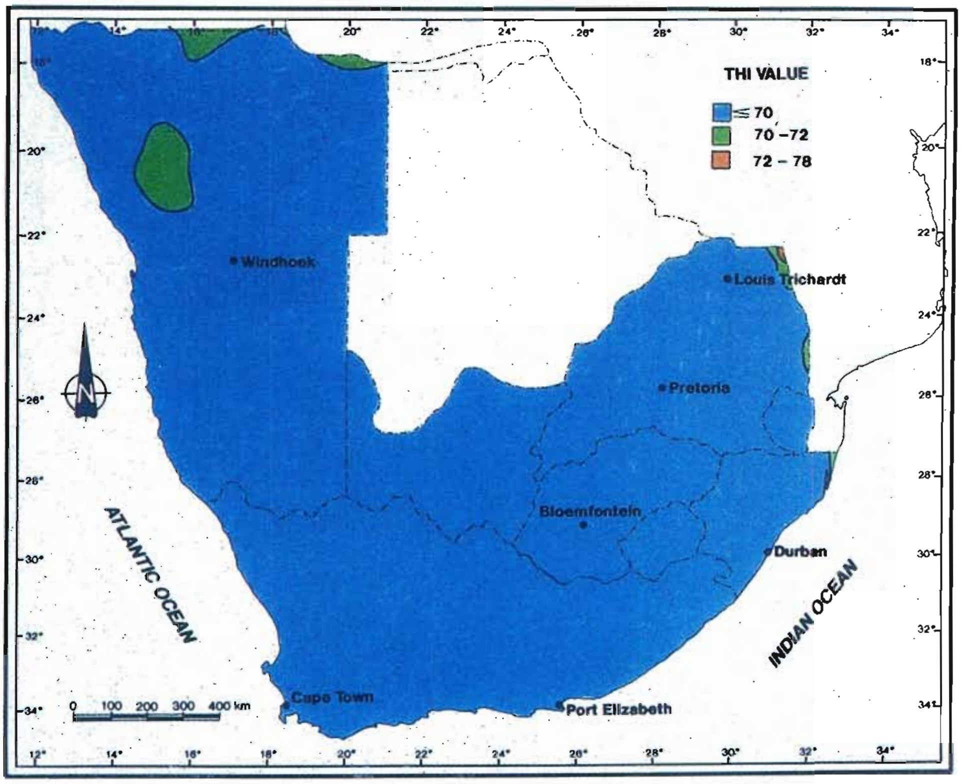

FIG. 3 Mapping of South Africa and South West Africa/Namibia according to the mean winter arithmetical THI values

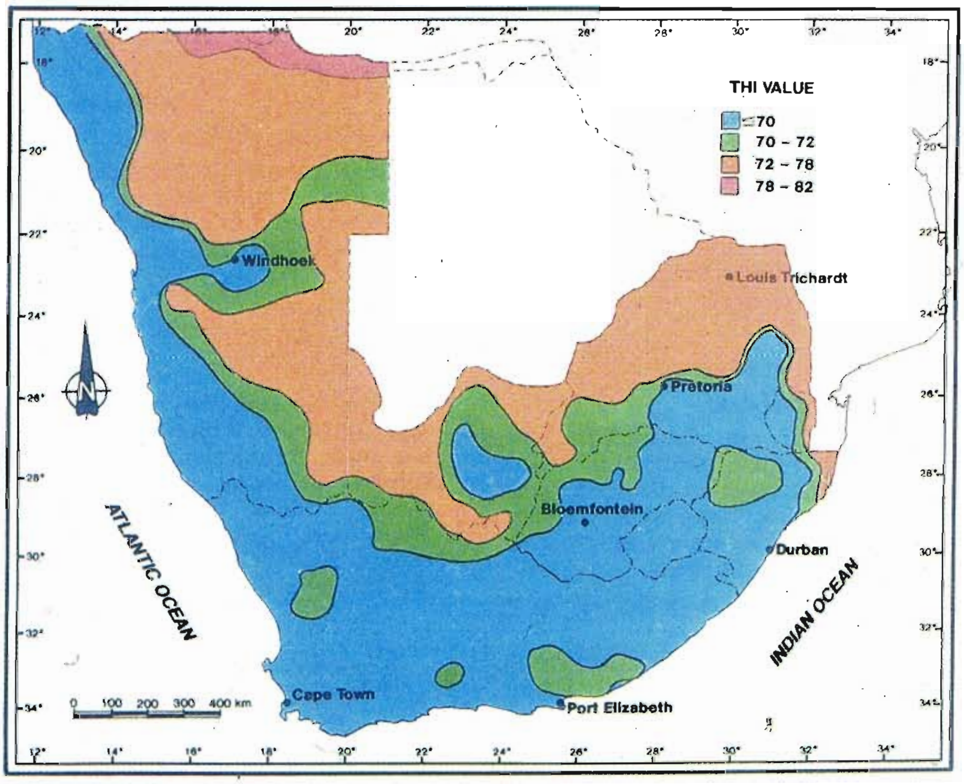

FIG. 4 Mapping of South Africa and South West Africa/Namibia according to the mean spring arithmetical THI values

values were entered on a South African standard grid map of numbered meteorological sections provided by the Weather Bureau. Contouring for mapping was done on the main frame computer of the University of Pretoria using the Surface II graphics system (Sampson, 1975) for weather stations with THI values of equal LWSI(LDC) categories to indicate regions with different LWSI(LDC) zones.

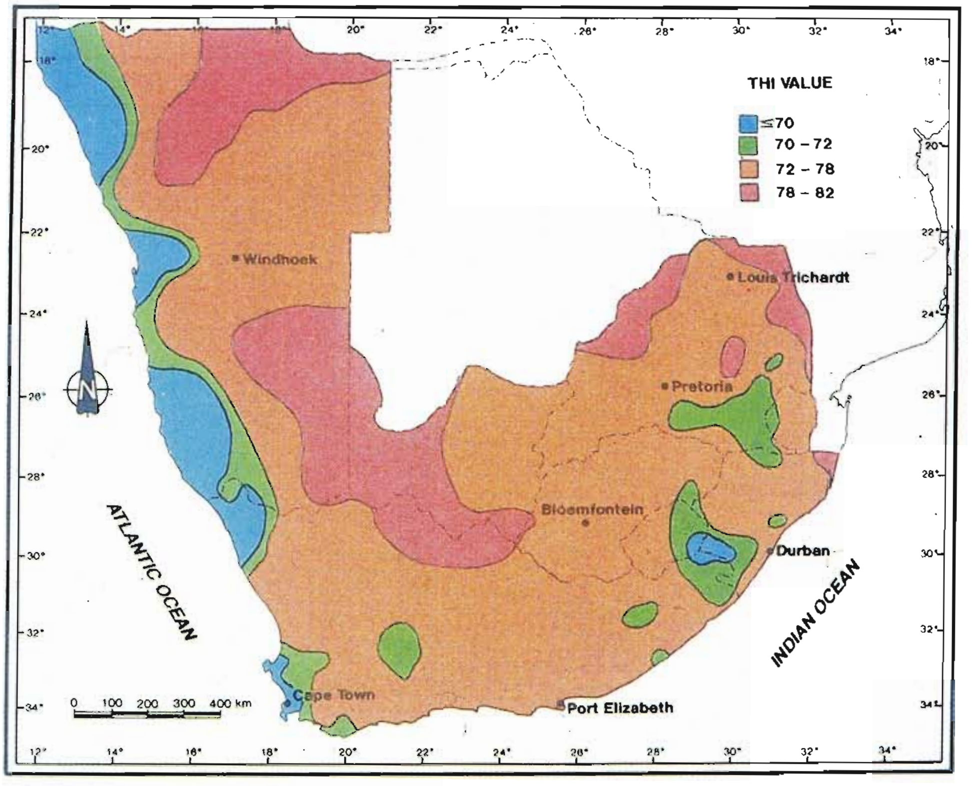

FIG. 5 Mapping of South Africa and South West Africa/Namibia according to the mean summer arithmetical THI value

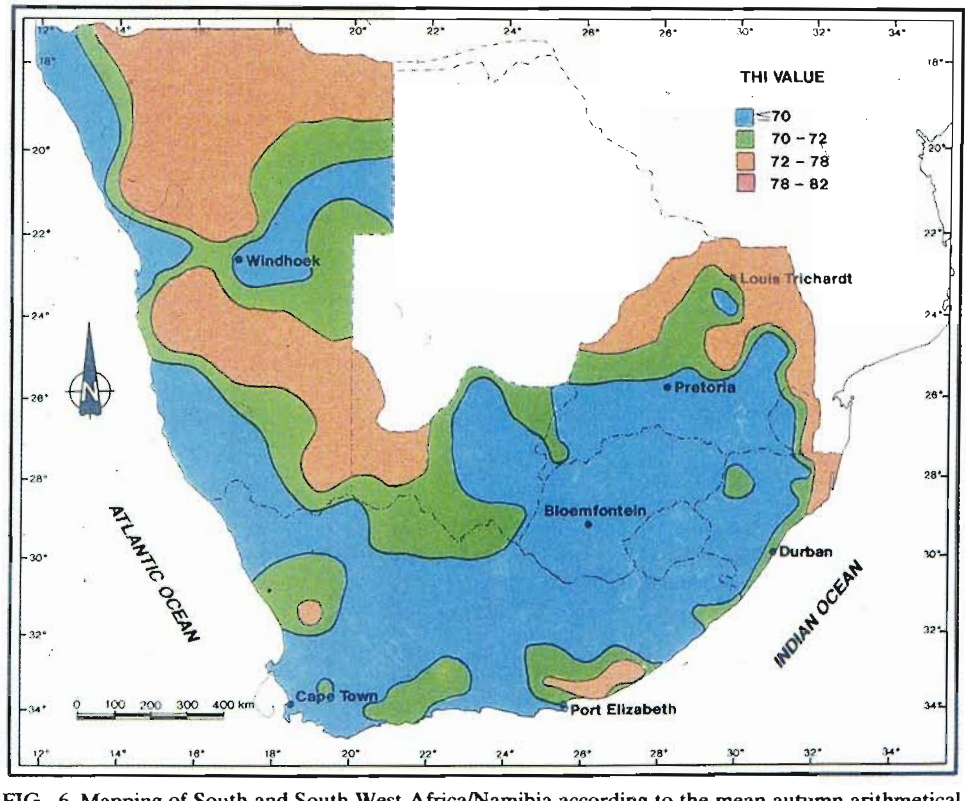

FIG. 6 Mapping of South and South West Africa/Namibia according to the mean autumn arithmetical THI values

Mapping of South Africa and South West Africa/Namibia, using the THI values (Table 1) was done for winter (Fig. 3, June, July and August), spring (Fig. 4, September, October and November), summer (Fig. 5, December, January and February) and autumn (Fig. 6, March, April and May). For the interpretation of the results, the mapped LWSI (LDC) zones should be visualized as superimposed on a map of South African dairy cattle distribution (Fig. 2).

TABLE 1 Mean arithmetical THI values of various weather bureau stations for summer, autumn, winter and spring for South Africa and South West Africa/Namibia

Weather bureau map section numbers	Weather bureau stations	THID values			
		Seasons			
		Summer	Autumn	Winter	Spring
35	Addo	75,6	71,9	66,0	70,2
274	Alexanderbaai	70,0	68,8	64,5	65,7
75	Aliwal Noord-Welverdiend	74,3	66,8	58,7	67,8
432	Armoedsvlakte (Vryburg)	77,2	70,1	62,7	72,8
399	Balkfontein	75,9	69,3	61,8	71,1
519	Barberton—AGR	76,4	73,0	67,2	73,0
519	Barberton—TNK	75,5	72,0	66,4	72,1
37	Bathurst	73,0	70,6	65,3	67,9
92	Beaufort West	76,8	69,1	61,0	69,0
92	Beaufort West WK	75,6	68,0	60,2	67,9
478	Bethal	71,3	65,9	59,4	67,8
331	Bethlehem (Loch Lomond)	71,9	64,6	57,9	67,2
21	Bien Donné	74,0	69,3	62,2	67,4
261	Bloemfontein—Tempe	73,9	66,4	58,4	68,0
261	Bloemfontein—JBM Hertzog	74,9	66,9	59,3	69,0
253	Boegoeberg Dam	79,3	71,3	62,8	72,4
291	Boshof	75,0	68,6	59,3	69,1
190	Brandvlei	76,5	69,2	60,4	69,4
512	Brits	77,1	71,6	65,2	74,1
125	Cala	72,3	66,7	59,2	67,1
134	Calvinia	75,4	68,8	60,2	67,6
03	Cape Agulhas	70,6	67,1	62,3	65,0
60	Cape Columbine	89,4	65,1	61,3	63,8
129	Cape Hermes (Port St Johns)	73,4	71,6	67,5	69,1
04	Cape Point	68,4	64,8	61,1	63,5
12	Cape St Blaize (Mosselbaai)	71,0	68,1	64,0	65,9
17	Cape St Francis	70,5	68,0	64,5	65,7
339	Cape St Lucia	76,8	74,4	68,7	71,8
21	Cape Town—D. F. Malan	72,1	68,3	62,2	66,3
20	Cape Town—A.S. Astr Obs	72,7	68,9	62,8	66,7
21	Cape Town—Wingfield	71,5	67,8	62,1	65,6
474	Carletonville	73,0	62,2	60,3	69,4
165	Carnarvon—AGR	75,3	66,8	58,1	67,7
480	Carolina	69,7	64,5	57,6	66,2
239	Cedara	72,0	68,0	62,1	67,9
42	Ceres	74,7	68,0	60,6	66,7
98	Cradock	75,5	69,1	61,3	69,2
590	Crecy	76,6	72,6	66,0	74,6
01	Danger Point	68,9	66,2	62,0	64,3
40	Dassen Island	66,1	64,5	61,4	63,5
170	De Aar	75,6	67,2	58,8	68,3
413	Diaz Point (Lüderitz)	67,5	66,0	62,9	63,6
79	Döhne	71,6	67,3	61,0	66,4
435	Doornlaagte	74,1	67,4	60,7	70,5
148	Dordrecht (Willow Park)	71,0	64,0	59,9	65,0
256	Douglas	79,2	70,7	62,8	71,9
555	D. R. de Wet	73,5	70,0	64,9	70,5
258	Drieplotte	78,1	69,3	61,7	72,0
335	Dundee	73,6	66,7	62,5	71,2
240	Durban—Louis Botha	76,1	73,7	68,3	71,5
59	East London—AGR	72,6	70,3	65,4	67,7
59	East London—Ben Schoeman	72,7	70,3	65,6	67,9
21	Elsenburg	73,8	68,5	61,4	66,7
442	Ermelo (Nooitgedacht)	70,1	65,2	58,1	66,5
268	Estcourt—AGR	73,5	68,3	61,4	69,3
300	Estcourt—TNK	74,1	68,8	62,1	69,4
229	Fauresmith	74,5	66,7	58,6	68,1
595	Fleur-de-Lys	77,1	74,1	68,6	74,1
476	Frankenwald II	71,8	66,8	59,5	68,3
403	Frankfort	73,4	67,7	60,3	69,3
113	Fraserburg	73,1	65,4	56,9	65,4
28	George	70,9	68,0	63,0	65,7
28	George—P. W. Botha	70,9	68,2	62,7	65,5
724	Giyani	79,5	75,0	69,9	75,9
293	Glen College	75,3	67,8	59,9	69,4
649	Gobabeb	76,6	76,0	69,1	72,8
787	Gobabis	76,3	70,7	63,8	72,5
632	Goedehoop	76,0	71,6	65,7	73,9

Weather bureau map section numbers	Weather bureau stations	THID values			
		Seasons			
		Summer	Autumn	Winter	Spring
96	Graaff-Reinet	76,6	69,8	61,9	69,6
631	Groendraai	76,8	71,8	65,0	73,5
270	Groenekop Estate	71,8	68,0	61,7	68,3
1010	Grootfontein-Dorp	75,4	71,5	65,5	74,2
1010	Grootfontein—WK	75,8	72,0	66,1	74,8
594	Grootfonteinberg	68,5	65,8	60,0	66,4
568	Hardap	79,9	72,6	64,6	73,5
62	Heldervue	70,7	65,4	58,2	63,6
173	H. F. Verwoerd Dam	75,0	67,0	58,6	67,7
35	Hermitage	76,1	72,2	65,7	70,5
22	High Noon	70,7	66,0	59,0	63,6
147	Hillside	72,6	65,1	56,3	65,6
54	Hillside Farm	77,2	72,3	66,3	71,4
638	Hoedspruit	79,5	75,6	69,5	74,9
362	Hoopstad—TNK	76,6	69,2	61,0	71,4
363	Hoopstad—Plessis Draai	75,4	68,8	61,1	70,6
103	Idutywa	72,0	68,9	64,0	68,2
513	Irene	72,9	67,3	60,6	69,4
476	Jan Smuts	70,8	65,1	58,4	67,1
74	Jansenville	76,6	72,2	63,6	67,4
784	J. G. Strydom—Windhoek	74,5	68,8	62,8	70,3
476	Johannesburg—Joubertpark	71,0	65,5	58,6	67,6
419	Keetmanshoop	78,0	71,4	62,8	71,4
251	Kenhardt	78,9	71,2	62,4	70,9
290	Kimberley	76,6	68,9	60,8	70,4
79	King William's Town	74,8	71,1	64,4	68,4
180	Kokstad	71,6	66,4	59,5	66,7
557	Komatipoort	81,1	77,8	72,2	77,8
323	Koopmansfontein	75,1	67,8	59,6	69,4
365	Kroonstad—TNK	74,0	66,9	59,0	69,1
365	Kroonstad—MUN	75,0	68,4	61,0	70,2
393	Kuruman	76,4	69,2	61,4	71,1
300	Ladysmith—WK	75,1	70,0	63,0	70,7
300	Ladysmith—CON	75,9	70,7	63,5	71,7
61	Langebaanweg	73,1	69,5	63,1	67,1
723	Levubu	76,8	72,8	67,8	73,5
366	Lindley	72,8	66,9	59,2	68,5
554	Lydenburg—VIS	71,9	67,5	61,4	68,8
809	Macuville	80,3	76,0	69,9	77,3
508	Mafikeng	76,7	69,9	62,8	72,5
1250	Mahanene	77,5	74,4	69,2	76,4
411	Makatini	80,7	76,7	71,1	75,8
320	Mancorp Mine	75,9	68,4	59,8	68,7
722	Mara	76,7	73,0	66,8	73,7
568	Mariental	80,3	73,3	65,6	74,5
00	Marion Island	53,8	52,5	49,2	50,3
719	Marnitz	77,5	72,9	66,5	74,8
43	Matroosberg—Helpmekaar	71,5	65,1	56,9	63,7
412	Mbazwane	79,3	76,4	71,5	75,4
303	Melmoth	74,8	71,6	65,8	71,0
810	Messina	79,5	76,0	69,6	76,8
145	Middelburg (CP) Grootfontein—AGR	74,3	66,3	57,5	66,8
145	Middelburg (CP) Grootfontein II—AGR	74,6	66,3	58,2	67,3
263	Modderpoort (OFS)—Priory	73,5	66,2	58,6	68,3
42	Mont Pellier	76,4	69,7	62,8	68,7
24	Montagu	77,3	70,9	63,6	69,8
241	Mount Edgecombe	75,9	73,4	68,5	71,9
179	Mount Frere	71,8	67,2	60,4	67,2
1045	Möwe Bay	68,2	67,0	63,1	63,6
125	Ncora Flats	73,2	68,2	61,9	67,5
447	Nduma Game Reserve	80,9	76,8	71,8	76,1
555	Nelspruit—Friedenheim—AGR	76,6	73,0	67,6	73,3
208	New Amalfi—AGR	71,7	65,9	59,7	68,0
370	Newcastle	75,5	69,9	63,3	71,7
590	Nylsvlei	76,7	71,3	64,6	73,9
828	Okahandja	79,0	73,5	66,6	75,9
1051	Okaukuejo	80,5	75,4	69,0	78,3
214	Okiep	74,4	68,9	60,2	67,2
1200	Ondangwa	78,2	75,6	69,9	78,0
227	Orange River Salt Pan	77,4	68,9	60,3	70,2
1008	Otavi	77,2	73,0	67,5	76,4
962	Otjiwarongo	77,3	73,2	66,8	75,9

Weather bureau map section numbers	Weather bureau stations	THID values			
		Seasons			
		Summer	Autumn	Winter	Spring
435	Ottosdal	76,2	68,8	61,6	71,4
552	Oudestad	77,4	72,3	65,7	73,8
28	Oudtshoorn	77,2	71,6	63,4	70,3
28	Oudtshoorn—CON	77,9	71,7	63,8	70,3
961	Outjo	78,5	74,1	69,7	76,2
21	Paarl	75,1	70,0	62,4	68,0
734	Pelican Point	66,1	65,3	62,9	62,3
681	Phalaborwa	79,2	75,0	69,5	75,5
408	Piet Retief	73,3	69,1	62,5	68,4
444	Piet Retief—TNK	71,9	67,6	61,5	68,8
677	Pietersburg	74,0	69,3	62,9	71,1
594	Pilgrim's Rest	72,7	68,4	63,3	69,8
247	Pofadder	76,4	68,9	60,1	68,9
410	Pongola	76,3	75,0	68,6	74,3
411	Pongola Poort Dam	78,6	74,5	69,4	74,2
35	Port Elizabeth—H. F. Verwoerd—WK	72,0	69,2	64,4	66,8
242	Port Nolloth	65,9	64,9	62,9	63,5
182	Port Shepstone	74,6	72,4	67,7	70,0
437	Potchefstroom	75,1	68,6	62,1	71,6
634	Potgietersrus	72,6	71,0	64,3	72,5
513	Pretoria—Forum	74,2	68,5	61,9	70,4
513	Pretoria—Lynnwood Rd	73,8	68,2	61,3	70,2
513	Pretoria—UP Proefplaas	74,9	69,8	63,3	71,9
224	Prieska	79,4	71,2	62,4	70,6
768	Punda Maria	81,3	78,1	73,4	79,0
123	Queenstown	74,6	68,2	61,0	68,4
305	Richards Bay—Alusaf	78,6	75,5	70,0	74,1
258	Rietrivier	76,9	69,3	60,9	71,3
158	Rietpoort	77,5	70,6	63,4	69,1
513	Rietvlei—Pretoria	72,7	67,6	60,6	69,8
339	River View	78,6	75,1	69,9	73,8
10	Riversdale	74,4	70,4	64,1	68,1
557	Riverside II	78,8	76,2	70,1	75,0
23	Robertson	76,1	70,4	63,1	69,1
513	Roodeplaat—AGR	75,4	70,1	63,2	72,1
591	Rooibokkop	79,5	74,1	68,0	76,5
28	Rooiheuwel	77,0	71,0	63,1	69,8
1208	Rundu	78,4	75,7	70,4	78,7
511	Rustenburg	76,1	70,4	63,5	72,9
29	Saasveld	70,3	68,0	63,1	65,1
718	Sandpan	79,7	74,0	67,3	76,1
548	Saulspoort	77,4	71,4	64,1	73,5
270	Seven Oaks Ryhill	72,4	68,1	61,6	68,2
178	Sheeprun	73,0	67,4	60,9	67,6
1006	Sitrusdal (S.W.A.)	78,0	73,4	67,9	77,0
596	Skukuza	80,4	76,7	71,4	76,9
76	Somerset East	74,6	68,9	61,9	68,1
43	Spes Bona	75,3	68,5	59,5	67,3
441	Standerton	72,4	66,6	60,2	68,8
05	Steenbras Dam	71,7	65,4	59,3	64,1
337	Surprise Store	72,9	69,0	63,6	69,0
88	Sutherland	70,7	63,4	54,6	62,8
735	Swakopmund	66,6	65,6	62,9	61,9
20	Table Mountain House	65,3	62,4	55,7	59,4
587	Thabazimbi	78,0	72,7	66,4	75,3
679	Thabina	79,0	75,0	69,5	76,3
44	Touwsrivier	74,2	67,7	58,9	66,3
589	Towoomba	76,2	69,4	64,6	73,4
00	Tristan Da Cunha	66,7	64,7	59,3	60,5
1055	Tsumeb	77,4	73,6	67,3	76,0
461	Twee Rivieren	80,7	73,3	64,8	74,5
57	Tyefu	77,0	73,4	66,8	71,2
07	Tygerhoek	74,2	69,4	62,5	67,8
679	Tzaneen	77,4	73,9	68,3	73,5
868	Uis Mine	77,7	76,8	70,4	75,1
34	Uitenhage	75,0	71,4	66,7	69,7
239	Ukulinga	73,3	70,0	64,4	69,5
127	Umtata	74,4	70,7	64,7	69,8
127	Umtata—AER	74,3	70,0	63,6	68,9
237	Underberg (Waterford)	69,8	64,5	57,9	65,2
317	Upington	79,0	71,9	63,2	72,3
317	Upington Pierre van Ryneveld	78,9	71,7	63,0	72,3

Weather bureau map section numbers	Weather bureau stations	THID values			
		Seasons			
		Summer	Autumn	Winter	Spring
360	Vaalharts	77,5	70,0	61,9	73,6
193	Van Wyksvlei	77,8	69,6	60,8	69,8
141	Victoria West	73,0	65,2	56,8	65,5
328	Virginia	75,5	67,9	60,6	70,7
106	Vredendal	75,5	72,0	64,9	69,8
432	Vryburg—Armoedsvlakte	77,2	70,1	62,7	72,8
407	Wakkerstroom	69,8	64,7	58,0	66,3
734	Walvis Bay	69,7	69,7	66,8	65,5
312	Warmbad—SWA	79,0	72,4	63,7	71,7
364	Welkom	74,4	67,3	59,4	69,6
21	Wellington	76,7	71,3	63,4	69,5
233	Wepener	74,0	66,4	58,6	68,0
148	Willow Park (Dordrecht)	70,7	64,0	56,9	65,0
50	Willowmore	74,2	67,3	59,7	66,9
740	Windhoek (Office)	73,4	68,0	62,7	71,1
509	Zeerust	76,9	70,9	63,5	73,0

AER	Aerodrome	OBS	Observatory
AGR	Agriculture	POL	Police
BOS	Forestry	POS	Post Office
BOT	Botanical Gardens	POW	Power Station
CEM	Cemetary	PUR	Purification Works
COL	Coloured Affairs	RSV	Reservoir
CON	Convent	RWB	Rand Water Board
DYN	Dynamite Factory	SAR	Railways
GM	Gold Mine	SKL	School
HOSP	Hospital	TNK	Prisons
GSH	Health	VET	Veterinary Service
IRR	Water Affairs (Irrigation)	VIS	Pisciculture
LAN	Land Affairs	VRT	Lighthouse
MAG	Magistrate	WB	Weather Bureau
MUN	Municipality	WK	Weather Office

Discussion

The THI stress index is suitable for measurements of the thermal environment and assesments of its effects on cattle (Kibler, 1964). From previous research it is apparent that an animal's first response to heat stress is to increase functions facilitating heat loss while simultaneously reducing functions leading to heat production. The hormones associated with heat loss functions and water regulation tend to increase, whereas calorigenic pituitary and target organ hormones decrease and growth rate, as well as reproductive and milk production performance decline. 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 to the animal's physiology and performance (Johnson, 1985).

Hardly any cattle are at risk of heat stress during winter except those in a small area in Northern Natal (green area between 26° and 28° latitude) and North-eastern Transvaal (green and orange areas between 22° and 28° latitude), as seen in Fig. 3.

During spring (Fig. 4) the dairy cattle in large areas of South Africa and South West Africa/ Namibia become exposed to an increasing risk of heat stress where the LWSI(LDC) conditions exceed their normal limit at THI value of 70. During transition from winter to spring most of the important milk-producing areas (Fig. 2; Fig. 4) have a THI value of 70 or less.

The THI values of the months (November and March, Table 1) which border the summer have not been taken into account in the determination of the mean seasonal indexes. These will annually lengthen the risk period of heat stress to cattle. There is no Weather Bureau station in South Africa or South West Africa/Namibia with a mean seasonal emergency THI value (83 or above), although some daily THI values are above 83.

Most of the South African and South West African/Namibian summer THI values (Table 1) as mapped (Fig. 3) exceed the normal LWSI(LDC) limit of 70. Only a small area (Fig. 3, blue colour) of South Africa has summer THI values of 70 or less, which is normal according to the LWSI(LDC). According to the summer THI values (Table 1 and Fig. 5), most of the cattle, especially lactating dairy cattle (Fig. 2) in South Africa and South West Africa/Namibia are at an elevated risk of developing heat stress or of being in a state of heat stress. This has a detrimental effect on production and reproduction performance, nutritional state and related aspects (Bond & McDowell, 1972; Fuquay, 1981; Hall *et al.*, 1959; Hillman, 1982; Ingram & Dauncey, 1985, Johnson, 1985; Maden & Johnson, 1973; Thatcher, 1974; Stott, 1961; Ulberg & Burfening, 1967), as well as an udder health and mastitis therapy (Nickerson, 1987). Du Preez (1988) stated that mastitic treated cows should be protected against exogenous (e.g. sun, wind, etc.), and endogenous stressors as far as possible for optimum recovery.

During summer, most of the important milk-producing areas in South Africa and South West Africa/ Namibia (Fig. 2) are affected by temperatures above the upper limit of the thermoneutral (comfort) zone (−5 to 21 °C) for Holsteins (Johnson, 1986) and exceeding the THI value of 72 which is critical for milk production (Johnson, 1985) and is within the alert range of the LSWI(LDC).

During autumn (Fig. 6) the greater parts of South

Africa and South West Africa/Namibia has THI values (Table 1) within normal LWSI(LDC) conditions. This implies a thermal environment reasonably favourable to udder health, production, reproduction and related aspects of performance. Nevertheless, in certain areas (Fig. 6) the THI values (Table 1) continue to exceed the normal LWSI(LDC) conditions at a THI of 70.

CONCLUSION

The LWSI(LDC) indicates that cattle in large areas of South Africa and South West Africa/Namibia and for prolonged periods of the year are at risk to heat stress which will hamper their performance. Just as cattle should be protected against certain seasonal diseases by vaccination, they should also be protected against heat stress by zootechnological arrangements (e.g. shade, moving of air, wetting, etc.). To make optimal use of the summer vegetation for animal performance, protecting against heat stress is of the utmost importance.

Further research needs to be done in South Africa to determine the state of all aspects of production and reproduction performance among cattle and especially of dairy cattle. Artificial cooling of dairy and feedlot cattle for optimum performance in areas where the cattle suffer from heat stress in South Africa and South West Africa/Namibia is of the utmost importance.

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