Influence of Short- and Long-Term Exposure to a Hot Environment on Rumen Passage Rate and Diet Digestibility by Friesian Heifers[1]

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ABSTRACT

Effects of short- and long-term exposure to a hot environment on diet digestibility and rumen passage rate were studied in four, 10-mo-old Friesian heifers housed in a climatic chamber. The trial lasted 65 d. Twenty-five days were spent under thermal comfort (temperature-humidity index = 64), and 40 d were spent under hot conditions (temperature-humidity index = 84). Three digestibility and rumen passage rate trials were performed during the 65 d. Chromium oxide was used as an external marker. The first digestibility and rumen passage rate trial (trial 1) was performed under thermal comfort; trials 2 and 3 were performed under hot conditions. Exposure to the hot environment reduced dry matter intake and increased water intake and rectal temperature compared with those during the thermal comfort period. Digestibility coefficients for dry matter, organic matter, neutral detergent fiber, and acid detergent fiber were higher in trial 2 than in trials 1 and 3. No statistical differences were found between trials 1 and 3 for these variables. Rumen passage rate was more rapid in trial 1 than in trials 2 and 3. No difference was observed between trials 2 and 3.

These results indicated that exposure to a hot environment can affect digestibility in a time-dependent fashion, suggesting an adaptation of the digestive tract to hot environments.

(**Key words**: heifers, heat stress, digestibility, rumen passage rate)

Abbreviation key: **DT** = digestibility trial, **ETHI** = elevated temperature-humidity index, **NFC** = nonfiber carbohydrates, **RPRT** = rumen passage rate trial, **TC** = thermal comfort.

INTRODUCTION

Alteration of the dynamic characteristics of digestion is recognized as a possible mechanism through which heat stress can affect the nutrition of animals (3). Slower passage rates and longer mean retention times of digesta have been described for dairy cows maintained under hot environments (20, 32, 35) when compared with cows maintained under thermal comfort (**TC**) conditions. Conflicting results regarding diet digestibility by ruminants housed in hot environments have been reported. Increases in diet digestibility by animals exposed to hot environments have been observed in dairy cattle (6, 20, 24). In contrast, negative or no relationships between exposure to high ambient temperature and diet digestibility have been reported for dairy cattle (18, 19, 24) and small ruminants (17, 31), respectively. Previous studies (6, 20) suggest that the variation in the rate of passage of digesta appeared to be a major cause of change in digestibility by heat-stressed ruminants.

Effects of different durations of exposure to hot environments on diet digestibility by ruminants have not been well documented. The objectives of this study were to examine the effects of different intervals of exposure to heat above TC on rumen passage rate and diet digestibility by dairy heifers and to determine the relationship between rumen passage rate and diet digestibility under heat stress conditions.

MATERIALS AND METHODS

Heifers, Housing, and Feeding

Four 10-mo-old, half-sibling, Friesian heifers with a mean BW of 352 ± 15 kg were used. The heifers were housed in a climatic chamber with individual tie stalls equipped with individual feeders and waterers. Ambient temperature and relative humidity were computer-controlled and monitored continuously. Photoperiod schedule [10 h of light (400 lx) and 14 h of darkness] and air circulation (0.5 ambient volume/

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TABLE 1. Composition of feeds used during the experiment. Data are expressed on a DM basis.

	DM	CP	Ash	NDF	ADF	NFC[1]
	(%)					
Italian ryegrass hay						
Trial 1[2]	90.11	8.14	9.33	64.22	49.18	16.81
Trial 2[2]	91.14	6.65	8.12	66.92	51.12	16.97
Trial 3[2]	90.98	7.06	7.75	66.97	50.68	16.80
Concentrate[3]	90.63	16.51	8.51	10.15	6.01	62.03

[1]Nonfiber carbohydrates.

[2]Trial 1 was conducted under thermal comfort conditions (temperature-humidity index = 64), trial 2 was conducted 3 d after heifers were placed in a hot environment (temperature-humidity index = 84), and trial 3 was conducted after heifers were in a hot environment for 24 d.

[3]Composition of concentrate: 41% corn meal, 30% barley meal, 15% soybean meal, 10% wheat bran, 1.2% $Ca_3(PO_4)_2$, 0.8% $CaCO_3$, 0.6% NaCl, 0.6% MgO, 0.6% vitamin and mineral premix. The vitamin and mineral premix supplied (per kilogram of concentrate): 45,000 IU of vitamin A, 4000 IU of vitamin D, 55 mg of vitamin E, 130 mg of vitamin PP, 14 mg of vitamin B_1, 12.5 mg of vitamin B_2, 5 mg of vitamin B_6, 0.02 mg of vitamin B_{12}, 0.2 mg of folic acid, 1 mg of Co, 100 mg of Fe, 2.5 mg of I, 65 mg of Mn, 13 mg of Cu, 225 mg of Zn, and 0.14 mg of Se.

h) were maintained at a constant during the entire trial. The heifers were fed 1.5 kg/d of concentrate and Italian ryegrass hay (Table 1) for ad libitum consumption. The heifers were fed at 0745 and 1645 h daily and had free access to tap water.

Experimental Design

The heifers were maintained continuously for a 15-d preexperimental period under TC (18°C and 70% relative humidity = temperature-humidity index of 64) to allow them to adapt to the new housing conditions. The temperature-humidity index was calculated according to the formula reported by Johnson (14). During this period, no measurements were carried out.

The experimental period lasted 65 d and started immediately after the end of the preexperimental period. During the first 25 d of the experimental period, heifers were housed under TC conditions. Then, they were exposed continuously for 40 d to an elevated temperature-humidity index (**ETHI**) (33°C and 60% relative humidity = temperature-humidity index of 84).

Three digestibility (**DT**) and rumen passage rate (**RPRT**) trials were performed during the 65-d experiment. The first DT and RPRT were carried out under TC conditions (trial 1). The second and third DT and RPRT were conducted following different lengths of exposure to ETHI. The second DT and RPRT started on d 28 and ended on d 44 (trial 2), and the third DT and RPRT started on d 49 and ended on d 65 (trial 3) after the beginning of the experimental period.

DT. Digestibility trials were conducted according to Bittante and Andrighetto (5). Chromium oxide was blended into the concentrate so that the concentrate contained 1% Cr_2O_3 and was used as an external marker (5).

The following protocol was performed for each of the three DT. Concentrate containing Cr_2O_3 was given for 12 d. During the first 7 d, no fecal samples were taken. During the last 5 d, individual grab fecal samples were collected twice daily from the rectum at standardized times (at 0700 and at 1600 h). For each heifer, the 10 fecal samples (equal weights) were combined and mixed thoroughly to form a composite sample from which a representative sample was obtained.

RPRT. Immediately after the end of each DT, heifers were fed a Cr-free concentrate, and RPRT were carried out. Individual fecal grab samples were obtained from the rectum at 0, 4, 8, 12, 16, 20, 24, 30, 36, 44, 50, 62, 68, 74, and 96 h after the Cr-free concentrate was fed. Changes in the concentration of Cr in the feces were used to estimate the passage rate [assumed to correspond to the outflow rate from the rumen (11, 25)]. The fecal samples were stored at –20°C until the laboratory analyses were carried out.

Measurements, Sampling, and Laboratory Analyses

The following measurements were also performed on each heifer during the experimental periods. Orts from the previous day were measured once daily at 0715 h. Water consumption was measured once daily at 0730 h using individual water meters. Heifers were weighed, and body condition was scored (9), at the beginning of trials 1 and 2 and at the end of trial 3. The same person performed the scoring of body condition. Rectal temperatures were measured at 0900 h

TABLE 2. Least square means for DMI, water intake, BW, and body condition score.

Item	TC[1]	ETHI[1]		SE	TC vs. ETHI
	Trial 1	Trial 2	Trial 3		
					P
DMI, kg/d					
Total	8.01[A]	7.48[B]	7.18[B]	0.13	0.01
Hay	6.80[A]	6.24[B]	5.96[B]	0.13	0.01
Concentrate	1.20	1.24	1.22	0.01	0.64
Water intake, L/d	27.55[B]	42.61[A]	45.54[A]	1.83	0.01
BW, kg	312[c]	325[b]	343[a]	1.30	0.05
Body condition score[2]	3.0[a]	2.9[a]	2.7[b]	0.05	0.05

[a,b,c]Means within a row with different superscripts differ ($P < 0.05$).

[A,B]Means within a row with different superscripts differ ($P < 0.01$).

[1]Environmental conditions: TC = thermal comfort (temperature-humidity index = 64); ETHI = elevated temperature-humidity index (temperature-humidity index = 84). Trial 1 was conducted under TC conditions (temperature-humidity index = 64), trial 2 was conducted 3 d after heifers were placed in a hot environment (temperature-humidity index = 84), and trial 3 was conducted after heifers were in hot environment for 24 d.

[2]A five-point scale over values from 1 to 5 with fractions of 0.3, 0.5, and 0.7 used [where 1 = emaciated, 3 = average, and 5 = obese (9)].

every 3 d during the experimental period but daily during the last 6 d of each DT using a digital thermometer (Crison T-637; Crison Strumenti, Carpi, Italy) with 0.1°C accuracy of measurement. Concentrate and hay samples and orts were collected daily for 12 d during the digestibility trials and pooled.

Dry matter of feed, orts, and fecal samples was determined by forced-air oven-drying at 65°C to a constant weight. Organic matter (1) was determined on dried samples by ignition in a furnace at 550°C overnight. Ether extract was determined using the AOAC (1) method. Crude protein was determined by the macro-Kjeldhal method (1). The NDF and ADF were analyzed according to the method described by Goering and Van Soest (10). Nonfiber carbohydrate (**NFC**) was calculated as [OM – (NDF + CP + ether extract)]. Chromium content of feed, orts, and feces was determined according to the method of Williams et al. (36).

Apparent digestibility coefficients of DM, OM, NDF, ADF, and NFC were calculated based on the formula reported by Bittante and Andrighetto (5). The excretion kinetics of Cr were estimated according to the mathematical model of Grovum and Williams (11).

Statistical Analysis

Data were analyzed using the general linear models procedure of SAS (29). To test the trial effect, a model including heifers, trial (1, 2, and 3), and an error term was used. To test the environmental effect, a model including heifers, environmental effect (TC vs. ETHI), and an error term was used. Least squares means were separated with the PDIFF procedure of SAS (29). Linearity of rectal temperature under ETHI conditions was tested by regressing rectal temperature against time (29) using data from rectal temperature peak (d 10 of ETHI exposure) to the end of the trial. Pearson's correlation coefficients were calculated among DMI, digestibility coefficients, and rumen passage rate coefficients. Significance was declared at $P < 0.05$.

RESULTS

Rectal Temperature

Rectal temperatures of heifers under ETHI were higher ($P < 0.05$) than those of heifers exposed to TC. Rectal temperatures peaked (39.8°C) on d 10 of the ETHI period and then declined until the end of the experiment (Figure 1).

Feed Consumption

Exposure to ETHI was responsible for reduced DMI and increased water intake (Table 2). The DMI and water intake did not differ ($P > 0.05$) between the two trials carried out under ETHI, although DMI was slightly lower in trial 3 than in trial 2 (Table 2). As a consequence of reduced DMI and increased water intake, the heat-stressed heifers had higher water consumption per kilogram of DM ingested ($P < 0.05$) than did nonstressed heifers.

Because the reduction of DMI was mainly due to a lower intake of hay (Table 2), the exposure to ETHI was also indirectly responsible for a slight variation

TABLE 3. Least square means of digestibility coefficients of DM, OM, NDF, ADF, and nonfiber carbohydrates (NFC) and rumen passage rate constants.

Item	TC[1]	ETHI[1]		SE	TC vs. ETHI
	Trial 1	Trial 2	Trial 3		*P*
Digestibility, %					
DM	57.3^{b,B}	68.4^{a,A}	60.6^{b,AB}	1.26	0.05
OM	59.3^{b,B}	70.2^{a,A}	62.8^{b,AB}	1.09	0.05
NDF	51.4^{B}	66.6^{A}	57.8^{B}	1.01	0.05
ADF	44.2^{B}	60.8^{A}	47.3^{B}	1.02	0.05
NFC	81.7	81.9	81.0	1.14	0.72
Rumen passage rate, %/h	5.38^{A}	4.02^{B}	3.98^{B}	0.04	0.01

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

^{A,B}Means within a row with different superscripts differ ($P < 0.01$).

[1]Environmental conditions: TC = thermal comfort (temperature-humidity index = 64); ETHI = elevated temperature-humidity index (temperature-humidity index = 84). Trial 1 was conducted under TC conditions (temperature-humidity index = 64), trial 2 was conducted 3 d after heifers were placed in a hot environment (temperature-humidity index = 84), and trial 3 was conducted after heifers were in hot environment for 24 d.

($P > 0.05$) of the hay to concentrate ratio (85:15 in trial 1 vs. 83:17 in trials 2 and 3).

Digestibility and Rumen Passage Rate

Digestibility coefficients of DM and OM (Table 3) measured in trial 2 were higher compared with those recorded in trial 1 under TC conditions ($P < 0.01$) and after a more prolonged exposure to ETHI (trial 3) ($P < 0.05$) (Table 3). No differences ($P > 0.05$) in digestibility between trials 1 and 3 were observed (Table 3).

The digestibility of NDF and ADF followed the same changes as DM and OM (Table 3). Conversely, no differences ($P > 0.05$) were found among the three DT for NFC digestibility (Table 3).

Based on excretion kinetics of Cr in feces, rumen passage rate in trial 1 was higher ($P < 0.01$) than that in trials 2 and 3 (Table 3). Rumen passage rate did not differ ($P > 0.05$) between the two trials carried out under ETHI (Table 3). Negative relationships between rumen passage rate and DM digestibility ($r = -0.60$; $P < 0.01$) and between DM digestibility and feed intake ($r = -0.68$; $P < 0.01$) were recorded in trial 2 but not in trials 1 and 3.

Average Daily Gain and Body Score

Body weight of heifers increased during the experimental period (Table 2). However, the average daily gain of heifers under ETHI was 26.8% lower ($P < 0.05$) than the average daily gain found under TC (476 ± 60 vs. 650 ± 72 g/d, respectively). Body condition score did not change during the TC period and declined during exposure to ETHI (Table 2).

DISCUSSION

Johnson (14) reported that sudden exposure of heifers to a hot environment resulted in a rapid increase in rectal temperature followed by a gradual decline when heifers were exposed to hot environments for a long period. Johnson (14) also reported that the gradual decline of rectal temperature might

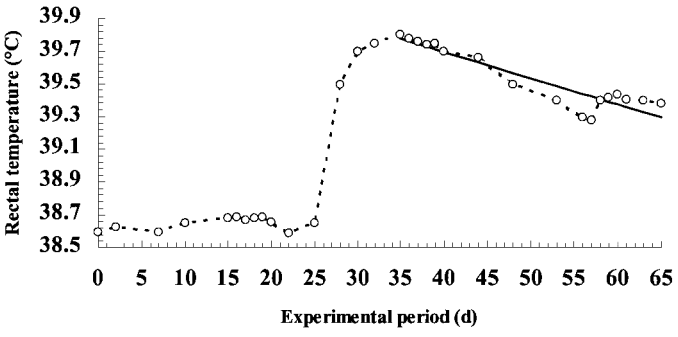

Figure 1. Changes in rectal temperatures during the experimental period. Trial 1 (thermoneutral conditions) was conducted from d 8 through 25, trial 2 [elevated temperature-humidity index (ETHI)] was conducted from d 28 through 44, and trial 3 (ETHI) was conducted from d 49 through 65. Linearity of rectal temperatures under ETHI conditions was tested by regressing rectal temperatures against time using rectal temperature data from the peak (d 10 of ETHI exposure) to the end of the experimental period. Continuous line represents the following regression equation: $Y = -0.01601X + 39.93581$; $P < 0.05$.

be caused by the acclimation of heifers to the hot environments. A reduction in endogenous heat production (decreases in DMI, thermogenic hormones, basal metabolism, digestive and motor activity, etc.) and increased heat dissipation (increases in breathing rate and peripheral vasodilatation) may occur (14). Although our data did not permit measurement of thermal balance, the duration of our study probably permitted acclimation of the heifers to hot environments.

Decreases in DMI usually occur in animals exposed to hot environments (14, 24, 31). Under TC conditions, reduction of DMI is generally associated with an increase in diet digestibility and a decrease in rumen passage (34). Conversely, it was reported (2, 16, 20, 35) that under hot conditions, diet digestibility and rumen passage rate were not affected by a reduction in DMI. When forages and concentrates are fed separately, heat-stressed cows reduce fiber intake by reducing hay consumption (8), which leads to changes in the forage to concentrate ratio in the diet. This behavior is considered an adaptive response to reduce heat production from rumen fermentation (4).

The small changes in the hay to concentrate ratio observed in our study between TC to ETHI confirm results reported by Coppock and West (8). Furthermore, results of previous studies suggest that the small variation in the forage to concentrate ratio observed in our study would not have influenced VFA production (22), digesta passage (26), or diet digestibility (12). Christopherson and Kennedy (7) described positive effects of high ambient temperature on diet digestibility and suggested that the reduction in passage rate of digesta caused by the reduction of gastrointestinal motility that usually occurs under hot environments (27, 30) was responsible. Mathers et al. (18) also found positive effects of high ambient temperature on diet digestibility by Ayrshire cattle exposed to a 33°C temperature for 20 d and suggested that the reduction of DMI was the cause. Miaron and Christopherson (20) reported an increase in DM and NDF digestibility in steers housed under warm environments (28°C for 21 d) when compared with steers under thermoneutral conditions (10°C for 21 d), although DMI in the stressed and control animals was similar. Other researchers (17, 24, 31) reported no variation or a decrease in diet digestibility by ruminants kept under hot environments. Those researchers explained such results by reduced digestibility of forages grown under hot environment or by the reduction in blood flow to tissues of the digestive tract.

Our results indicated that DM digestibility under ETHI was not always strictly dependent on DMI or changes in rumen passage rate. In trial 2, digestibility of the diet increased, and rumen passage rate and DMI decreased, in comparison with trial 1. Furthermore, negative relationships between rumen passage rate and DM digestibility and between DM digestibility and DMI were recorded in trial 2. In trial 3, DM digestibility did not change compared with that in trial 1. At the same time, rumen passage rate and DMI were lower in trial 3 compared with trial 1. Therefore, in our experiment, rumen passage rate and feed intake did not appear to be the determinant factors influencing DM digestibility after prolonged exposure to ETHI (trial 3). These facts imply that other factors might have been important in determining DM digestibility changes when animals were chronically exposed to ETHI.

Dilution of rumen contents caused by increased water intake (21, 28), reduction of saliva production (32), or a decline in rumen motility (30) might have reduced digestibility in trial 3 compared with trial 2. Furthermore, our results regarding changes in NDF, ADF, and NFC digestibility and data reported by Yousri et al. (37) would suggest that ETHI may depress rumen cellulolytic activity. The negative effect of such depression of rumen cellulolytic activity on diet digestibility might have overcome the positive effects caused by the decline in DMI and rumen passage rate, resulting in no difference in diet digestibility between trials 1 and 3. A recent study (33) in goats demonstrated that short exposure to high air temperatures was responsible for increased diet digestibility and that prolonged exposure of those same animals to hot environments caused a return to diet digestibility values recorded under thermoneutrality.

The different responses in digestibility when heifers were exposed to ETHI for different times might be related to lower rumen and intestinal absorption of nutrients that can occur in animals chronically exposed to high ambient temperature (6). The lower absorption of nutrients might be dependent on an adaptive redistribution of cardiac output from the digestive system to peripheral tissues and the respiratory system to increase heat loss (6). This hypothesis would be supported by the gradual reduction of rectal temperature observed in heifers during ETHI.

Our data on digestibility changes might explain, at least in part, the discrepancy among results found in the literature. If the contrast between trials 1 and 2 and between trials 1 and 3 are examined separately,

two different conclusions are reached. In the first comparison, the exposure to ETHI induced an increase in diet digestibility, but, in the second comparison, high temperatures did not affect diet digestibility.

The increase in BW concomitant with the decline in body score under heat-stress conditions has been reported previously (13, 15, 23). The increase in water intake and the decrease in passage rate observed in heat-stressed heifers might have increased gut fill during ETHI exposure (32). These two important factors might explain the discrepancy between the changes in average daily gain and body score observed under ETHI conditions.

CONCLUSIONS

Short-term and long-term heat stress reduced DMI and rumen passage rate in dairy heifers. Diet digestibility was affected by heat stress in a time-dependent fashion (digestibility increased with short-term exposure but was not affected by long-term exposure to heat stress) and did not appear to be related simply to changes in feed intake and passage rate of digesta when heifers were chronically exposed to the hot environment.

Changes in diet digestibility suggest an adaptive response of the digestive tract to heat stress. However, the factors responsible for changing digestibility response in chronically heat-stressed heifers were not identified.

REFERENCES

1 Association of Official Analytical Chemists. 1984. Official Methods of Analysis. 14th ed. AOAC, Arlington, VA.

2 Attebery, J. T., and H. D. Johnson. 1969. Effects of environmental temperature, controlled feeding and fasting on rumen motility. J. Anim. Sci. 29:734–737.

3 Beede, D. K., and R. J. Collier. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. J. Anim. Sci. 62:543–554.

4 Beede, D. K., and J. K. Shearer. 1991. Nutritional management of dairy cattle during hot weather. Agri-Practice 12:5–13.

5 Bittante, G., and I. Andrighetto. 1986. Comparazione del bilancio ingesta-escreta con dieci tecniche di stima della digeribilità nei bovini basate sull'impiego degli indicatori. Zoot. Nutr. Anim. 12:237–247.

6 Christopherson, R. J. 1985. The thermal environment and the ruminant digestive system. Pages 163–180 *in* Stress Physiology in Livestock. Vol. I. M. K. Yousef, ed. CRC Press, Boca Raton, FL.

7 Christopherson, R. J., and P. M. Kennedy. 1983. Effect of the thermal environment on digestion in ruminants. Can. J. Anim. Sci. 63:477–496.

8 Coppock, C. E., and J. W. West. 1986. Nutritional adjustments to reduce heat stress in lactating dairy cows. Pages 19–26 *in* Proc. Georgia Nutr. Conf. Feed Industry, Atlanta, GA Univ. Georgia, Athens GA.

9 Edmondson, A. J., I. J. Lean, L. D. Weaver, T. Farver, and G. Webster. 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72:68–78.

10 Goering, H. K., and P. J. Van Soest. 1970. Forage Fiber Analyses (Apparatus, Reagents, Procedures, and Some Applications). Agric. Handbook No. 379. ARS-USDA, Washington, DC.

11 Grovum, W. L., and V. J. Williams. 1977. Rate of passage of digesta in sheep. 6. The effect of level of food intake on mathematical prediction of the kinetics of digesta in the reticulorumen and intestines. Br. J. Nutr. 38:425–436.

12 Hatendi, P. R. 1996. The effect of diet and frequency of watering on the performance of growing cattle given food at maintenance. Anim. Prod. 63:33–38.

13 Ingram, D. L., and L. E. Mount. 1973. Animals in hot environment. Pages 123–145 *in* Man and Animals in Hot Environments. D. L. Ingram and L. E. Mount, ed. Springer-Verlag, New York, NY.

14 Johnson, H. D. 1980. Environmental management of cattle to minimize the stress of climate change. Int. J. Biometeorol. 24(Suppl. 7):65–78.

15 Lacetera, N., B. Ronchi, U. Bernabucci, and A. Nardone. 1994. Influence of heat stress on some biometrics parameters and body condition score in female Holstein calves. Riv. Agric. Subtrop. Trop. 88:81–89.

16 Lippke, H. 1975. Digestibility and volatile fatty acids in steers and wethers at 21 and 32°C ambient temperature. J. Dairy Sci. 58:1860–1864.

17 Lu, C. D. 1989. Effects of heat stress on goat production. Small Ruminant Res. 2:151–162.

18 Mathers, J. C., R. P. Baber, and R. F. Archibald. 1989. Intake, digestion and gastro-intestinal mean retention time in Asiatic buffaloes and Ayrshire cattle given two contrasting diets and housed at 20° and 33°C. J. Agric. Sci. (Camb.) 113:211–222.

19 McDowell, R. E., E. G. Moody, P. J. Van Soest, and R. P. Lehmann. 1969. Effect of heat stress on energy and water utilization of lactating cows. J. Dairy Sci. 52:188–194.

20 Miaron, J.O.O., and R. J. Christopherson. 1992. Effect of prolonged thermal exposure on heat production, reticular motility, rumen-fluid and particulate passage-rate constants, and apparent digestibility in steers. Can. J. Anim. Sci. 72:809–819.

21 Muna, M.M.A., and A. M Abdelatif. 1992. Utilization of nutrients by sheep as affected by diet composition and solar radiation. Small Ruminant Res. 9:37–45.

22 Murphy, M. R., R. L. Baldwin, and L. J. Koong. 1982. Estimation of stoichiometric parameters for rumen fermentation of roughage and concentrate diets. J. Anim. Sci. 55:411–421.

23 Nardone, A., N. Lacetera, B. Ronchi, and U. Bernabucci. 1993. Feed intake and weight gain in female calves exposed to thermal stress. Pages 155–159 *in* Proc. of 10th Congr. Nazionale Assoc. Sci. Prod. Anim. (ASPA), Bologna, Italy. ASPA, Bologna, Italy.

24 National Research Council. 1981. Effects of Environment on Nutrient Requirements of Domestic Animals. Natl. Acad. Sci., Washington, DC.

25 Ørskov, E. R., I. Ojwang, and G. W. Reid. 1988. A study on consistency of differences between cows in rumen outflow rate of fibrous particles and other substrates and consequences for digestibility and intake roughage. Anim. Prod. 47:45–51.

26 Owens, F. N., and A. L. Goetsch. 1986. Digesta passage and microbial protein synthesis. Pages 193–223 *in* Control of Digestion and Metabolism in Ruminants. L. P. Milligan, W. L. Growum, and A. Dobson, ed. Prentice Hall, New York, NY.

27 Robertshaw, D. 1981. The environmental physiology of animal production. Pages 3–17 *in* Environmental Aspects of Housing for Animal Production, J. A. Clark, ed. Butterworths, London, UK.

28 Roger, J. A., and C. L. Davis. 1982. Rumen volatile fatty acids production and nutrient utilization in steers fed a diet supplemented with sodium bicarbonate and monensin. J. Dairy Sci. 65:944–952.

29 SAS® User's Guide: Statistics, Version 6.11 Edition. 1996. SAS Inst., Inc., Cary, NC.
30 Schneider, P. L., D. K. Beede, and C. J. Wilcox. 1988. Nycterohemeral patterns of acid-base status, mineral concentrations and digestive function of lactating cows in natural or chamber heat stress environments. J. Anim. Sci. 66:112–125.
31 Silanikove, N. 1985. Effect of dehydration on feed intake and dry matter digestibility in desert (black Bedouin) and nondesert (Swiss Saanen) goats fed on lucerne hay. Comp. Biochem. Physiol. 80A:449–452.
32 Silanikove, N. 1992. Effect of water scarcity and hot environment on appetite and digestion in ruminants: a review. Livest. Prod. Sci. 30:175–194.
33 Sunagawa, K., M. Sakurada, H. Takahashi, F. Hongo, A. Shinjio, and S. Shiroma. 1997. The ruminal concentration of volatile fatty acids and digestibility of feed fractions in goats exposed to hot environment. Anim. Sci. Technol. 68:156–162.
34 Van Soest, P. J. 1994. Nutritional Ecology of the Ruminants. 2nd ed., Cornell Univ. Press, Ithaca, NY.
35 Warren, W. P., F. A. Martz, K. H. Asay, E. S. Hilderbrand, C. G. Payne, and J. R. Vogt. 1974. Digestibility and rate of passage by steers fed tall fescue, alfalfa and orchard grass in 18°C and 32°C ambient temperature. J. Anim. Sci. 39:93–96.
36 Williams, C. H., D. J. David, and O. Iismaa. 1962. The determination of chromic oxide in feces samples by atomic absorption spectrophotometry. J. Agric. Sci. 59:381–385.
37 Yousri, R. M., A. R. Abou Akkada, and A. K. Abou Raya. 1977. Rumen activity and blood urea of sheep as affected by climatic conditions. World Rev. Anim. Prod. 23:51–56.