*Aust. J. Biol. Sci.*, 1980, **33**, 449–56

# Effects of Heat Stress on the Lactation Performance of Ewes Accustomed to Tropical Conditions and the Total Fluid Intake of their Lambs

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*Abstract*

The impact of heat stress on the feed intake, milk production, water intake and urine output of undernourished lactating ewes and on the growth rate and water intake of their lambs was measured both in a climate chamber and during exposure to natural high ambient temperature conditions. Similar liveweight increases occurred in both stressed and unstressed lambs. Feed intake was depressed in heat-stressed ewes in the climate chamber but not under natural heat-stress conditions. During the first and second weeks of lactation calculated milk yield (200–500 ml/day) and composition were unaffected by heat stress *per se*. However, undernutrition due to the poor quality roughage offered apparently depressed milk production of all ewes. Increased water intake (27%) and plasma prolactin concentrations (220%) were recorded in heat-stressed ewes, but daily urine output (27–36 ml/kg body wt) was unaffected. No relationship between prolactin concentrations, milk production and antidiuretic activity was obvious. At the age of 5–6 weeks water intake accounted for 67% (500 ml/day) and 80% (1000 ml/day) of total fluid intake (water plus milk) of unstressed and heat-stressed lambs respectively. These data indicate the importance of making water freely available to lambs subjected to extensive grazing systems of tropical regions.

## Introduction

Climatic extremes and nutritional inadequacies characterize the semi-arid sheep-breeding country of tropical Australia (Moule 1950). One effect of this harsh environment on animal production is low lamb survival (e.g. Moule 1954 found a total loss between birth and marking of 36·4% of lambs born), and poor milk production of ewes—300–500 ml/day (Stephenson, unpublished data). Hopkins *et al.* (1980) have described the survival of lambs in relation to the rectal temperatures and respiratory rates of their dams during exposure to tropical summer conditions.

Macfarlane *et al.* (1956, 1958) have described the water intakes of non-lactating sheep under semi-arid conditions. No measurements of this parameter have been made in lactating ewes and their lambs under these conditions. The role of prolactin in water homeostasis has been described by Labella *et al.* (1975) and Hooley *et al.* (1978) have indicated the importance of circulating prolactin concentrations for maintaining lactation in the ewe.

These studies were designed to evaluate the limitations that hot environments impose on lactating sheep accustomed to tropical conditions and their lambs. In the first experiment the controlled environment of a climate chamber was used to determine the effect of heat stress on yield and composition of milk, feed intake, water intake, urine output, lamb growth rate and ewe plasma prolactin concentration. In the second experiment similar measurements were made under natural conditions of high ambient temperature, low relative humidity and high solar radiation.

## Materials and Methods

The following experiments were conducted at the 'Toorak' Research Station in north-western Queensland (long. 141°E.; lat. 21°S.) where mean monthly maximum temperatures exceed 35°C for 6 months of the year. Sheep used in the experiments were representative of those normally depastured on the vast, almost treeless plains. To reflect the nutritional status of these sheep when pastures are dry during the latter half of the year all ewes in the experiments were fed chopped native Flinders grass hay (*Iseilema* spp.). Digestibility of this roughage was 41% and nitrogen content 0·76% (Stephenson, unpublished data).

*Experiment 1*

Twenty Merino ewes and their 1- to 3-day-old September-born lambs were penned indoors for 4 days and subjected to the natural, mild temperature (18–30°C) and humidity (30–70%) fluctuations (thermoneutral conditions). Ewes were then stratified according to milk yield into two groups of equal lactation performance. Group I was housed for a further 4 days in an adjacent climate chamber where the ambient temperature and relative humidity were regulated to induce the degree of hyperthermia experienced in sheep exposed to the natural summer climate: viz. rectal temperature elevated by 0·5–1·0°C for 8–10 h/day (Hopkins *et al.* 1978). Group II remained in the thermoneutral conditions for the duration of the experiment. Ewe liveweights were measured at the commencement of the experiment. Lamb liveweights were monitored throughout.

Respiratory rates and rectal temperatures were measured once each day at the time of maximum heat load. Milk yields (4-h test, McCance 1959) were measured by administering 5 i.u. of oxytocin intravenously at the commencement of and during each hand-milking operation. Milk samples were stored at 0°C and assayed for protein and fat content (Australian Standards 1974). Feed and water intake and urine output of three ewes and their lambs in each group were monitored daily during the experiment. An empty metabolism cage was used to correct for evaporative water loss and procedural losses in urine collection. The feed intake of the ewes in the climate chamber progressively declined during the course of the experiment. Between-group differences in intake were minimized by feeding the control animals a restricted intake of the ration.

Jugular vein samples were taken via indwelling Silastic cannulae. Five ewes in each group were bled on eight occasions during 2 days pretreatment, and on nine occasions during 2 days of heat treatment (Fig. 1). The plasma was assayed for prolactin concentrations by the radioimmunoassay of Hooley *et al.* (1979). The within-assay variation was less than 15% over the range 0·6±0·1–13·6±2·2 ng per tube (mean ± s.e.m.) and the samples were diluted to fit this range. Three plasma pools were assayed repeatedly to measure between-assay variation and these read 90·2±29·0 ($n = 14$), 95·9±8·5 ($n = 8$) and 61·7±3·6 ng/ml ($n = 10$). The sensitivity of the prolactin assay was 0·2 ng/ml (0·02 ng per tube) using NIH-P-S8 standard.

*Experiment 2*

Fourteen ewes which had lambed 14–21 days previously and were similar to those used in experiment 1 were housed with their lambs in metabolism cages. Drinking water for lambs was made inaccessible to the ewes by means of a creep, while the elevated water and feed containers of the ewes were inaccessible to the lambs. As in experiment 1, ewes were stratified into two groups on the basis of milk yield measured after 4 days pretreatment. One group (unshaded) was moved outside and subjected to the summer climate for 17 days. Weather conditions during the first 5 days (acclimation period) caused heat stress; 6 days of relatively mild conditions followed (period 1); then another 6 days of high ambient temperatures (period 2) which again caused heat stress in ewes and lambs. The second group (shaded) remained indoors under marginally higher temperatures and lower humidity conditions than those recorded in group 2 of experiment 1 (average daily maximum–minimum temperature range 38·5–22·0°C, average relative humidity 33%). Mean ± s.e. (kg) liveweight of unshaded and shaded ewes was 27·5±1·8 and 27·0±1·0 respectively.

The cardinal indices of environmental physiology (rectal temperature, respiration rate and water intake) were not measured during the acclimation period when animals were allowed to adjust to experimental conditions. Measurements similar to those in experiment 1 were subsequently made in ewes (periods 1 and 2) and in lambs (period 2). Corrections were made for water and urine losses as in experiment 1. Ewe milk yields were measured during the acclimation period and at the end of period 2. The same diet as fed in experiment 1 was offered *ad libitum*. Lamb growth rates were

recorded for each period. Three lambs in the unshaded group died during the last 2 days of the experiment. Growth rate in this group was calculated on the four survivors.

Statistical analysis of the data was made using the unpaired *t*-test.

## Results

*Experiment 1*

Mean daily respiration rates and rectal temperatures were significantly greater ($P < 0{\cdot}01$) in the ewes housed in the climate chamber than in the thermoneutral room (Table 1). The data are indicative of animals experiencing heat stress. Water intake of these ewes was also significantly greater ($P < 0{\cdot}01$). However, there was no significant difference in the output of urine between the two groups ($P > 0{\cdot}05$).

**Table 1. Effect of increased ambient temperature and relative humidity on various parameters of lactating ewes**

Values given are means ± s.e. for 10 ewes and were recorded daily for 4 days (expt 1). Mean ± s.e. of similar parameters with the same superscript do not differ significantly ($P > 0{\cdot}05$)

| Parameter | Group I (climate chamber) | Group II (thermoneutral) |
|---|---|---|
| Respiration rate (per min) | $156^{a} \pm 10{\cdot}9$ | $53^{b} \pm 7{\cdot}9$ |
| Rectal temperature (°C) | $40{\cdot}7^{a} \pm 0{\cdot}36$ | $39{\cdot}8^{b} \pm 0{\cdot}81$ |
| Milk yield (ml/4 h)[A] | $80^{a} \pm 6{\cdot}7$ | $82^{a} \pm 8{\cdot}6$ |
| Milk protein (g/100 ml) | $5{\cdot}3^{a} \pm 0{\cdot}25$ | $5{\cdot}0^{a} \pm 0{\cdot}31$ |
| Milk fat (g/100 ml) | $10{\cdot}8^{a} \pm 1{\cdot}28$ | $8{\cdot}6^{a} \pm 0{\cdot}46$ |
| Feed intake (g/day) | $428^{a} \pm 80$ | $510^{b} \pm 61$ |
| Daily water intake (ml/kg) | $114^{a} \pm 2{\cdot}3$ | $90^{b} \pm 5{\cdot}1$ |
| Daily urine output (ml/kg) | $37^{a} \pm 0{\cdot}6$ | $36^{a} \pm 2{\cdot}2$ |

[A] Milk yield and composition measurements were made on the last day of the experiment.

The voluntary feed intake of the ewes in the climate chamber declined significantly ($P < 0{\cdot}01$) from a pretreatment mean ± s.e. of $803 \pm 79$ g/day to $268 \pm 42$ on the fourth day of heat stress. The feed intake of the control ewes was reduced from a voluntary pretreatment mean ± s.e. of $760 \pm 140$ g/day to a restricted intake mean of $410 \pm 30$ on the fourth day of the experiment, so that total feed intake over the experiment did not differ significantly between groups (Table 1).

The plasma prolactin levels of heat-stressed ewes were significantly elevated above those of control ewes ($P < 0{\cdot}01$), except for the first sampling after the commencement of heat stress (Fig. 1).

Table 1 shows that mean milk yields and composition (protein and fat) did not differ significantly between groups during the experiment period ($P > 0{\cdot}05$). Mean yields fell significantly during the experiment ($P < 0{\cdot}05$), but the fall was similar in both groups ($r = 0{\cdot}993$, Table 3).

Ewe liveweight at the commencement of the experiment was $33{\cdot}1 \pm 1{\cdot}9$ and $29{\cdot}8 \pm 1{\cdot}1$ kg for group 1 and group 2 respectively. Lamb liveweights increased during the experimental period in both groups. At no recording was there a significant difference in liveweight or growth rate between groups ($P > 0{\cdot}05$); the liveweight means ± s.e. (g) were $3530 \pm 130$, $3770 \pm 140$ and $3860 \pm 130$ for heat-stressed lambs

and 3600 ± 240, 3820 ± 260 and 4140 ± 310 for non-heat-stressed lambs at the commencement of the pretreatment and treatment periods, and at the termination of the experiment respectively.

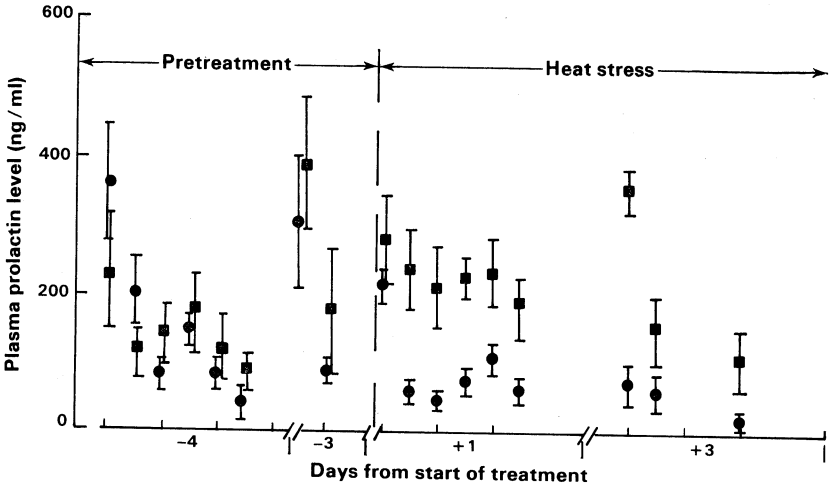


**Fig. 1.** Effect of heat stress on mean (± s.e.) plasma prolactin levels of 10 ewes. In the pretreatment period all ewes were in a thermoneutral environment; in the period of heat stress ewes were kept in either a hot (■) or thermoneutral (●) environment.

*Experiment 2*

As respiration rates and rectal temperatures of ewes and lambs in the unshaded group varied in accordance with daily climatic conditions the results were divided into two periods—period 1 with relatively mild conditions, and period 2 with high ambient temperatures (Table 2). Significant differences ($P < 0{\cdot}05$) in the rectal temperatures and respiration rates of unshaded and shaded ewes and lambs were observed during period 2. Respiratory rates but not rectal temperatures were significantly different in the cooler period 1. Similarly, significant differences in water intake of ewes occurred only during period 2 ($P < 0{\cdot}05$). Water intake of unshaded ewes and lambs was significantly greater than that of the shaded animals during period 2 ($P < 0{\cdot}01$).

Feed intakes of ewes (*c.* 660 g/day) remained unchanged throughout the experiment and there were no significant differences between groups. Large variations in the urine output of ewes occurred in both groups but no significant differences were measured (Table 2). As in experiment 1 there was a significant but similar fall in the milk yield of both groups (Table 3).

The liveweight of surviving lambs increased in all periods in both groups. No significant differences in liveweight or growth rate occurred between groups at any of the four recordings ($P > 0{\cdot}05$); the liveweight means ± s.e. (g) were 5100 ± 410, 5240 ± 420, 5560 ± 430 and 5710 ± 620 g/day for unshaded, and 4700 ± 760, 4990 ± 360, 5210 ± 410 and 5380 ± 350 g/day for shaded lambs at the commencement of acclimation period, period 1, period 2 and at the end of the experiment respectively. Three of the seven unshaded lambs died. Initial milk yield of dams of non-survivors was

37 ± 3 ml/4 h. These yields were the lowest in the group. Although no lambs in the shaded group died, three ewes in this group also yielded only 40 ± 3 ml milk/4 h.

**Table 2. Mean maximum ambient temperature and ewe and lamb parameters of unshaded and shaded groups**

Values are means ± s.e. for seven ewes and seven lambs (expt 2). Mean ± s.e. of similar column parameters with the same superscript do not differ significantly ($P > 0.05$)

| Parameter | Treatment group | Ewes (period 1) | Ewes (period 2) | Lambs (period 2) |
|---|---|---|---|---|
| Maximum ambient temperature (°C)[A] | Unshaded | 43·8 ± 0·63 | 49·3 ± 0·94 | |
| | Shaded | 37·1 ± 0·73 | 39·9 ± 0·60 | |
| Rectal temperature (°C) | Unshaded | 39·7[a] ± 0·31 | 40·5[b] ± 0·18 | 40·9[b] ± 0·34 |
| | Shaded | 39·5[a] ± 0·52 | 39·5[a] ± 0·63 | 39·6[a] ± 0·61 |
| Respiration rate (per min) | Unshaded | 100[b] ± 3·1 | 136[b] ± 5·2 | 155[b] ± 3·7 |
| | Shaded | 46[a] ± 2·3 | 54[a] ± 5·6 | 42[a] ± 3·1 |
| Daily water intake (ml/kg) | Unshaded | 107[a] ± 4·0 | 103[b] ± 3·6 | 175[b] ± 4·2 |
| | Shaded | 105[a] ± 12·9 | 82[a] ± 5·8 | 94[a] ± 3·7 |
| Feed intake (g/day) | Unshaded | 669[a] ± 73 | 692[a] ± 55 | n.d.[B] |
| | Shaded | 653[a] ± 54 | 638[a] ± 57 | n.d. |
| Daily urine output (ml/kg) | Unshaded | n.d. | 28[a] ± 5·3 | n.d. |
| | Shaded | n.d. | 27[a] ± 3·5 | n.d. |

[A] Mean of six recordings. [B] Not determined.

**Table 3. Milk yield of heat-stressed and non-heat-stressed ewes**

Number of ewes in each treatment group given in parentheses. Values given are means ± s.e. No significant difference occurred between groups in either experiment

| Expt No. | Treatment group | Milk yield (ml/4 h) Pretreatment | Exptl period |
|---|---|---|---|
| 1 | Thermoneutral (10) | 125 ± 6·4 | 82 ± 8·6 |
| | Climate chamber (10) | 129 ± 7·4 | 80 ± 6·7 |
| 2 | Unshaded (7)[A] | 50 ± 7·8 | 25 ± 2·4 |
| | Shaded (7) | 53 ± 4·7 | 29 ± 4·8 |

[A] Ewes were heat-stressed during the experimental period.

## Discussion

Both the artificial and natural heat treatments imposed in these experiments caused heat stress in ewes. This effect was demonstrated in both experiments by marked increases in rectal temperature, respiration rate and water intake of ewes. The average daily amount of water used in milk synthesis (*c.* 400 ml; 14 ml/kg) was only 13–18% of total daily water intake of these ewes. Nutritional restrictions had already reduced milk production to a low level and any effect due to heat stress was apparently countered by other mechanisms controlling lactation.

Experiment 1 lambs were observed to drink regularly from water troughs. This observation, together with the degree of hyperthermia observed in heat-stressed lambs, suggested that fluid derived from the milk secretion of poorly nourished ewes is inadequate to provide the total fluid requirements of such lambs. In experiment 2 the total daily fluid intake of unshaded lambs (200 ml/kg) was calculated from daily

water intake of 175 ml/kg plus milk intake of 25 ml/kg. These values are derived from lamb liveweights and milk yields recorded at the end of the experiment. In contrast, the total daily fluid intake of shaded lambs was 124 ml/kg, calculated from daily water intake of 94 ml/kg plus daily milk intake of 30 ml/kg. Water accounted for 80 and 67% of total fluid intake of unshaded and shaded lambs respectively. The extra water intake of unshaded lambs was associated with extreme hyperthermia (*c.* 40·9°C) when high ambient temperatures prevailed (period 2; Table 2). Under extensive grazing conditions in tropical Queensland ewes and lambs are often away from water for long periods.

Previous studies under paddock conditions have reported hyperthermia in unshaded lambs (Smith 1961; Hopkins 1969) and deaths due to starvation (Moule 1954). The results of experiment 2 suggest that the low milk (nutrient) intakes of lambs in the heat-stressed group have been exacerbated by the effects of heat stress. Mortalities were observed in the heat-stressed lambs of ewes producing 37 ml milk/h. No such losses occurred in non-heat-stressed lambs whose mothers were producing similar volumes of milk.

Milk yield of ewes in both experiments did not differ between treatments. In experiment 1 milk protein and milk fat were unaffected by heat treatment. Although milk fat tended to be higher (10–12%) in the heat-stressed group, all other values were within the normal reported range (Pattie and Trimmer 1964). This indicates that ambient temperature did not affect milk composition. However, the significant decline of milk yield in each group in both experiments (3–5% per day) suggests that the poor quality diet was inadequate to maintain lactation. In earlier paddock studies in which milk yields and lamb growth rates were similar to those reported in this study, supplementation to improve ewe milk yields significantly improved lamb survival and growth rate during 2 months of high ambient temperatures (Stephenson and Hopkins 1978). It is apparent from these results that the availability of milk (nutrient) and water are both important factors affecting lamb growth and survival.

The marked decrease in voluntary food consumption of heat-stressed ewes in experiment 1 did not occur with their counterparts in experiment 2. Thwaites (1968) found depression of voluntary food consumption in sheep exposed to hot environments in a climate chamber which is in agreement with measurements in experiment 1. However, Arnold (1962) and Lorimer (1976) found that diurnal grazing patterns, but not feed intake of paddock sheep, were affected by high ambient temperatures.

The range of variation in urine excretion between sheep is similar to that reported by Hopkins *et al.* (1978), but there were no differences between treatments in these experiments. This is probably due to the obligatory higher water turnover of lactating sheep, as Macfarlane *et al.* (1958) report lower values for dry sheep exposed and acclimatized to summer conditions.

The elevated prolactin levels observed in the heat-stressed lactating ewes of experiment 1 are similar to previous findings for heat-stressed, non-pregnant or ovariectomized ewes (Schillo *et al.* 1978; Hooley *et al.* 1979). The basal plasma prolactin concentrations of the non-heat-stressed ewes in this study are similar to levels measured in lactating ewes elsewhere (Fell *et al.* 1972). It would be unlikely that elevated prolactin levels influence milk yield in these experiments, since Morag *et al.* (1971) found that elevated prolactin levels did not improve milk yields of ewes. In this study individual prolactin levels did not show any significant correlations with water intake, milk production or urine output.

The results of these experiments suggest that heat stress *per se* does not significantly affect the milk yield or milk composition of ewes fed a poor quality ration. Although high ambient temperatures cause heat stress in lambs, their viability depends largely on the level of milk intake and the provision of adequate water. Poor nutrition, inadequate watering facilities and high ambient temperatures can all prevail at lambing time throughout much of the semi-arid tropics, and contribute to the poor productivity of Merinos depastured in the area.

## Acknowledgments

The technical assistance of Messrs J. C. Edwards and B. W. Doughton and of Miss E. Wilson is gratefully acknowledged. This work was supported by a grant from the Wool Research Trust Fund on the recommendation of the Australian Wool Corporation.

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Manuscript received 17 September 1979, accepted 16 May 1980