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Effect of season on thermoregulatory responses and energy expenditure of goats on semi-arid range in India

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SUMMARY

A study of the physiological responses and energy expenditure of goats was carried out from June 1999 to May 2000 by conducting two experiments: one on bucks maintained on stall feeding in autumn 1999 (Expt 1) followed by year-round grazing on native ranges over three seasons: monsoon, winter and summer (Expt 2). Physiological responses and energy expenditure (EE) measurements of housed and grazing goats were recorded at 06.00 h and 14.00 h for 5 consecutive days in each season. Goats were fixed with a face mask and meteorological balloon for collection of expired air and measurement of EE. Respiration rate (RR) at 06.00 h was similar in all seasons (14 respiration/min) except in the monsoon, where a significantly ($P < 0{\cdot}05$) higher value (26 respiration/min) was recorded. At 14.00 h, RR was higher in monsoon and summer (81 and 91 respiration/min) than in winter (52 respiration/min). Irrespective of the season, heart rate (HR) was higher at 14.00 h (86 beat/min) than at 06.00 h (64 beat/min). The rise of rectal temperature (RT) from morning (06.00 h) to peak daily temperature (14.00 h) was 0·9 °C in housed goats in autumn and 1·0, 2·1 and 2·0 °C in grazing goats during monsoon, winter and summer, respectively. The mean value was 1·7 °C. Skin temperature (ST) was lowest in winter (30·1 °C) and highest at 14.00 h in summer (40·3 °C). Energy expenditure of goats at 06.00 h was 32·7 W in winter and significantly ($P < 0{\cdot}05$) increased to 52·0 W in summer and 107·8 W in monsoon. At 14.00 h, EE was 140·2 W in winter and increased to 389·0 W and 391·3 W respectively in monsoon and summer. It is concluded that monsoon and summer are both stressful seasons in semi-arid regions. Animals should be protected from direct solar radiation during the hottest hours of the day to ameliorate the effect of heat stress.

INTRODUCTION

Grazing of animals is one of the most practical ways of exploiting the natural vegetation in the semi-arid region of India. Most of the goat flocks are maintained on native ranges under an extensive system. Goats perform well under harsh climatic and sparse vegetation conditions because of their opportunistic and selective grazing behaviour. They are able to maintain a constant level of energy and nutrient intake, despite wide fluctuation in supply from these ranges (Shinde *et al*. 2000). Under free grazing, they are exposed to wide environmental temperatures ranging from 10 °C in winter to 45 °C in summer and sustain intense muscular activity while travelling long distances during feed scarcity. Thermal environment and muscular activity usually raise energy expenditure by at least 1·5 times the equivalent for pen-fed animals (White 1993). Little information on energy expenditure of goats on pasture is available. Moreover, data which have been published pertain to specific climatic conditions and are of little application for other climatic and grazing situations because of wide variation in biotic and abiotic components. No information on energy expenditure of native goats reared under harsh environmental conditions of semi-arid regions of India is available. Such knowledge is required for the understanding of animal energetics and development of a suitable system of grazing management. The present study was designed to examine these issues.

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MATERIALS AND METHODS

Two experiments for measurement of energy expenditure (EE) in Kutchi goats were conducted. The first was based on a maintenance ration under stall feeding and the second on range grazing during three seasons, *viz*. monsoon, winter and summer. The study was carried out at the Central Sheep and Wool Research Institute, Avikanagar, India from June 1999 to May 2000. The station is located at 75°28′E, 26°17′N and 320 m a.s.l. in a semi-arid region. The annual minimum and maximum temperatures and precipitation of the region ranges from 6 to 26, 23 to 42 °C and 350 mm, respectively.

Experiment 1

The experiment was conducted in the autumn (September), when the ambient conditions were comfortable (minimum temperature 14 °C, maximum temperature 36 °C and relative humidity 49%). Four bucks (3–4 years old) with a mean body weight of 55 kg, maintained under free grazing, were randomly selected for the study. They were housed in an open-sided and asbestos-roofed shed. Individual goats were fed on the amount of ration (500 g concentrate mixture and 900 g dry *Zizyphus nummularia* leaves) calculated to meet their maintenance requirement (Ranjhan 1998). The total quantity of feed was offered in two equal portions at 08.00 and 15.00 h. Goats had free access to drinking water. Meteorological observations, EE and physiological measurements were recorded at 06.00 and 14.00 h for 5 consecutive days.

Experiment 2

The grazing experiment was initiated in June 1999 and continued up to May 2000, encompassing one each of monsoon, winter and summer seasons. The bucks were allowed to graze all year on native range along with 100 does except during autumn, when they were moved to stalls for conducting Expt. 1. The animals were allowed 9 h of grazing (08.00 to 17.00 h) following a continuous grazing system. Animals were grazed on a 35-ha plot of native range dominated by *Prosopis cineraria*, *Acacia senegal*, *Gymnosporia spinosa* and *Acacia tortolis* shrubs and *Melilotus indica*, *Tribulus terrestris*, *Crotolaria burhia* and *Indigofera cordifolia* grasses and forbs. Average yield of range including shrub foliage and ground vegetation was 1200, 2600 and 1760 kg DM/ha during monsoon, winter and summer respectively. Range vegetation remains green during monsoon, stemmy and mature during winter and dries and withers during summer. Shrub foliage was available throughout the year, but utilization by the goats was maximal in winter.

Meteorological observations, physiological responses and EE measurements were recorded at 06.00 h in the shed and at 14.00 h in the range for 5 consecutive days during monsoon, winter and summer seasons.

Meteorological observations

A black globe thermometer (BGT) consists of a thermometer in the centre of a 155-mm diameter hollow copper sphere and is used for measuring net radiation impinging on the animal. The globe was hung at animal height in the shed as well as in the field. Dry and wet temperatures were recorded using a wet and dry bulb-thermometer. Relative humidity was calculated from dry and wet temperatures. Temperature–humidity index (THI) was calculated by the formula of McDowell (1972)

$$\text{THI} = 0{\cdot}72\,(\text{wb}+\text{db})+40{\cdot}6$$

where wb = wet bulb temperature and db = dry bulb temperature in °C.

Physiological measurements

Respiration rate (RR) was measured by counting thoracic and flank movements and heart rate (HR) by using a stethoscope placed on the ventro-lateral thorax. Rectal temperatures (RT) and skin temperatures (ST) were measured twice daily at 06.00 h and 14.00 h using a multi-channel tele-thermometer. Thermal contact was enhanced by shaving off the hair in the selected site, washing the skin with alcohol and applying a conducting jelly to the probe. The probe was held in place by adhesive tape.

Collection of expired air

Expired air was collected by a face mask manufactured in the laboratory and was made from transparent polyvinyl chloride sheet. The mask was attached to the animals by means of an adapter, which was sufficient to prevent air escaping from the top of the mask. Two lateral inlet valves (10-mm diameter) are fixed at the level of nostrils and one outlet valve (30-mm diameter) is fixed in the middle of the face mask. These valves separate the air stream and ensure free movement of air without any distress to the animals. The outlet valve is connected to a meteorological balloon by a 1-m long corrugated pipe (30-mm diameter). Breathing rate was determined with the mask on by counting the flap movement in the outlet valve during three 1-min intervals. Without the mask, the recording was carried out in a similar way by counting the movement of the animal flanks. Both the recordings were made on the animal while quietly standing; no abnormal behaviour was detected as a result of wearing the mask. The breathing rate was similar both with and without the mask.

The animals used for the experiment were accustomed to the mask for a period of one week before recordings of expired air were made. The dead space in the mask and connecting tube was determined. The dead space was adjusted so as to prevent any alteration in breathing pattern.

During the gaseous exchange measurements, the air-tight end of the mask was fixed to the animal's face with an adapter. The expired air was collected in a balloon of 30–35 litre capacity for 5–10 min in each recording until the balloon was completely filled but not distended. In the field, goats were held without chasing them, so that it was possible to obtain a satisfactory recording of expired air that was not affected by extreme activity such as running. The volume of air in the balloon was determined and corrected for standard temperature and pressure. The O_2 content of expired air was determined using a Haldane gas analyser.

Energy expenditure (kJ) was calculated according to the formula of Young & Webster (1963):

$$EE = 20{\cdot}28 \times VO_2$$

where VO_2 = volume of O_2 consumed at standard temperature and pressure.

Statistical analysis

Data on physiological parameters and energy expenditure were analysed by one way analysis of variance with season as the main effect in a complete randomized block design using the SPSS package. The day-to-day variation was avoided by considering the days with similar dry bulb temperature and relative humidity in a season. The significant differences between seasonal means were tested at $P < 0{\cdot}05$. Linear regression was used to describe the relationship between dry bulb temperatures with rectal temperature. An exponential model was used to describe the relationship between dry bulb temperature and energy expenditure and rectal temperature and energy expenditure.

RESULTS AND DISCUSSION

Stall-fed goats

In Expt 1, goats were stall-fed on a maintenance ration in a shed during the autumn. Animals were thus protected from exposure to intense solar radiation and walking. The temperature and humidity in the autumn season of the semi-arid region were neither too high nor low (see Table 1). The critical dry bulb (that point at which an animal must increase its heat production to prevent body temperature from rising) temperature range for goats is 20–26 °C (Brody 1945). As Table 1 shows, the dry bulb temperature at 06.00 h was 4 °C below the lower critical temperature (LCT) and by 14.00 h is 9 °C above. Over this period, respiration rates ranged from 10·6 and 25·8. This was probably to dissipate body heat by respiratory evaporation (Abdel *et al.* 1995). Heart rate increased from 55·0 to 65·2 b.p.m. (Table 2). In part this might be to increase circulation to skin, encouraging cutaneous evaporative cooling (Sano *et al.* 1983). However, another factor might be to increase blood supply to respiratory muscles, to meet the increased energy needs. Da Silva & Minoma (1995) reported diurnal variation in RT of animals related to ambient temperature with minimum value in the morning hours and maximum in afternoon. The rectal temperature rose only 0·9 °C but EE more than doubled (38·0 to 81·3 W). Rises of EE per unit rise in RT, DBT, BGT and THI are shown in Table 2. Rajpoot (1978) reported 96·4 W as maintenance EE of Indian goats. The difference could be due to differences in DBT, breed, type, body condition or diet. Blaxter & Joyce (1963) reported that 50–60% of increase in metabolic rate was due to feeding (in sheep). Assuming on this basis that 60% of the increased EE between 06.00 h and 14.00 h is due to eating, the remaining rise 0·4 (81·3 − 38·0) or 17·3 W appears to be due to the 9 °C rise in DBT above the critical temperature. Thus, even in autumn, energy expenditure increased substantially at the hottest part of the day in a well-protected shed.

Grazing goats

In Expt 2, goats were freely grazed on the open range during the day and herded in a shed during the night. They were exposed to a wide range of ambient conditions in different seasons. Dry bulb temperature at 06.00 h (Table 1) was already near the upper critical temperature in the monsoon and summer but below the lower critical temperature in the winter. However, respiration rates were elevated only in the monsoon (see Table 3). In winter although the DBT had risen by 10·7 °C by 14.00 h, it still remained below the upper critical temperature. Nevertheless the RR was markedly greater than at 06.00 h. In the monsoon and summer seasons, the temperature at 14.00 h was well above the upper critical temperature and RR rose markedly. RR was highest in the summer (91·4 resp./min; Table 3), when DBT reached 39 °C and 88·5 THI than in the monsoon (81·2 resp./min) when DBT was 31 °C and THI 82·1. Dahlanuddin (1993) reported that goats approached the limit of heat tolerance at 40 °C DBT, with RR of 166. RR in these conditions was appreciably below this limit. However as the EE studies (see below) indicate, there may be a rapid rise near the limit of tolerance. Heart rate at 06.00 h was higher in winter than in summer, probably to meet the energy demands of the lower winter temperature. By 14.00 h there was little variation in HR.

Table 1. *Meteorological observations during recording of physiological responses and energy expenditure of goat*

Time of recording	Expt 1 Autumn	Expt 2 Monsoon	Expt 2 Winter	Expt 2 Summer
Dry bulb temperature (°C)				
06.00 h	16·0	25·8	12·3	27·6
14.00 h	35·2	31·0	23·0	39·1
Mean	25·6	28·4	17·7	33·4
Black globe temperature (°C)				
06.00 h	18·5	28·0	14·2	30·2
14.00 h	39·4	43·7	35·8	52·0
Mean	29·0	35·9	25·0	41·1
Relative humidity (%)				
06.00 h	67·0	90·0	81·0	67·0
14.00 h	30·0	68·0	56·0	40·0
Mean	48·5	79·0	68·5	53·5
Temperature-humidity index				
06.00 h	61·5	77·0	64·4	77·7
14.00 h	80·8	82·1	70·1	88·5
Mean	71·2	79·5	65·3	83·1

Table 2. *Physiological responses and energy expenditure of stall-fed goats on maintenance ration during autumn season*

	Rectal temperature (RT)	Skin temperature (ST)	Gradient temperature (RT−ST)	Respiration rate (resp/min)	Heart rate (beat/min)	Energy expenditure (W)
06.00 h	38·2	33·1	5·1	10·6	55·0	38·0
14.00 h	39·1	38·2	0·9	25·8	65·2	81·3
Increase Δ °C RT	–	–	–	16·9	11·3	48·1
Increase Δ 10 °C DBT	0·5	–	–	7·9	5·3	22·5
Increase Δ 10 °C BGT	0·4	–	–	7·3	4·9	20·7
Increase Δ 10 °C THI	0·5	–	–	7·8	5·3	22·4

The rectal temperature was on average slightly elevated. At 14.00 h, when animals are exposed to intense solar radiation and walking, they resort to thermo-regulatory mechanisms to dissipate body heat. The combination of heat due to a high DBT and exercise while walking plus body heat results in a rise in body temperature. The linear relationship between dry bulb temperature and rectal temperature has been illustrated in Fig. 1. Rectal temperature of animals linearly increased toward the dry bulb temperature at peak hours of days. The rise of RT from 06.00 to 14.00 h in monsoon, winter and summer was 1·0, 2·1 and 2·0 °C, respectively with a mean of 1·7 °C. A 1·5 °C rise in RT from 06.00 to 14.00 h in sheep on semi-arid range was reported by Shinde *et al.* (1998). The difference in season may be because of modification in physiological responses of animals to change in environmental conditions (Bligh 1970). Skin temperature represented the thermal state of the periphery and showed diurnal variation with a minimum in the morning and maximum in the afternoon (Karim *et al.* 1985). Skin temperature was 0·9 and 1·0 °C lower than RT in monsoon and winter and almost negligible (0·1 °C) in summer at 14.00 h. This shows animals were unable to regulate skin temperature under the intense solar exposure of the summer season despite a substantial rise of pulmonary and cutaneous evaporation.

EE at 06.00 h in the shed was minimal in the winter and increased by 3·3 times in monsoon and 1·6 times in summer with 13·5 and 15·3 °C rise in DBT over winter. EE at 06.00 h in the shed before grazing indicates the minimum expenditure since animals were resting and variation between seasons was a reflection of dry bulb temperature and humidity. Animals normally respond to a low dry bulb temperature by raising their EE. That the Kutchi goats do not do so is probably because DBT of 12 °C

Table 3. *Physiological responses and energy expenditure of goats on range*

	Monsoon	Winter	Summer	S.E. (D.F. = 57)
Respiration rate (respiration/min)				
06.00 h	25·8	10·8	13·9	1·40
14.00 h	81·2	51·6	91·4	8·07
Increase Δ °C RT	55·4	19·4	38·7	7·23
Increase Δ 10 °C DBT	106·5	38·1	67·4	9·83
Increase Δ 10 °C BGT	35·3	19·6	35·5	4·32
Heart rate (beat/min)				
06.00 h	75·4	70·2	57·8	1·69
14.00 h	95·2	94·0	90·6	1·72
Increase Δ °C RT	19·8	11·9	16·7	1·49
Increase Δ 10 °C DBT	38·1	22·1	28·3	3·66
Increase Δ 10 °C BGT	12·6	11·3	14·9	1·53
Rectal temperature (°C)				
06.00 h	38·6	37·7	38·2	0·11
14.00 h	39·6	39·8	40·2	0·12
Increase Δ 10 °C DBT	1·9	1·9	1·8	0·25
Increase Δ 10 °C BGT	0·6	0·9	1·0	0·08
Skin temperature (°C)				
06.00 h	36·4	30·1	35·5	0·52
14.00 h	38·7	38·9	40·3	0·20
Gradient temperature °C (rectal temp-skin temp)				
06.00 h	2·2	7·6	2·7	1·72
14.00 h	0·9	1·0	0·1	0·30
Oxygen consumption (lit/h)				
06.00 h	19·1	5·8	9·2	4·10
14.00 h	69·0	24·9	69·5	14·50
Energy expenditure (W)				
06.00 h	107·8	32·7	52·0	7·45
14.00 h	389·0	140·2	391·3	31·94
Increase Δ °C RT	281·2	51·2	169·6	25·20
Increase Δ 10 °C DBT	540·7	100·5	295·0	67·51
Increase Δ 10 °C BGT	179·1	49·7	155·6	18·84

in winter is not sufficiently low to provoke this because of their acclimatization to a wider range of dry bulb temperature. At 14.00 h in the field, EE rose by 2·8 times in monsoon and summer from a minimum value of 140 W in winter. The rise of EE from morning (06.00 h) to afternoon (14.00 h) was 3·6, 4·3 and 7·5 times in grazing goats during monsoon, winter and summer, respectively. Borut *et al.* (1979) has reported the increase as 1·2 times. The values in the present study were much higher, because of wide diurnal variation in ambient conditions and distance travelled by the animals. EE of goats at variable DBT is shown in Fig. 2. At dry bulb temperature below the critical temperature (°C), goats maintained minimum EE by non-evaporative heat loss. At higher DBT, EE increased with increase in cost of thermoregulation. Variation in EE of goats with rise of RT suggested that animals can maintain a minimum EE up to 38·5 °C RT with an increase in evaporative heat loss. Above 38·5 °C, there is increasing use of respiration to increase evaporative heat loss, resulting in gradual rise of EE (see Fig. 3).

Goats spent 540·7, 100·5 and 295·0 W energy per 10 °C rise in DBT in monsoon, winter and summer (Table 3). In winter and summer, the diet consumed and distance travelled by the goats was comparable, however there was a large increase in EE during summer (339·3 W) compared with winter (107·5 W). The crucial factor responsible was DBT, which was thermoneutral in winter and 13 °C above CT in the summer. In the monsoon, the distance travelled by the animals was lowest, due to the abundant availability of pasture, however DBT coupled with high humidity elevated the EE (281·2 W). The mean EE of goats was slightly reduced from monsoon (248·4 W) to summer (221·7 W) with poorer quality of vegetation. In contrast to this, in a temperate environment, Sahlu *et al.* (1989) reported lowest EE in sheep grazing high quality pasture and increase as the quality deteriorated; this response confirms the earlier observations

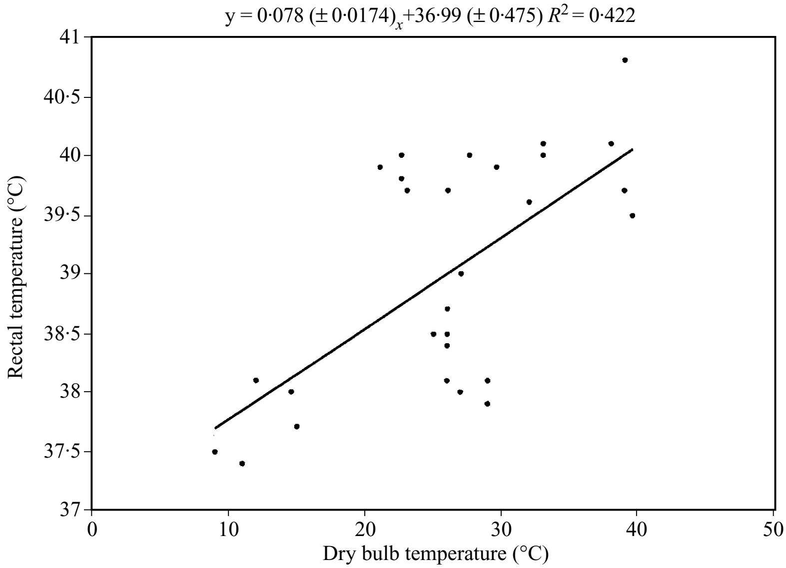

Fig. 1. Relationship between dry bulb temperature and rectal temperature of goats.

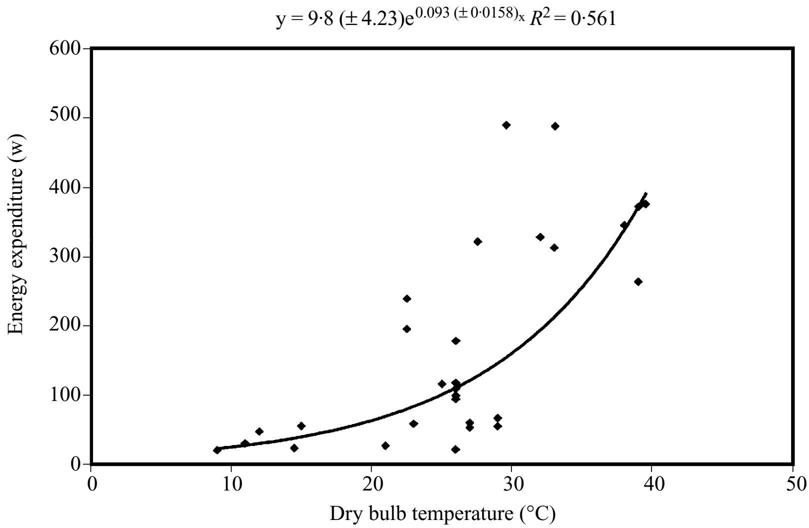

Fig. 2. Relationship between dry bulb temperature and energy expenditure of goats.

of a higher EE in sheep during monsoon and summer in a semi-arid region (Shinde *et al.* 1998).

It is perhaps anomalous to see a marked rise in energy expenditure when animals are subjected to heat stress. A possible explanation is that goats cannot use shallow respiration for cooling and thus their attempts at thermoregulatory control through increased respiration actually result in increasing energy expenditure. Clearly such a positive feedback (as shown in Fig. 3) can only occur for a limited period.

The current study has demonstrated how stressful conditions are for goats grazing in the semi-arid zone in the summer and monsoon seasons. In such conditions good management practice requires that animals be sheltered at least to protect them from direct solar radiation during the peak daily temperatures.

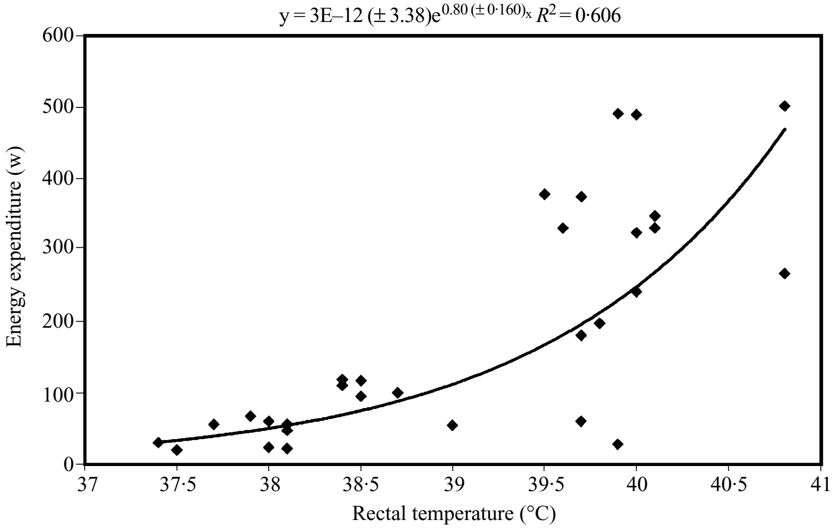

Fig. 3. Relationship between rectal temperature and energy expenditure of goats.

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