Effect of shade on various parameters of Friesian cows in a Mediterranean climate in South Africa. 2. Physiological responses

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Received 15 January 1993; revised 5 August 1993; accepted 22 September 1993

The effect of a shade structure on some physiological parameters of lactating Dutch-type Friesian cows was determined over three consecutive summer periods. Plasma cortisol concentration of no-shade cows was significantly ($P < 0.05$) higher than that of shade cows during the 1985/86 experimental period as well as the combined analysis over the two experimental periods. Cortisol levels were increased ($P < 0.05$) owing to higher temperatures during the 1984/85 period only. Plasma thyroxine concentration of the no-shade cows tended to be lower than that of shade cows. Thyroxine levels were reduced ($P < 0.01$) by increasing maximum ambient temperatures during the 1984/85 experimental period only, while a negative trend was observed during 1985/86. The average respiration rate and the average rectal temperature of no-shade cows were higher ($P < 0.01$) than those of shade cows at 11:00, 13:00 and 15:00 on hot days (maximum day-time temperature $\geqslant$ 25.1 °C) but there was no difference at any time of the day on cool days (maximum ambient temperature $\leqslant$ 25.0 °C). Both respiration rate and rectal temperature of shade and no-shade cows increased ($P < 0.01$) with increasing ambient temperatures.

Die invloed van 'n skaduwee-afdak op sekere fisiologiese eienskappe is by lakterende Hollandse-tipe Frieskoeie gedurende drie opeenvolgende somerperiodes bepaal. Die kortisolkonsentrasie in die bloedplasma van koeie sonder skaduwee was betekenisvol ($P < 0.05$) hoër as by koeie met skaduwee gedurende die 1985/86-proefperiode sowel as die gekombineerde ontleding oor die twee proefperiodes. Kortisolvlakke is verhoog ($P < 0.05$) weens hoër temperature gedurende die 1984/85-periode alleenlik. Die tiroksienkonsentrasie in die bloedplasma van koeie sonder skaduwee het geneig om laer te wees as by koeie met skaduwee. Tiroksienpeile is deur hoër omgewingstemperature gedurende die 1984/85-proefperiode verlaag ($P < 0.01$), terwyl 'n negatiewe tendens gedurende 1985/86 waargeneem is. Die gemiddelde asemhalingstempo en gemiddelde rektale temperatuur van koeie sonder skaduwee was om 11:00, 13:00 en 15:00 op warm dae (maksimum temperatuur $\geqslant$25.1 °C) hoër ($P < 0.01$) as by koeie met skaduwee. Daar was geen verskille in asemhalingstempo en rektale temperatuur gedurende enige tyd van die dag op koel dae (maksimum temperature $\leqslant$ 25.0 °C) nie. Beide hierdie parameters is met toenemende omgewingstemperature verhoog ($P < 0.01$).

Keywords: Cortisol, dairy cows, heat stress, rectal temperature, respiration rate, shade, thyroxine.

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Introduction

The adverse effects of high ambient temperature, humidity levels and solar radiation on the production of lactating dairy cows, is well documented (Stott & Williams, 1962; Ingraham *et al.*, 1974; Roman-Ponce *et al.*, 1977; Wise *et al.*, 1988). Research has indicated that various physiological parameters are influenced by adverse climatic conditions and may be used as indicators of climatic stress. Parameters that may be useful in this regard are rectal (body) temperature, respiration rate and changes in some hormonal secretions.

The normal body temperature of cattle is usually accepted to be 38.3 °C (Brody, 1945) with some deviations owing to age, stage of lactation, level of nutrition and reproductive state (Seath & Miller, 1946; McDowell, 1958). Various studies under field conditions have demonstrated that body temperature increases with increasing environmental temperatures above 21 °C in European breeds (McDowell, 1958). At high temperatures, an increased respiration rate is an important way of increasing heat loss by domestic livestock. It is usually the first visible sign of heat stress (McDowell, 1972). The greater the volume of air that is breathed in, warmed, humidified and breathed out, the greater the resultant heat loss. The increase in respiration rate is most pronounced at temperatures over 29 °C (McDowell, 1958).

Studies conducted at Missouri in 1955 have suggested that air temperatures over 35 °C decreased thyroid activity by 30 to 65% (McDowell, 1958). However, Zoa-Mboe *et al.* (1989) found no difference in mean concentrations of thyroxine (T_4) for shade and no-shade cows. This was ascribed to previous exposure of both groups to high environmental temperatures immediately prior to the experiment. Thompson (1973) concluded that adaptation to high environmental temperatures caused an increase in body temperature and a decrease in thyroid activity. Magbub *et al.* (1982) and Pratt & Wetteman (1986) also found that heat-stressed cows had decreased concentrations of thyroid hormones while Roman-Ponce *et al.*

(1981) found increased plasma concentrations of corticoids. Cortisol is the primary glucocorticoid produced by the adrenal cortex and has a wide variety of physiological actions influencing metabolism, body water distribution, electrolyte balance and blood pressure. According to Wise *et al.* (1988), plasma cortisol concentrations were higher in heat-stressed cows compared to cows maintained at 22 °C. Although a number of experiments have been conducted to evaluate hormonal secretions during heat stress, a disparity in results has been obtained. This may, however, have been due to differences in experimental conditions (Wise *et al.*, 1988).

Summer days in the Western Cape are characterized by intense heat periods, varying in duration, during the day with relatively cool nights. This study investigated the effect of a shade structure in a temperate climate on different physiological parameters such as respiration rate, rectal temperature and blood serum concentrations of T_4 and cortisol in lactating Friesian cows.

Materials and Methods

The study was conducted over three consecutive summer periods from 1984/85 to 1986/87 inclusive, at the Elsenburg Experimental Station in the Winter Rainfall Region. Primi- and multiparous Friesland cows from the Elsenburg herd were divided into two groups according to stage of lactation and average daily milk production. Cows were kept under zero-grazing conditions in two adjacent dry lots. A shade structure, 4.5 m wide, 16.5 m long and 3.5 m high, provided an unbroken area of shade of 4.1 m^2/cow. An additional shade structure of 2.7 m wide and 2.9 m high was erected over the feed trough to provide a further 2.5 m^2 shade per cow.

For 40 and 60 days respectively during the 1984/85 and 1985/86 experimental periods, blood samples were taken daily at 15:15, just before milking, from the external jugular veins of 10 cows per treatment. Heparinized vacutainers (10 cm^3) were used for blood sampling. Samples were kept in an ice bath until centrifugation to recover plasma. The plasma was then stored in a frozen state at –20 °C until analysed. From the start of each experimental period cows had been made accustomed to the procedure by taking them through the collecting chute and neck clamp daily. Blood plasma was analysed for T_4 by using the Amerlex-M T_4 Radio-immuno-analysis kit. The cortisol concentration was determined by using the Amerlex Cortisol RIA kit which is suitable for the direct measurement of total cortisol in blood plasma.

During the 1986/87 experimental period the rectal temperatures and respiration rates of five cows from each treatment were determined on 24 non-consecutive days at 2-h intervals between 07:00 and 19:00. Rectal temperatures and respiration rates of cows were obtained on cool (maximum ambient temperature $\leqslant$25.0 °C) as well as hot (maximum ambient temperature $\geqslant$25.1 °C) days. Respiration rate was measured by counting the flank movements of individual cows over a 1-min period of uninterrupted breathing. Rectal temperatures of cows were measured by inserting a veterinary thermometer approximately 80 mm into the rectum for 60 s and the temperatures were recorded to two decimals.

Differences between shade and no-shade cows for respiration rate and rectal temperatures at different times of the day were tested by *t*-test procedures (Snedecor & Cochran, 1980). Linear regressions for the various physiological parameters on maximum ambient temperature were fitted within groups. Cortisol and thyroxine concentrations of shade and no-shade cows were compared by analysis of variance, using the Genstat-5 statistical package.

Results and Discussion

Meteorological conditions

Meteorological conditions on test days were similar to those generally experienced during summer. During 1984/85 the average maximum ambient temperature was 26.1 ± 5.5 °C with maximum temperatures higher than 25.1 °C on 22 days (55% of test days). During 1985/86 and 1986/87 average maximum ambient temperatures and number of hot ($\geqslant$25.1 °C) days were 28.6 ± 4.2 °C and 44 (73%), and 27.5 ± 4.3 °C and 16 (67%), respectively.

Cortisol concentration

The plasma cortisol concentrations for shade and no-shade cows during the different experimental periods are presented in Table 1.

Table 1 Average (± *SD*) plasma cortisol concentration for shade and no-shade cows during summer in a temperate climate

Experimental period	Cortisol concentration (nmol/l) Shade	No shade	SE_d	Significance
1984/85	26.91 ± 6.80	30.15 ± 6.04	2.88	$P = 0.275$
1985/86	15.65 ± 3.38	20.99 ± 4.83	2.12	$P < 0.05$
Overall mean	22.27 ± 7.93	25.57 ± 7.10	1.76	$P < 0.05$

SE_d: Standard error of difference.

Average cortisol concentration of no-shade cows was significantly ($P < 0.05$) higher during the 1985/86 experimental period as well as the combined analysis over the two years. During 1984/85 a similar trend was observed, but the difference (12%) was, however, not significant. The increased cortisol levels of the no-shade cows could be regarded as a direct effect of heat stress from solar radiation, since stress conditions activate the hypothalamic-pituitary-adrenal axis (Christison & Johnson, 1972). The hypothalamus is stimulated to release a corticotrophin-releasing factor (CRF) that acts on the anterior pituitary causing the release of adrenocorticotropic hormone or corticotrophin (ACTH). This stimulates the adrenal cortex to produce corticosteroid (cortisol) hormones (Frandson, 1974). Christison & Johnson (1972) correspondingly demonstrated an increased ($P < 0.05$) plasma cortisol concentration in cows when exposed to an ambient temperature of 35 °C in a climatic chamber within the first 20 min of exposure. The plasma cortisol concentration continued to increase for two hours ($P < 0.01$) and reached a plateau between two and four hours after the onset of heat stress. Marked elevations of plasma glucocorticoids have also been noted when cattle were acutely exposed to high environmental temperatures (Stott & Robinson, 1970; Christison & Johnson, 1972). Abilay *et al.* (1975) furthermore found a significant ($P < 0.01$) rise in plasma cortisol on the first day of heat exposure. These results are in agreement with those of Wise *et al.* (1988) who found higher serum cortisol levels in heat-stressed cows (outdoor corrals with access to shade only) compared to cows maintained under cool conditions in a refrigerated, air-conditioned barn.

Regressions of plasma cortisol levels (y) of shade and no-shade cows on daily maximum ambient temperatures (x) suggested that cortisol levels were increased ($P < 0.05$) on days with higher temperatures during the 1984/85 period only; the regression equations being $y = 1.5x - 15.82$, $R^2 = 0.36$ for shade cows and $y = 1.9x - 24.0$, $R^2 = 0.34$ for no-shade cows. During 1985/86, cortisol levels were not affected by high maximum ambient temperatures although there was a tendency for lower cortisol levels. These results may be related to different responses to acute and chronic heat stress as a result of altered adrenal metabolism (Beede & Collier, 1986). Christison & Johnson (1972) also indicated that, with chronic heat stress, plasma cortisol levels were significantly depressed ($P < 0.01$) compared to values at thermoneutrality (18 °C). Stott & Wiersma (1974) noted a similar trend in cattle exposed to a hot summer. Abilay *et al.* (1975) found that a prolonged heat exposure (33.5 °C) resulted in a general reduction effect of plasma cortisol concentrations. Collier *et al.* (1982) also found elevated glucocorticoid concentrations during acute but not chronic thermal stress.

Thyroxine concentration

There was no difference ($P > 0.05$) in plasma thyroxine levels during the 1984/85 and 1985/86 experimental periods between shade and no-shade cows, although the no-shade cows tended to have lower values (Table 2). The anterior lobe of the pituitary gland produces thyrotropin (TSH) that acts primarily on the thyroid gland to produce thyroxine [tetraiodothyronine (T_4) and triiodothyronine (T_3)]. These hormones influence different cellular processes in the body such as its calorigenic (heat-producing) activity that accounts for about 50% of the basal metabolic rate of normal animals. Certain physical stress factors tend to inhibit secretion of the thyroid gland (Frandson, 1974). The plasma thyroxine concentration of heat-stressed lactating cows in Egypt was increased by cooling cows (Aboulnaga *et al.*, 1989).

Under chronic thermal stress conditions the basal metabolic rate (energy metabolism) of cattle decreases, while there is an increase in water and electrolyte metabolism (Beede & Collier, 1986). These adaptations are reflected in lower concentrations of metabolic hormones such as T_4 (Bianca, 1965; Beede & Collier, 1986). It has been shown, however, that cool night-time conditions for four to five hours had a beneficial (increased) effect on plasma T_4 levels. These conditions probably allowed animals to recover from thermal stress. Maximum ambient temperature (x) reduced ($P < 0.01$) plasma T_4 levels (y) for shade and no-shade cows during the 1984/85 experimental period only. Regression equations for shade and no-shade cows were $y = 107.61 - 1.15x$, $R^2 = 0.24$ and $y = 128.67 - 2.02x$, $R^2 = 0.43$, respectively. T_4 was not affected ($P > 0.05$) during 1985/86 although a similar negative trend was observed. These results are generally in agreement with those obtained by Johnson (1980). It therefore seems that under local climatic conditions, T_4 concentration was not a useful indicator of heat stress.

Table 2 Average (± *SD*) plasma thyroxine (T_4) concentration for shade and no-shade cows during summer in a temperate climate

Experimental period	Thyroxine concentration (nmol T_4/l) Shade	No shade	SE_d	Significance
1984/85	77.43 ± 8.54	76.10 ± 8.15	3.73	$P > 0.05$
1985/86	75.87 ± 4.35	73.96 ± 9.28	3.79	$P > 0.05$
Overall mean	76.79 ± 6.98	75.03 ± 8.57	2.55	$P > 0.05$

SE_d: Standard error of difference.

Respiration rate

The respiration rates of shade and no-shade cows at different times of cool (maximum ambient temperature ≤25.0 °C) and hot (maximum ambient temperature ≥25.1 °C) days are presented in Table 3. On cool days there were no significant ($P > 0.05$) differences between shade and no-shade cows. On hot days, however, the average respiration rate of the no-shade cows was significantly higher at 09:00 ($P < 0.05$) and at 11:00, 13:00 and 15:00 ($P < 0.01$), with the greatest difference between shade and no-shade cows at 13:00. Berman & Morag (1971) found maximum respiration rates at 15:00 for high producing (30–35 kg milk/day) Holstein cows. This trend in respiration rate is similar to that shown by Roman-Ponce *et al.* (1977) from results obtained in Florida, USA. Respiration rates for shade and no-shade cows were, however, lower than reported by the latter author (approximately 75 and 115 inhalations/min at 12:00, respectively). Climatic conditions in Florida differ from local conditions, being subtropical with higher maximum ambient temperatures and higher relative

Table 3 Average (standard deviation) respiration rate of shade and no-shade cows at different times of the day

Days with maximum temperature	Hour	Respiration rate (inhalations/min) Shade cows	No-shade cows	Difference (no shade – shade)
≤25.0 °C				
$n = 8$	07:00	42.73 (4.78)	40.98 (7.80)	–1.75
	09:00	48.85 (9.78)	45.68 (9.51)	–3.17
	11:00	49.40 (8.58)	54.33 (11.37)	4.93
	13:00	52.98 (15.26)	53.60 (17.18)	0.62
	15:00	55.18 (9.67)	51.60 (10.15)	–3.58
	17:00	45.93 (8.52)	45.73 (11.04)	–0.20
	19:00	37.65 (8.53)	35.05 (8.40)	–2.60
≥25.1 °C				
$n = 16$	07:00	49.66 (6.93)	51.48 (8.20)	1.82
	09:00	60.18 (7.04)	65.55 (10.79)	5.37*
	11:00	62.00 (7.56)	75.36 (13.07)	13.36**
	13:00	63.66 (7.43)	80.99 (14.69)	17.33**
	15:00	66.20 (12.10)	77.59 (20.53)	11.39**
	17:00	60.94 (13.99)	62.25 (16.83)	1.31
	19:00	47.05 (8.86)	45.16 (9.55)	–1.89

* $P < 0.05$; ** $P < 0.01$.

humidity levels. In Israel, respiration rates of Holstein cows were found to be 59 ± 1 and 73 ± 2 inhalations/min in barns with forced ventilation and no ventilation, respectively (Berman *et al.*, 1985).

The regressions of respiration rate on maximum ambient temperature for shade and no-shade cows are presented in Figure 1. Respiration rate increased significantly ($P < 0.01$) with increasing ambient temperatures. This is in agreement with results obtained by Berman *et al.* (1985) with a relationship between respiration frequency (Rf) and ambient temperature (Ta) of $Rf = 0.5 + 2.5Ta$; $R^2 = 0.67$, $P < 0.01$. Harris *et al.* (1960) also reported that solar radiation was of considerable importance as a direct cause of increased respiration rates of both Jersey and Holstein cows in Texas, USA. According to McDowell (1972) the respiration rate of lactating Holstein cows increased by 194% from 32 inhalations/min in a cool environment (18 °C) to 94 inhalations/min in a hot (30 °C) environment.

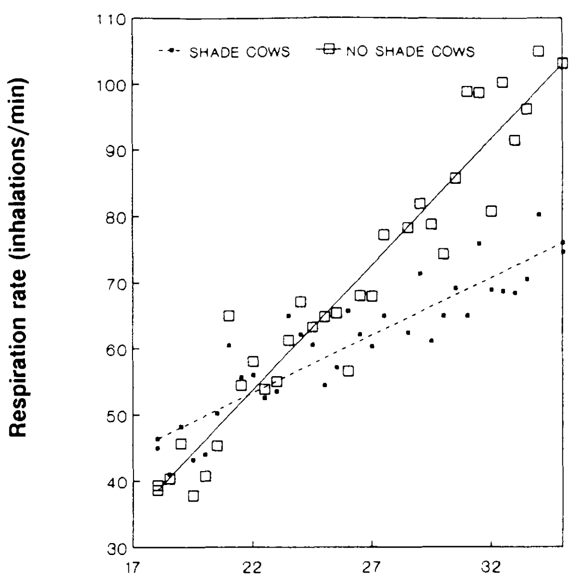

Figure 1 The effect of ambient temperature (x) on the respiration rate (y) of shade cows ($y = 14.92 + 1.75x$; $R^2 = 0.81$; $P < 0.01$) and no-shade cows ($y = -29.60 + 3.79x$; $R^2 = 0.92$; $P < 0.01$).

Rectal temperature

Under ambient conditions that do not impose severe heat stress the body temperature of dairy cattle is usually maintained within 1 °C of normal. Body temperature gradually rises at air temperatures above the critical temperature (24–26 °C). This is usually associated with a gradual deterioration of feed intake and productivity (Berman *et al.*, 1985). The rectal temperatures of shade and no-shade cows at different times of cool (maximum ambient temperature ≤25.0 °C) and hot (maximum ambient temperature ≥25.1 °C) days are presented in Table 4. On days with cool climatic conditions there was no difference between shade and no-shade cows at different times of the day. On hot days the average rectal temperatures of shade and no-shade cows differed significantly at 07:00 ($P < 0.05$) and at 11:00, 13:00 and 15:00 ($P < 0.01$).

Table 4 Average (standard deviation) rectal temperatures of shade and no-shade cows at different times of the day

Days with max. temp. (°C)	Hour	Rectal temperature (°C) Shade cows	No-shade cows	Difference (no shade – shade)
≤25.0 °C				
$n = 8$	07:00	38.39 (0.21)	38.40 (0.05)	0.01
	09:00	38.48 (0.19)	38.42 (0.11)	–0.06
	11:00	38.38 (0.13)	38.45 (0.11)	0.07
	13:00	38.58 (0.13)	38.54 (0.13)	–0.04
	15:00	38.55 (0.15)	38.63 (0.17)	0.08
	17:00	38.76 (0.12)	38.79 (0.04)	0.03
	19:00	38.82 (0.13)	38.89 (0.20)	0.07
≥25.1 °C				
$n = 16$	07:00	38.50 (0.10)	38.44 (0.12)	–0.06*
	09:00	38.57 (0.14)	38.57 (0.17)	0.00
	11:00	38.47 (0.12)	38.71 (0.27)	0.24**
	13:00	38.68 (0.23)	38.99 (0.27)	0.31**
	15:00	38.69 (0.21)	39.05 (0.41)	0.36**
	17:00	39.05 (0.28)	39.08 (0.34)	0.03
	19:00	38.99 (0.27)	39.03 (0.32)	0.04

* $P < 0.05$; ** $P < 0.01$.

The difference in rectal temperature at 07:00 is probably coincidental, and not due to environmental conditions. The average ambient temperature at that time of the day was 16.0 °C, which falls within the thermal comfort range of 13–18 °C for dairy cattle (McDowell, 1972).

Owing to a significant ($P < 0.01$) increase in rectal temperature of the shade cows from 15:00 to 17:00, there was no difference in rectal temperatures between shade and no-shade cows at 17:00 and 19:00. Both groups of cows were moved to the milking parlour for blood sampling and milking at the same time (15:15), and the rectal temperature of the shade cows probably increased owing to this activity during the hottest time of the day.

Both groups showed a significant ($P < 0.01$) increase in rectal temperature from 07:00 to 19:00. These results are in agreement with those for Jersey and Holstein cows under shade and no-shade conditions in Florida, USA (Roman-Ponce *et al.*, 1977). No-shade cows exhibited peaks in respiration rate and rectal temperature at midday (13:00), while shade cows had peak rectal temperatures during the late afternoon.

The regressions of rectal temperature on ambient temperature in shade and no-shade cows are presented in Figure 2. Rectal temperatures of both groups increased significantly ($P < 0.01$) with increasing ambient temperatures. Ambient temperature affected the rectal temperature of no-shade cows to a greater extent (0.064 vs. 0.025 °C / 1 °C increase in ambient temperature) than that of shade cows. This is in agreement with results obtained by Berman *et al.* (1985) who noted that different responses to a given ambient temperature may arise from the nature of animal shelter systems. In a roofed (shaded) area in Israel, the thermal load was significantly less than in a sun-exposed yard. Little effect on rectal temperature was noted at ambient temperatures below 24 °C. A gradual rise in rectal temperature was, however, evident at higher ambient temperatures (>25–26 °C). This temperature

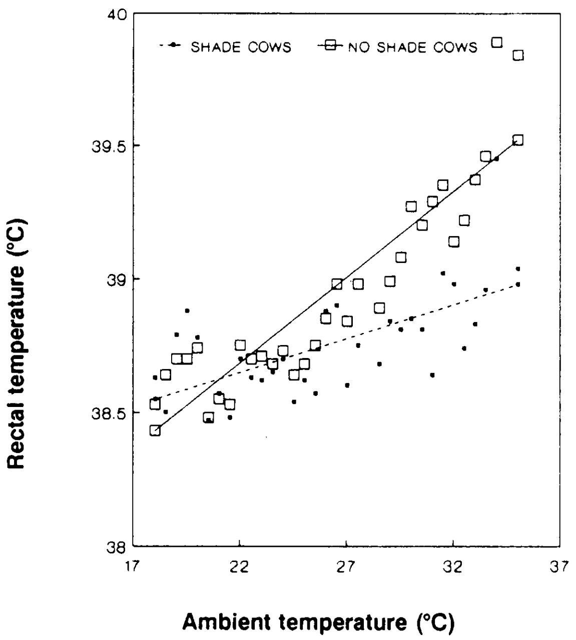

Figure 2 The effect of ambient temperature (x) on rectal temperature (y) of shade cows ($y = 38.10 + 0.025x$; $R^2 = 0.40$; $P < 0.01$) and no-shade cows ($y = 37.28 + 0.064x$; $R^2 = 0.80$; $P < 0.01$).

was therefore suggested to be the upper limit of ambient temperature at which Holstein cattle may maintain stability of body temperature (Berman *et al.*, 1985). Zoa-Mboe *et al.* (1989) also found higher respiration rates and rectal temperatures in no-shade cows in comparison to shade cows. The rectal temperature measured between 14:00 and 15:00 was 39.6°C for shade cows and 40.2 °C for no-shade cows.

Conclusions

The physiological parameters measured in the present study clearly suggest that lactating dairy cows are sensitive to heat stress, even in a temperate climate. The provision of a shade structure resulted in various physiological responses, as shade cows maintained lower plasma cortisol concentrations, as well as lower rectal temperatures and respiration rates during periods of peak heat stress. The increased rectal temperatures of shaded cows between 15:00 and 17:00 indicate that attempts should be made to cool animals in the milking parlour or on exiting from the milking parlour by spraying them with water. The holding area should also be shaded. Observed physiological responses were also reflected in enhanced levels of animal production and economic efficiency.

Acknowledgements

The authors thank the Elsenburg Bio- and Datametrical Section, particularly Mr D. Capatos, for statistical advice, and Mr A. van Rooyen for datametrical services. Mr A.H.C. Shipman and milkers are also thanked for help with the practical execution of the experiment.

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