Heat Production and Thermoregulatory Responses of Sheep Fed Different Roughage Proportion Diets and Intake Levels When Exposed to a High Ambient Temperature

A. Sudarman and T. Ito[1]
Faculty of Applied Biological Science, Hiroshima University, Kagamiyama 1-4-4
Higashihiroshima 739-8528, Japan

ABSTRACT : Six yearling Suffolk ewes were used to study the effect of different roughage proportion diets (30%=LR, and 70%=HR) and intake levels (0.7 M and 1.3 M) on heat production and thermoregulatory responses in sheep exposed to different ambient temperatures (20 and 30℃). Sheep fed HR had higher heat production (HP) and time spent eating (TSE) and lower time spent standing (TSS) than those fed LR. But effect of roughage proportion on vaginal temperature (Tv) was obvious only at high intake and at 30℃. Sheep fed high intake had higher Tv, HP, TSS, and TSE than those fed low intake. Roughage proportion and intake level did not have an effect on respiration rate (RR), but ambient temperature did. Ambient temperature did not have an effect on HP, TSS and TSE. At 30℃ sheep had higher Tv and RR than those at 20℃. There were interactions between intake level and ambient temperature in TSS, between intake level and roughage proportion in TSE, and between roughage proportion and ambient temperature in HP. Results indicate that high roughage diet imposes a greater potential heat load on animals than low roughage diet when given at high ambient temperature, but not at low ambient temperature. And the effects is more pronounced at high intake. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 5 : 625-629)*

Key Words : Sheep, Roughage Proportion, Intake Level, Hot Ambient Temperature, Heat Production, Thermoregulation

INTRODUCTION

It is well known that in a hot environment animals reduce their feed intake. Since body temperature is a result of a balancing process between heat production and heat loss, and because heat production increase with the increase of feed intake level, it is argued that reducing feed intake in hot environments is a thermoregulation effort by the animal to prevent an excessive increase in body temperature. The decrease is more pronounced with animals fed a high proportion of roughage diet (Moose et al., 1969; Bhattacharya and Hussain, 1974; Collier et al., 1982), because for a given amount of DE, roughages have a greater heat increment than concentrates (Kleiber, 1975). Due to this phenomenon, some researchers, therefore, suggested that feeding ruminants a high roughage diet in cold environments is advantageous. However, reports concerning heat production and thermoregulation as effects of diet eaten are limited, especially those associated with ambient temperature.

The present experiment was conducted to study the effect of different roughage proportion diets on heat production (HP) and thermal regulation in sheep at different ambient temperatures and intake levels.

* Address reprint request to T. Ito. Tel: +81-824-24-7957, Fax: +81-824-22-7067, E-mail: r737745@ipc.hiroshima-u.ac.jp.
Received May 6, 1999; Accepted August 17, 1999

MATERIALS AND METHODS

Animals and diets

Six growing Suffolk ewes weighing 37.8-41.0 kg and a fleece length of about 10 cm were used. They were placed in individual cages (125×60 cm) at 20±0.5℃ in a controlled temperature room. Lighting management was 12L:12D where lighting period commencing at 0700. They were offered either a low roughage diet (LR) which consisted of a concentrate : alfalfa hay cube ratio of 70:30, or a high roughage diet (HR) which consisted of a concentrate:alfalfa hay cube ratio of 30:70. Vitamin-mineral mix was added to each diet at the level of 1%. Composition of the diets is presented in table 1. Daily feeds, at levels of 0.7 (Low) and 1.3 (High) times maintenance (NRC, 1985), were offered to the animal in two equal daily meals, distributed at 0900 and 1700 h, and time spent for eating (TSE) was recorded. Water was provided after respiration rate measurements for 30 min and then was withdrawn. The water was stored at ambient temperature overnight before being given to the animals. Feeding, watering and water withdrawing times were during sampling of the inlet air.

Animals were adapted to experimental diets for 30 days during which they were also trained to a hood. The sheep were first fed Low followed by High level for 5 days in the individual cages, and for 2 days in the hoods for each level. During adaptation and on days when they were not used, sheep were fed experimental diet at a maintenance level for 40 kg live weight.

Table 1. Ingredient and chemical composition of diets

Diet	LR	HR
Ingredient composition (%)		
Alfalfa hay cube	30	70
Corn, grain	54.5	29
Soybean meal	14.5	-
Vitamin-mineral mix.	1	1
Chemical composition		
Dry matter (%)[1]	86.7	87.5
Composition of dry matter[2]		
ME (Mcal/kg)	3.03	2.44
Crude protein (%)	18.1	14.5
Crude fiber (%)	11.1	21.7
P:E ratio[3]	59.7	59.4

[1] By analysis.

[2] Calculated values based on AFFRC (1995).

[3] Calculated crude protein (g) relative to ME (Mcal/kg).

Parameters and measurement

Parameters were measured at two periods, first at 20 followed by 30℃ ambient temperatures. For measuring heat production (HP) and other parameters sheep were placed in individual cages, located in the same room, connected to a hood (162 liters), and stayed for 2 days for each intake level of each diet. In the first day, parameters were not measured in an attempt to reduce effects of handling. Heat production was measured continuously using an open circuit respiratory apparatus and 80 liters of air/min were drawn through the hoods. The hoods were connected to an oxygen analyzer (Morgan oxygen analyzer, OA 500D), data were recorded on a data logger (Advantest, R7430), and then calculated using a personal computer (NEC-PC9801VX) connected to a data logger. During that time, body posture was detected using an infrared detector. Vaginal temperature (Tv) was measured using a thermocouple inserted for about 10 cm depth, connected to the data logger, and recorded at 5 min intervals. Hourly mean temperatures were then calculated for statistical analysis.

Respiration rate (RR) was measured at 15 min before feeding and at 30 min after feeding using a heart girth carbon pick up (Nihon Kohden, TR-601T) using bioelectric amplifier (Nihon Kohden, AB-621G), which then recorded on the polygraph recorder (NEC Omniace RT-3300).

For estimating the digestibility of the diets, feces were collected using a bag for 5 consecutive days when the animals were individual caged. The collected feces were then dried in an oven at 104℃ for 24 h. Dry matter digestibility was then calculated.

Data were subjected to Analysis of Variance (ANOVA) (Steel and Torrie, 1980) based on a factorial design incorporating 3 factors: 2 diets, 2 levels of intake, and 2 ambient temperatures. Treatment means were compared by least significant difference (LSD) and significance was declared at $p \leq 0.05$.

RESULTS AND DISCUSSION

Heat production

Heat production (HP) was significantly affected by type of diet and level of intake but was not affected by ambient temperature. Heat production (HP) of sheep fed low intake, as was expected, was significantly lower than that of sheep fed high intake. Sheep fed HR diet had a significantly higher HP than those fed LR diet and this was more pronounced at high ambient temperature (table 2).

Kleiber (1975) noted that for a given amount of DE, roughages have a greater heat increment than concentrates. The heat increment of roughages is directly proportional to the crude fiber content of the diet (Kellner, in Kleiber, 1975). He, further, assumed that half of the calorigenic effect of crude fiber resulted from action by fermentation in the rumen and that the other half was due to the work of chewing.

The different crude fibre contents of diets results in different proportions of VFA in which the higher proportion of roughage in a ruminants diet produces a higher concentration of acetate (Osuji et al., 1975; Webster et al., 1975). Correspondingly, concentration and rate of production (Evans and Smith, 1975; Carro et al., 1988) of propionate in the rumen increases when roughage is replaced by concentrate. It has been reported (Armstrong and Blaxter, 1956) that a higher proportion of acetate produced a higher heat increment. In fermentation of 1 mole of hexose to 2 moles of acetate, 252 kcal is lost, while in fermentation of 1 mole of hexose to 2 moles of propionate, 62 kcal is gained (Hungate, 1966).

However, the results of Osuji et al. (1975) showed that the increase in heat production during and after fistula-feeding were only 2-8% of those obtained during eating, indicating that nearly all the increase in heat production during eating could be attributed to the energy cost of eating. Present results showed that TSE of sheep fed HR diet was longer than that of those fed LR diet and HP of the later one was lower, though the level of ME offered was similar. Orskov et al. (1991) reported that there were not differences in HP over a range of VFA proportions (45-75 mol/100 mol for acetic acid and 15-45 mol/100 mol for propionic acid) normally found in ruminants. Furthermore, they reported that when acetate proportion exceeded the normal range, some metabolic disturbance occurred. The excess acetic acid was excreted via urine and HP was found not to be elevated.

Table 2 shows that HP was different between HR sheep and LR counterparts at high ambient temperature, but it was not different at low ambient temperature. In a hot ambient temperature, since the animal receives a great heat load from the environment, body temperature increases; in the present experiment it was indicated by the increase of Tv, and the increase in body temperature causes metabolic rate to increase (Blaxter, 1962). This together with the high heat increment of the HR diet probably caused a significant difference in HP between LR and HR diets.

Heat production of sheep was not affected by ambient temperature. This may be caused by the long (10 cm) fleece of sheep in the present experiment. The result agrees with those of Blaxter et al. (1959) that HP of sheep with fleece length varying from 2.5 to 12 cm remained constant throughout the range of 15-35℃ environmental temperature. Above 35℃ an increase occurred. At 11℃ a slight rise in HP occurred in the sheep with a 2.5 cm fleece. They, therefore, concluded that long fleece enables sheep to have a wide range thermoneutral zone.

Time spent standing

Intake level and type of diet significantly affected time spent standing (TSS). However, ambient temperature did not significantly affect TSS. The same result from calves was reported by Schrama et al. (1993). There was an interaction between level of intake and ambient temperature. Time spent standing by the low intake group and that by high intake group tended to increase and to decrease, respectively, in high ambient temperature.

Sheep fed LR spent a significantly longer time standing than those fed HR (table 2). The longer TSS of sheep fed LR may be due to a desire to eat because the gut fill was emptier than those fed HR. However, this seemed not to be true, because the results also shown that sheep fed Low were standing for a significantly shorter time than those fed High (table 2).

The present results are in agreement with the results of Orskov et al. (1991). In an experiment using cattle given different proportions of VFA, Orskov et al. (1991) reported that time spent standing was lower at the highest proportion of acetate than with the other VFA compositions. They also found that steers at the higher proportion of acetate had high plasma concentrations of β-hydroxybutyrate indicating that steer experienced metabolic disorder.

Since the energy cost of standing is greater than for lying, 10 kJ/kg per day (ARC, 1980), therefore in the present experiment HP due to standing is greater in sheep fed LR. However, total daily HP of sheep fed LR was lower than those fed HR. It may, therefore, be concluded that the higher HP of HR fed sheep was primarily due to their higher feeding activity.

Vaginal temperature

Ambient temperature and level of intake significantly affected Tv of sheep, but type of diet did not (figure 1). Sheep at 30℃ had Tv higher than those at 20℃ indicating that at 30℃ heat load is greater than heat dissipation. The higher Tv of sheep fed high intake may due to a higher metabolic activity as shown by their higher heat production.

In general, Tv increased when feed was given and reached the peak in 1 hour, then decreased. There was a tendency that the increment was greater, especially

Table 2. Effects of roughage proportion in diet and intake levels on heat production, vaginal temperature, respiration rate, time spent standing, and time spent eating by sheep at 20 and 30℃

Ambient Temperature	Intake Level	Diet	Parameters				
			HP	RR		TSS	TSE
				Pre-feeding	Post-feeding		
20℃	Low	LR	369.6 ± 9.12^{ab}	44 ± 12^{a}	55 ± 11^{a}	27.4 ± 2.97^{a}	11.4 ± 0.61^{ab}
		HR	393.0 ± 4.37^{ab}	39 ± 6^{a}	55 ± 8^{a}	33.0 ± 3.00^{ab}	16.4 ± 0.67^{cd}
	High	LR	446.9 ± 10.69^{de}	35 ± 10^{a}	53 ± 14^{a}	53.4 ± 6.46^{d}	21.1 ± 1.03^{e}
		HR	457.4 ± 14.54^{de}	35 ± 6^{a}	37 ± 3^{a}	42.6 ± 4.86^{bcd}	30.8 ± 2.97^{f}
30℃	Low	LR	359.3 ± 7.52^{a}	65 ± 3^{ab}	98 ± 2^{b}	47.8 ± 8.18^{cd}	10.4 ± 0.58^{a}
		HR	405.1 ± 13.78^{bc}	99 ± 5^{bc}	129 ± 22^{b}	32.0 ± 3.55^{ab}	15.3 ± 1.20^{bc}
	High	LR	430.9 ± 18.12^{cd}	97 ± 13^{bc}	136 ± 5^{b}	43.5 ± 1.89^{bcd}	20.3 ± 1.31^{de}
		HR	471.8 ± 3.20^{e}	117 ± 27^{c}	122 ± 15^{b}	39.3 ± 2.23^{abc}	31.1 ± 3.15^{f}

Values (mean±SE) within columns with different superscripts differ significantly ($p\leq0.05$).
LR=30% roughage, HR=70% roughage, Low=0.7M, High=1.3M, HP=heat production (kJ/kg BW0.75/24h), RR=respiration rate (resp/min, value is average of two meal times), TSS=time spent for standing (% within 24 h), TSE=time spent for eating (min, sum of two meal times).

at low intake (figure 1a), and the decreasing rate was lower, especially after afternoon meal, in sheep fed HR. This resulted in Tv of sheep fed HR being slightly above those fed LR. However, at high ambient temperature and high intake level the difference in Tv is more obvious as is shown by a wider separation between curves for HR diet and LR diet (figure 1b) and physiologically it is great enough for sheep, a thermostabile animal. Little change in Tv was also shown in an experiment with Merino sheep by Parer (1963) who reported that exposure to infra-red radiation for one hour resulted in a rise in rectal temperature of only 0.2℃, while at the same time RR rose from an initial 26 to 154 respirations/min.

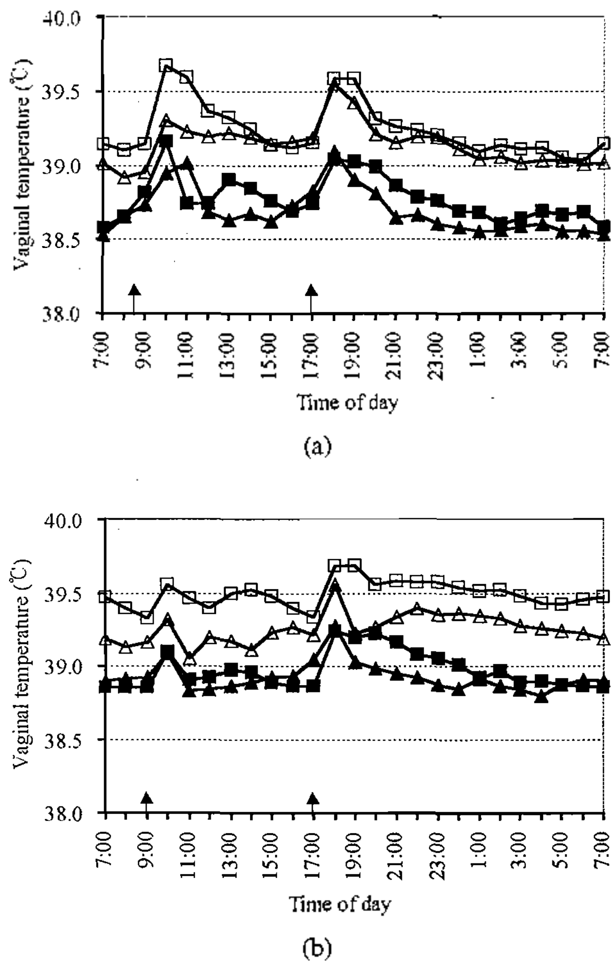

Figure 1. Effect of diet on vaginal temperature at different ambient temperatures
(a) Low intake level, (b) High intake level
▲: LR, 20℃ ■: HR, 20℃
△: LR, 30℃ □: HR, 30℃
LR: 70% concentrate+30% roughage
HR: 30% concentrate+70% roughage

The present results are also in agreement with data reported by Bhattacharya and Hussain (1974). Since high body temperature is one of the limiting factors of intake, the result that at 30℃ the Tv of sheep fed HR was higher than that of the LR group may confirm the lower intake of roughage in hot environments.

Respiration rate

Intake level and type of diet did not affect RR, neither measured pre- nor post-feeding. Ambient temperature significantly affected RR. Table 2 shows that sheep placed at 30℃ room temperature had RR greater than that of sheep placed at 20℃. The difference in RR between after and before feeding was also greater in high ambient temperature than that in low ambient temperature.

The increase in RR is one of common physiological responses of animal when ambient temperature increases which is aimed to dissipate the extra heat load in order to maintain normal body temperature. Unlike cattle, sheep has poor sweating ability, therefore, RR becomes the main channel for dissipating extra heat load. Knapp and Robinson (1954) reported that exposure of sheep to 42.2℃ caused a RR of up to 240/min. In contrast, the RR of cattle was only a quarter to half that of sheep.

Time spent eating

Time spent eating (TSE) was significantly affected by type of diet and level of intake, but not by ambient temperature. TSE by sheep fed HR was significantly longer than by sheep fed LR (table 2), and was significantly longer at the high intake level than at the low level. Since a roughage diet is more fibrous and has lower energy density than a concentrate diet, to meet a given ME requirement more HR diet should be supplied (on an as fed or DM basis) than LR. TSE for the roughage diet will therefore be longer and this may account substantially for the higher HP of the sheep fed HR. Experiments using sheep, (Osuji, 1974) and cattle (Adam et al., 1984) showed that the energy cost of eating is more related to the TSE than to the weight of feed eaten. In an environment where extra heat is difficult to dissipate, such as in a humid tropical region this, of course, is a disadvantage for ruminants. A similar explanation can be applied to the effect of level of intake. There was an interaction between level of intake and type of diet, showing a greater increasing rate of TSE at higher intake in sheep fed HR than in those fed LR.

Dry matter digestibility

Digestibility of concentrate diet was significantly higher than that of roughage, 82.7 vs. 68.8%, respectively (figure 2). The higher fiber content of HR diet than that of LR diet may be responsible. This may also indicate that roughage diet was utilized less efficiently than that of concentrate diet and part of this inefficiency may contribute to the higher heat produced by the roughage diet.

Ambient temperature did not significantly affect the digestibility of the diets, 76.4 and 75.1% for 20 and 30℃, respectively. It is often claimed that digestibility of diet increases at high ambient temperature. Low intake at high ambient temperature causes a longer retention time of feed in digestive tract and subsequently gives more chance of feed to be digested. However, Bhattacharya and Uwayjan (1975) and Christopherson (1984) concluded that the effect of high ambient temperature on digestibility was uncertain, lower or higher digestibility being associated more with change in intake. In the present experiment, during digestibility trial either at 20 or 30℃, sheep were fed at the same intake level (maintenance level of 40 kg live weight) and caused no change in diet digestibility due to change of ambient temperature, neither in HR nor in LR.

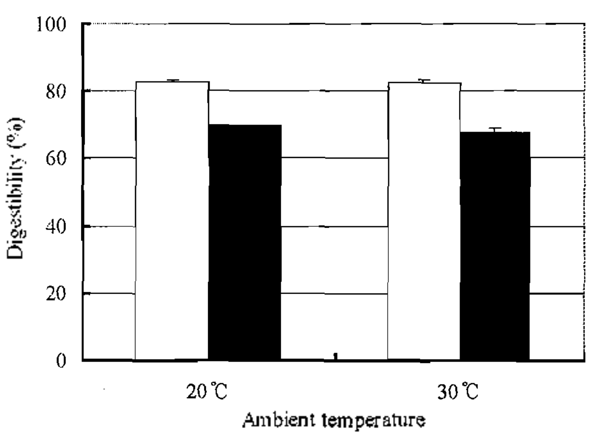

Figure 2. Dry matter digestibility (%) of experimental diets at different ambient temperature
□ : LR, low roughage ■ : HR, high roughage

REFERENCES

Agriculture, Forestry and Fisheries Research Council. 1995. Standard Tables of Feed Composition in Japan. Central Association of Livestock Industry, Japan.

ARC. 1980. The Nutrient Requirements of Ruminant Livestock. Commonwealth Agric. Bureaux, Slough, UK.

Adam, I., B. A. Young, A. M. Nicol and A. A. Degen. 1984. Energy cost of eating in cattle given diets in different form. Anim. Prod. 38:53-56.

Armstrong, D. G. and K. L. Blaxter. 1956. Heat increments of feeding in ruminants. Nature. 177:1183-1184.

Bhattacharya, A. N. and F. Hussain. 1974. Intake and utilization of nutrients in sheep fed different levels of roughage under heat stress. J. Anim. Sci. 38:877-886.

Bhattacharya, A. N. and M. Uwayjan. 1975. Effect of high ambient temperature and low humidity on nutrient utilization and some physiological responses in awasi sheep fed different levels of roughage. J. Anim. Sci. 40:320-328.

Blaxter, K. L. 1962. The Energy Metabolism of Ruminants. Hutchinson, London, UK.

Blaxter, K. L., N. Mc C. Graham and F. W. Wainman. 1959. Environmental temperature, energy metabolism and heat regulation in sheep. III. The metabolism and thermal exchanges of sheep with fleeces. J. Agric. Sci. 52:41-49.

Carro, M. D., C. Valdes, J. S. Gonzalez, P. Frutos and F. J. Giraldez. 1988. Effect of forage to concentrate ratio in the diet on rumen fermentation in sheep. Proc. Br. Soc. Anim. Sci. p. 91.

Christopherson, R. J. 1984. The thermal environment and the rumen digestive system. In: Stress Physiology in Livestock. Vol. I. Basic Principles (Ed. M. K. Yousef). CRC Press, Inc., Florida, USA.

Collier, R. J., D. K. Beede, W. W. Thatcher, L. A. Israel and C. J. Wilcox. 1982. Influences of environment and its modification on dairy animal health and production. J. Dairy Sci. 65:2213-2227.

Evans, E. and J. G. B. Smith. 1975. Effects upon glucose metabolism of feeding a low or high roughage diet at two levels of intake to sheep. Br. J. Nutr. 33:33-44.

Hungate, R. E. 1966. The Rumen and Its Microbes. Academic Press, New York, USA.

Kleiber, M. 1975. The Fire of Life. R. E. Krieger Publishing C., Huntington, New York, USA.

Knapp, B. J. and K. W. Robinson. 1954. The role of water for heat dissipation by a Jersey cow and a Corriedale ewe. Aust. J. Agric. Res. 5:568-577.

Moose, M. G., C. V. Ross and W. H. Pfander. 1969. Nutritional and environmental relationships in lambs. J. Anim. Sci. 29:619-627.

NRC. 1985. Nutrient Requirements of Sheep. National Academy Press, Washington, DC, USA.

Orskov, R. E., N. A. MacLeod and Y. Nakashima. 1991. Effect of different volatile fatty acids mixtures on energy metabolism in cattle. J. Anim. Sci. 69:3389-3397.

Osuji, P. O. 1974. The physiology of eating and the energy expenditure of the ruminant at pasture. Journal of Range Management. 27:437-443.

Osuji, P. O., J. G. Gordon and A. J. F. Webster. 1975. Energy exchanges associated with eating and rumination in sheep given grass diets of different physical forms. Br. J. Nutr. 34:59-71.

Parer, J. T. 1963. Wool length and radiant heating effects in sheep. J. Agric. Sci. 60:141-144.

Schrama, J. W., A. Arieli, H. A. Brandsma, P. Luiting and M. W. A. Verstegen. 1993. Thermal requirements of young calves during standing and laying. J. Anim. Sci. 71:3285-3292.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometric Approach. McGraw-Hill Book Co., New York, USA.

Webster, A. J. F., P. O. Osuji, F. White and J. F. Ingram. 1975. The influence of food intake on portal blood flow and heat production in the digestive tract of sheep. Br. J. Nutr. 34:125-139.