University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

1999

Feedlot Diet Roughage Level for Hereford Cattle Exposed to Excessive Heat Load1

T. L. Mader
University of Nebraska, Northeast Research and Extension Center, Concord, NE

J B. Gaughan
University of Queensland, Gatton College, Gatton Queensland, Australia

B A. Young
University of Queensland, Gatton College, Gatton Queensland, Australia

Follow this and additional works at: http://digitalcommons.unl.edu/ardhaskell

Part of the Agriculture Commons

Mader, T. L.; Gaughan, J B.; and Young, B A., "Feedlot Diet Roughage Level for Hereford Cattle Exposed to Excessive Heat Load1" (1999). *Haskell Agricultural Laboratory (Northeast Research and Extension Center)*. 13.
http://digitalcommons.unl.edu/ardhaskell/13

This Article is brought to you for free and open access by the Agricultural Research Division of IANR at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Haskell Agricultural Laboratory (Northeast Research and Extension Center) by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

The Professional Animal Scientist 15:53–62 (1999)

Feedlot Diet Roughage Level for Hereford Cattle Exposed to Excessive Heat Load[1]

T. L. MADER, PAS*, J. B. GAUGHAN†, and B. A. YOUNG†

*Department of Animal Science, University of Nebraska, Northeast Research and Extension Center, Concord, NE 68728, and †Department of Animal Production, University of Queensland, Gatton College, Gatton Queensland, Australia 4343

Abstract

In Exp. 1, six individually fed Hereford steers were exposed to hot (HOT) or thermoneutral (TNL) environmental conditions (ENV) while being adapted (stepped-up) to a finishing diet by decreasing roughage level from 55 to 10% of the diet DM over 17 d. Only at 10% roughage did heat exposure result in reduced ($P<0.05$) calculated ME intake (MEI) and measured DMI. In the TNL treatment group, pulse rates increased as MEI and diet energy density increased ($P<0.05$), whereas in the HOT treatment group, pulse rate tended to decline when MEI declined. Body temperature (BT) of steers increased under both TNL and HOT conditions. In Exp. 2, six individually fed feedlot steers were assigned in a replicated (n = 3) 2 × 3 factorial arrangement of treatments and exposed to HOT or TNL ENV, whereas the diet treatments were a 6% roughage diet fed ad libitum (HE), or 90% of ad libitum (RE), or a 28% roughage diet (HR) fed ad libitum such that MEI approximated the MEI of the RE group. Steers fed HR diets had lower ($P<0.05$) respiratory rate and BT than HE and RE fed steers. Steers fed RE diets had greater ($P<0.05$) water intake than HE fed steers when averaged across ENV. Lower BT ($P<0.05$) of cattle fed RE and HR would indicate MEI prior to exposure to excessive heat load (EHL) influences ability of cattle to cope with subsequent exposure to excessive heat load. Data also indicate that adapting cattle to high energy diets partially contributes to EHL.

(Key Words: Body Temperature, Feedlot Cattle, Thermoregulation.)

Introduction

Discomfort can be experienced by animals during periods of elevated climatic temperatures as a result of excessive heat load (EHL) derived from the combination of environmental heat and metabolic heat production (50). Economic losses associated with EHL are a result of reduced feed intake, reduced BW gain, and, in extreme cases, death of cattle (16, 17, 18, 23, 25, 32, 51). Problems in managing cattle may be complicated if they are exposed to multiple stressors (13, 21), such as EHL, while being adapted to or fed high energy diets, whereby normal rumen and physiological functions are challenged (4, 5, 14, 26, 36, 38, 42, 43).

Quantity of feed consumed, in relation to environmental conditions, also appears to influence an animal's ability to cope with EHL. Reducing ME intake (MEI) through feed restriction has been shown to improve feed efficiency in ruminants (19, 30), possibly by lowering maintenance energy expenditure, heat production, and increasing diet digestibility (29, 37, 39). Wester et al. (46) and Yambayamba et al. (47) reported lower metabolic liver activity and mass in lambs and lower resting metabolic activity in heifers, respectively, when diets were restricted (maintenance) vs ad libitum levels. Restricting MEI by diluting high concentrate diets with fiber may have the same effect as restricting feeding of a high energy diet. However, the greater heat increment, per unit of DE, often associated with fiber may offset any advantages from dilution (32, 45). The objectives of the present study were to evaluate DMI, MEI, and physiological responses of cattle exposed to EHL while being adapted to high energy diets or being fed diets varying in energy level and density.

Materials and Methods

Trials were conducted in the large animal metabolism facilities at the

---

[1] Published as paper no. 11901, Journal Series, Nebraska Agric. Res. Div., Univ. Of Nebraska, Lincoln 68583-0908.

[2] $\mathrm{THI} = T_{db} - (0.55 - 0.55\,\mathrm{RH})(T_{db} - 58)$; where T_{db} = dry bulb temperature (°F) and RH = relative humidity expressed as a decimal (31).

Reviewed by R. Albin and A. D. Howes.

University of Queensland-Gatton, Australia. Prior to initiating trials, the experimental unit was divided into two test rooms (3.5 × 6.0 m), each containing three stalls (3 × 1 m). An insulated partition separated the rooms to allow for two environmental treatments (ENV) to be imposed concurrently. One room had the capability of being heated to temperatures above 38°C (HOT) using a heat pump installed in the partition between the rooms. Cool air from the heat pump was used to modulate daytime temperatures in the other room to maintain conditions at or near thermoneutrality (TNL). Although ENV were imposed during the day, the actual HOT and TNL room temperatures were also influenced by and varied with outside conditions, particularly at night when the HOT and TNL rooms were exposed to normal ambient temperatures. During test periods, the HOT steer groups were exposed to EHL during the day by heating the HOT room from approximately 22°C to temperatures around 38°C between 1400 and 1900 h daily. Experiments were conducted by randomly selecting six *Bos taurus* (Hereford) steers from a group of eight. For 30 d prior to initiating the first experiment, all eight steers were accustomed to halters and being tied.

Experiment 1. Six steers (mean weight 239 kg) were initially brought into stalls and fed a 55% roughage diet (Table 1) 10 d prior to trial initiation. During the subsequent 17-d trial, steers were fed 40, 25, and 10% roughage diets during three diet periods (DPR), of 5, 5, and 7 d, respectively, while being exposed to HOT or near TNL ENV.

Experiment 2. Three diet treatments (DIET) were imposed (Table 2) with cattle being fed 1) a 6% roughage diet ad libitum (HE) or 2) the same diet at 90% of ad libitum (RE), or 3) a 28% roughage diet (HR) fed ad libitum, such that MEI of the 28% roughage diet approximated the MEI of the restricted 6% roughage diet. The trial was replicated three times with steers being randomly assigned to a DIET and ENV combination each 4-d test period. Steers (mean weight 354 kg) were accustomed to DIET over a 7-d period while housed at or near thermoneutral conditions, prior to each test period. Daily water intake (WTI) was measured for each steer.

In both experiments, steers were fed once daily in the morning at approximately 0800 h. Feed intake (DMI) and calculated MEI were determined daily for each steer. Water was consumed ad libitum. Respiratory rate (RESP) and pulse rate (PR) were measured daily at 1600 h on each steer in Exp. 1 and 0800 and 1600 h in Exp. 2. Respiratory rate was obtained by counting flank or rib cage movements over 1-min intervals. Pulse rate was determined via a pulse monitor (Model Pu-701; Sun Medical, Bowen Hills, Qld, Australia) attached to an ear clip sensor. In Exp. 1, a baseline PR (mean of 24 readings per steer) was determined for each steer by averaging six readings taken each day of the last 4 d of the pretrial period while the steers were on the 55% roughage diet. Body temperature (BT) was obtained via a 21-cm rectal probe with a thermal sensor mounted in the tip. The rectal probe was secured to steers by an elastic cord (4-mm diameter) attached to a heart girth harness. Probes were connected by leads to a data logger (Mini-Mitter Co., Sunriver, OR) secured to the harness above animal's withers. Steers were adjusted to rectal probes for a minimum of 4 d prior to each Exp. Body temperatures were recorded at 10-min intervals in Exp. 1 and at 5-min intervals during each test period in Exp. 2. Temperature and relative humidity of each metabolism room were recorded at 30 min intervals also using a Mini-Mitter data logger.

Data were analyzed using GLM procedure of SAS® (40). In Exp. 1, the statistical model included ENV, DPR, ENV × DPR interaction, animal (ENV × DPR), and day (ENV × DPR). Means

TABLE 1. Composition of diets in Experiment 1.

Ingredients and content	Pretrial	Step-up period		
		1	2	3
	(% DM)			
Ingredient				
Barley[a]	21.0	27.5	35.0	42.5
Sorghum[a]	21.0	27.5	35.0	42.5
Alfalfa hay[b]	11.0	–	5.0	10.0
Oat hay[b]	44.0	40.0	20.0	–
Supplement[c]	3.0	5.0	5.0	5.0
Calculated nutrient content				
Crude protein	13.5	13.4	13.4	13.4
Calcium	0.55	0.57	0.60	0.63
Phosphorus	0.34	0.39	0.42	0.44
Roughage	55.0	40.0	25.0	10.0
Monensin, mg/kg	15.0	25.0	25.0	25.0
NEg, mcal/kg	0.96	1.07	1.20	1.33
NEm, mcal/kg	1.57	1.69	1.84	1.99
ME, mcal/kg	2.48	2.62	2.79	2.96

---

[a] Grains were coarse rolled with 75 to 90% of kernels cracked or broken.

[b] Roughages were moderately ground to particle size of 7 cm or less.

[c] Commercial supplement containing 50% CP, 8.89% Ca, 1.89% P, 4.88% NaCl, Co 100 mg/kg, Cu 200 mg/kg, Fe 300 mg/kg, I 20 mg/kg, Mn 600 mg/kg, Mo 10 mg/kg, Se 2 mg/kg, Zn 1000 mg/kg, 102 IU vitamin A/g, 8.6 IU vitamin D/g, 0.086 IU vitamin E/g, monensin 500 mg/kg, and trace minerals.

were separated using the LSD test when ENV × DPR interactions were found to be significant (*P*< 0.05). In Exp. 2, data were analyzed using SAS® (40) procedures for a 2 × 3 (ENV × DIET) factorial arrangement of a randomized complete block design. The statistical model included ENV, DIET, ENV × DIET, period, day, day × period, and two- and three-way interactions of ENV and DIET with day. Means were separated using the LSD test when ENV × DIET interactions were found to occur (*P*< 0.05). Pre-planned comparisons were made for HE vs RE diets, HE vs HR diets, ENV × HE and HR diet interaction, and ENV × HE and RE diet interactions.

Results and Discussion

Experiment 1. As a result of changing outside ambient temperatures, a small but gradual increase (~0.2°C/d) in mean daily temperature (Table 3 and Figure 1) was observed from period 1 to period 3 in both TNL and HOT rooms. Averaged across periods, mean temperature humidity index (THI[2]) was 4.3 units greater (75.4 vs 79.7) in the HOT room than in the TNL room. Due to the influence of outside ambient conditions, mean THI was found to slightly overlap for the TNL (Period 3, THI=77.9) and HOT (Period 1, THI=77.8) treatment groups, although peak THI values did not overlap. Peak THI averaged 74.6, 77.5, and 80.9 in the TNL room and 83.8, 84.7, and 88.1 in the HOT room in periods 1, 2, and 3, respectively. The Livestock Conservation Institute (22) established the Livestock Weather Safety Index based on THI values. Categories are alert (THI 75 to 78), danger (THI 79 to 83), and emergency (THI≥84). Analysis by Hahn and Mader (18) supported the use of THI>79 as a threshold for feedlot cattle placed at risk from EHL and that several hours of THI ≥ 84 with limited or no recovery periods of THI≤74 can result in death of vulnerable animals unless action is taken to limit EHL. For this study, average THI remained below 79 in the TNL room, although daily mean THI did exceed 79 on the last day of the trial only. Average minimum THI was below 74 in all but period 3 for both ENV.

During periods 1 and 2 (Table 4), when steers were fed 40% and 25% roughage diets, respectively, DMI and MEI were unaffected by EHL. When the 10% roughage diet was fed (period 3), DMI and MEI decreased significantly (*P*< 0.05) for the steer group in the HOT room even though steers were exposed to EHL for 10 d previously. A decline in intake with EHL is often expected (32) and is a mechanism by which the animal maintains homeostasis (8). During period 2, mean DMI of the HOT cattle varied, but overall was maintained and comparable to DMI of TNL cattle (Figure 1). Upon feeding the higher energy diet (period 3), d 11 DMI dropped dramatically, recovered slightly, and then steadily declined the last 3 d of the study as THI continued to increase. The decline in period 3 DMI for the HOT treatment group supports LCI (22) suggestions that cattle exposed to EHL (THI≥84) need a recovery period (THI≤74), which they did not have in period 3. In the TNL group, DMI were greater in period 2 than in periods 1 and 3; although MEI were similar in periods 2 and 3 but greater than MEI in period 1.

Respiratory rates increased (periods 1 vs 3) in both TNL and HOT treatment groups. However, PR increased only in the TNL treatment; the lowest PR occurred in the HOT treatment when DMI and MEI were the lowest (period 3). Percentage change, from a baseline PR, followed a similar pattern. In general, PR tended to increase with diet energy density and(or) MEI, particularly in the HOT treatment group. As steers went from one diet period to the next, BT (*P*<

TABLE 2. Composition of diets in Experiment 2.

Ingredients and content	Roughage level 28%	 6%
	(% DM)	
Ingredient		
Barley[a]	34.0	44.8
Sorghum[a]	34.0	44.8
Alfalfa hay[b]	19.0	6.0
Barley straw[b]	9.0	–
Limestone	–	0.4
Dry supplement[c]	4.0	4.0
Calculated nutrient content		
Dry matter	90.0	90.0
Crude protein	12.8	12.8
Calcium	0.69	0.64
Phosphorus	0.38	0.43
Monensin, mg/kg	22.0	22.0
NEg, mcal/kg	1.15	1.36
NEm, mcal/kg	1.78	2.02
ME, mcal/kg	2.73	2.99

[a] Grains were coarse rolled with 75 to 90% of kernels cracked or broken.

[b] Roughages were moderately ground to particle size of 7 cm or less.

[c] Commercial supplement containing 50% CP, 8.89% Ca, 1.89% P, 4.88% NaCl, Co 100 mg/kg, Cu 200 mg/kg, Fe 300 mg/kg, I 20 mg/kg, Mn 600 mg/kg, Mo 10 mg/kg, Se 2 mg/kg, Zn 1000 mg/kg, 102 IU vitamin A/g, 8.6 IU vitamin D/g, 0.086 IU vitamin E/g, monensin 550 mg/kg, and trace minerals.

TABLE 3. Mean climatic conditions and temperature-humidity index (THI) associated with cattle fed step-up diets (1, 2, or 3)[a] and exposed to thermoneutral (TNL) or hot (HOT) environments in Experiment 1.

	TNL				Hot			
Variable	**1**	**2**	**3**	**Mean**	**1**	**2**	**3**	**Mean**
Temperature, °C	24.5	25.6	28.1	26.3	29.6	30.6	33.4	31.5
Relative humidity, %	65.3	69.5	65.9	66.8	52.1	51.4	46.4	49.5
THI[b]								
Mean	72.6	74.6	77.9	75.4	77.8	79.0	81.8	79.7
Maximum	74.6	77.5	80.9	78.1	83.8	84.7	88.1	85.8
Minimum	69.6	71.4	74.5	72.1	71.9	73.7	75.9	74.1

[a] Diets fed in periods 1, 2, and 3 contained 40, 25, and 10% roughage, DM basis, and were fed sequentially 5, 5, and 7 d, respectively.

[b] $THI = T_{db} - (0.55 - 0.55\ RH)(T_{db} - 58)$; where T_{db} = dry bulb temperature (°F) and RH = relative humidity expressed as a decimal (NOAA, 1976).

0.05) increased in both TNL and HOT treatments. As expected, the greatest increase in BT occurred in the HOT treatment. The inability of an animal to dissipate or rapidly acclimate to added heat from the diet appeared to contribute to the decline in DMI for cattle fed the 10% roughage diet in the HOT treatment. Although feeding pattern of steers were not monitored, it would appear that evening and(or) night feeding of the HOT treatment was curtailed as a result of EHL during the day and possible lack of night-time cooling during most of period 3.

Pretrial baseline temperatures, while cattle were fed the 55% roughage diet in the stalls, averaged 39.0°C for both HOT and TNL treatments. Normal rectal BT for healthy cattle

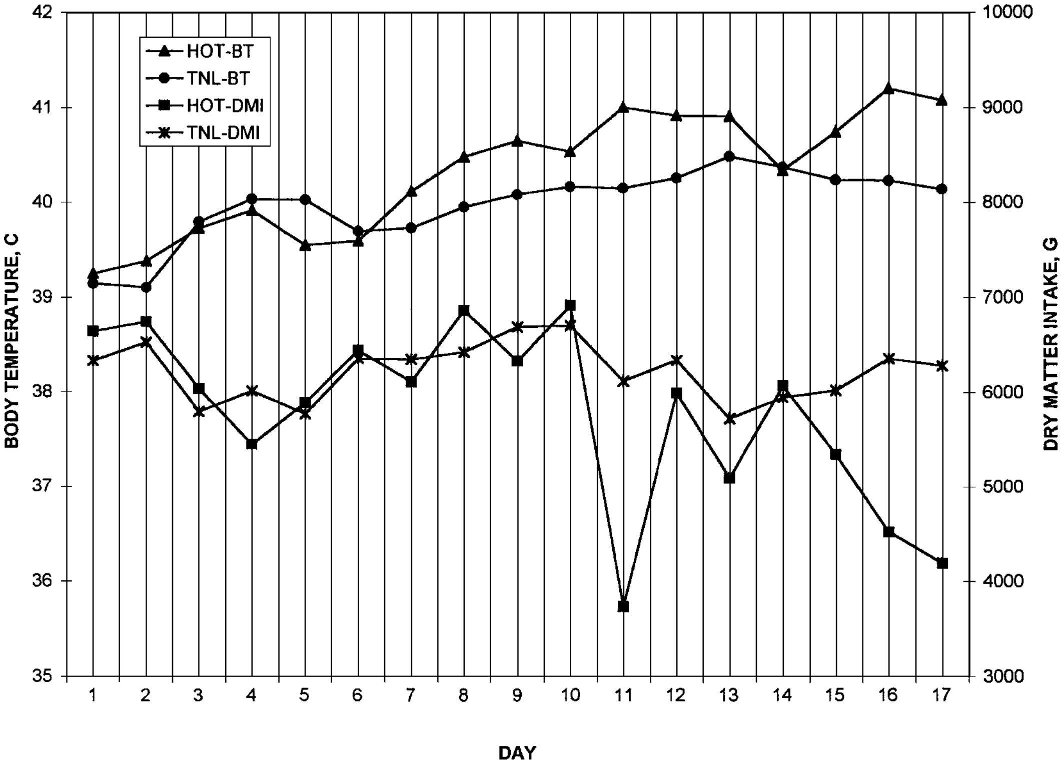

Figure 1. Temperature humidity index (THI) and DMI for cattle fed 40% roughage diet (d 1 to 5), 25% roughage diet (d 6 to 10), and 10% roughage diet (d 11 to 17) when exposed to hot (HOT) or near thermoneutral (TNL) environmental conditions.

TABLE 4. Mean dry matter intake (DMI), metabolizable energy intake (MEI), respiratory rate (RESP), pulse rate (PR), change from baseline PR (PRCHG), and body temperature (BT) for cattle exposed to near thermoneutral (TNL) or hot (HOT) environmental conditions (ENVCON)[a].

	Period 1		Period 2		Period 3		
Variable	**TNL**	**HOT**	**TNL**	**HOT**	**TNL**	**HOT**	**SE**
DMI, kg/d	6.09^{c}	6.15^{c}	6.50^{d}	6.53^{d}	6.11^{c}	4.99^{b}	0.15
MEI, mcal/d	15.98^{c}	16.14^{c}	18.11^{d}	18.20^{d}	18.05^{d}	14.74^{b}	0.20
RESP, breaths/min	58^{b}	109^{d}	64^{b}	132^{e}	80^{c}	135^{e}	4
PR, beats/min	87^{b}	92^{bc}	96^{cd}	93^{b}	102^{d}	86^{b}	3
PRCHG, %	2.9^{b}	8.4^{bc}	12.0^{cd}	10.2^{bcd}	18.2^{d}	2.7^{b}	2.5
BT, C	39.6^{b}	39.6^{b}	39.9^{bc}	40.3^{c}	40.3^{c}	40.9^{d}	0.1

---

[a] Diets fed in periods 1, 2, and 3 contained 40, 25, and 10% roughage and were fed sequentially for 5, 5, and 7 d, respectively.

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

should average 38.5±0.5°C (28). During the trial, average steer BT ranged between 39.6 to 40.3°C and 39.6 to 40.9°C in TNL and HOT treatment groups, respectively. There was no evidence of ill health in the steers during the trial. Intakes (DMI) remained between 2.1 and 2.7% of BW. The slight daily increase in ambient temperatures during the trial may have contributed to an increase in BT; although a gradual change in normal ambient temperature may have had only minimal effect on BT, particularly in the TNL group. Thermoregulatory processes should maintain stable BT as long as gradual changes in ambient temperature are within the animal's thermoneutral zone (TNZ) whereas abrupt changes (>12°C) in environmental temperatures within TNZ increase BT (27).

Higher roughage diets (≥25% of diet DM), which are lower in ME density, appear to contribute less to metabolic heat load. Also, diurnal ranges (Figure 2) in cattle BT can be up to three times greater than normal in cattle exposed to EHL, depending on season, daily ambient temperature fluctuations, production levels, and degree of acclimation to thermal heat load (2, 9, 41). Berman and Morag (2) reported peak BT (rectal temperature) at both 1800 and 2400 h with a range of 0.4°C. in the winter and at 1800 h in the summer with a range of 1.2°C. Peak BT were found to be around 1700 h in lactating dairy cows (3). In the present study, peak BT was near 1800 h in all three periods for the HOT treatment group. For the TNL treatment group, BT peaked around 2100 h in period 1 and near 2400 h in period 2 and 3. Lefcourt and Adams (23) reported peak BT around 2200 h in feedlot cattle. Hahn (15) suggested that on the average, there is about a 3-h phase lag between peak air and body temperature in HOT conditions. In the present study, HOT room maximum THI occurred around 1500 h. Lag time between peak BT and HOT are in very close agreement to that reported by Hahn (15).

Experiment 2. Mean THI was 7.4 (71.7 vs 79.1) units greater in the HOT room than in the TNL room. Peak THI averaged 75.6 and 86.6 in the TNL and HOT rooms, respectively, whereas lower THI levels averaged 67.8 for both rooms (Table 5).

Mean RESP (Table 6) was found to be greater ($P<0.05$) for HOT cattle at both 0800 and 1600 h. Cattle fed HE diets had greater ($P<0.05$) RESP than RE fed cattle at 0800 h only, and tended to have greater RESP than HR fed cattle at both 0800 and 1600 h. Only at 0800 h did PR differ; HE fed cattle had greater ($P<0.05$) PR than RE and HR fed cattle. Interactions between ENV and DIET existed for BT at both times and over the entire trial. Under HOT conditions (Table 6 and Figure 3), near the time of peak heat exposure (1600 h), HE and RE fed cattle had BT of 0.9 and 0.6°C. greater ($P<0.05$), respectively, than HR cattle. Under TNL conditions, BT were similar among diet treatments, although in the diet adaptation program (Exp. 1), greater BT and RESP were found under both TNL and HOT conditions for cattle fed the diet highest in energy density.

TABLE 5. Mean environmental conditions associated with cattle exposed to thermoneutral (TNL) or hot (HOT) environments in Experiment 2.

Variable	**TNL**	**HOT**
Temperature, °C	23.6	30.3
Relative humidity, %	68.4	56.0
Daily THI[a]		
Mean	71.7	79.1
Maximum	75.6	86.6
Minimum	67.8	67.8

---

[a] Temperature Humidity Index = T_{db} – (0.55 – 0.55 RH) (T_{db} – 58) where T_{db} = dry bulb temperature (°F) and RH = relative humidity expressed as a decimal (NOAA, 1976).

In the TNL treatment group (Table 7), DMI of the RE fed steers was 91.5% of the HE fed steers and near the designed level of 90%. Environmental condition by DIET interactions (P<0.05) were found for DMI, MEI, and WTI. In both TNL and HOT treatment groups, DMI (percentage BW) was similar between HE and HR fed steers. However, RE steers had the lowest DMI under TNL conditions, but they had the greatest DMI under HOT conditions. This same trend was particularly evident for MEI and MEI (percentage BW) under HOT conditions; whereas under TNL conditions, MEI was similar between LE and HR fed steers but greater than HE steers. A decline in intake with EHL is often expected (32) and a mechanism which the animal maintains homeostasis (8); this was particularly evident in ad libitum (HE and HR) groups.

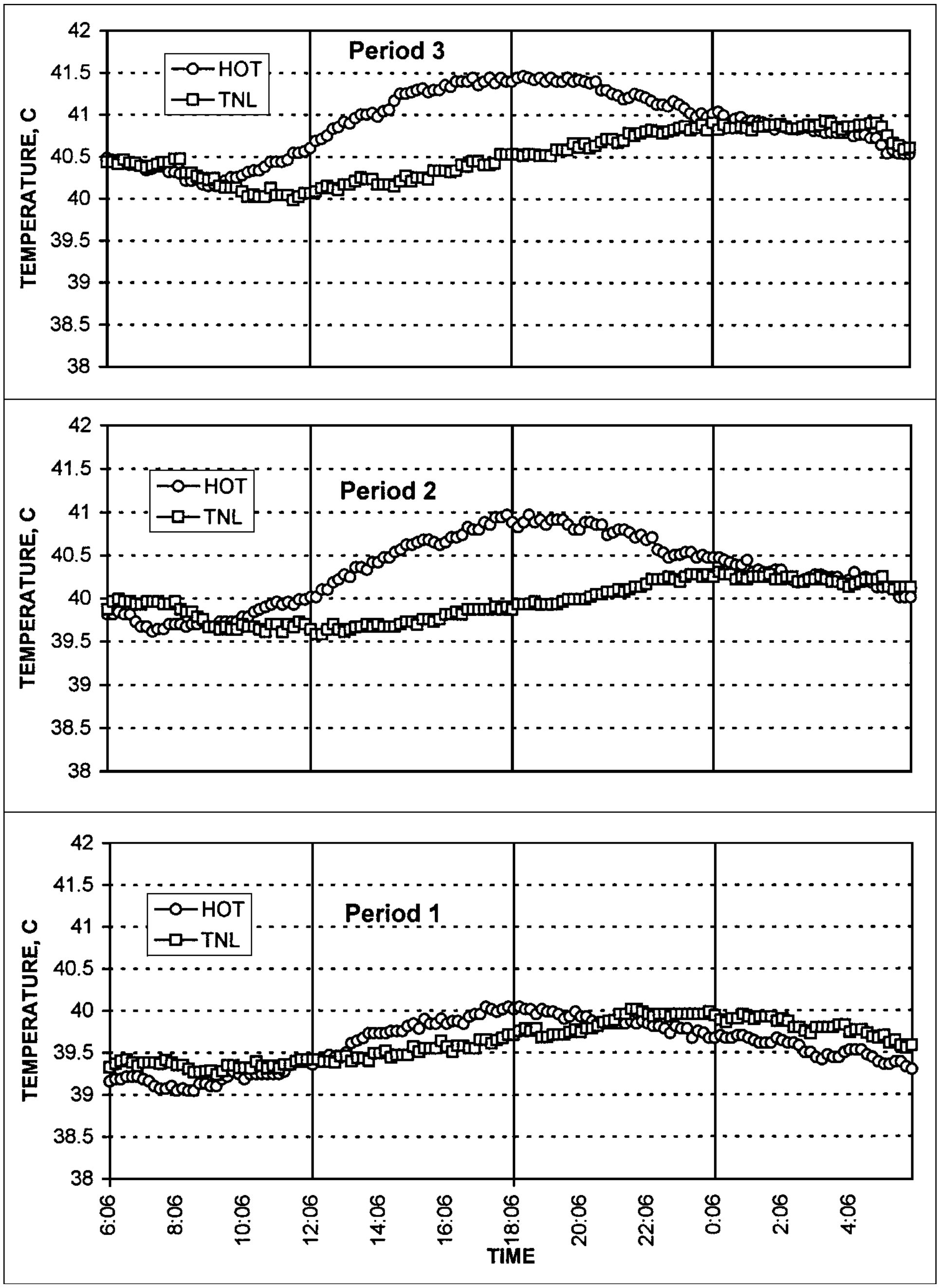

Figure 2. Rectal temperatures for steers fed 40, 25, and 10% roughage diet during periods 1 (d 1 to 5), 2 (d 6 to 10), and 3 (d 11 to 17), respectively.

TABLE 6. Mean respiratory rate (RESP), pulse rate (PR), and body temperature (BT) collected at 0800 h, 1600 h, and over entire trial (BT only)[a].

Environment (ENV):	TNL			HOT			
Diet:	HE	RE	HR	HE	RE	HR	SE
RESP, breaths/min							
0800 h[b,c]	60.9	55.6	56.1	66.4	59.5	60.9	3.0
1600 h[b]	74.7	70.5	61.3	128.0	125.4	122.7	5.2
PR, beats/min							
0800 h[c,d,e]	80.7	77.1	76.2	79.2	75.7	72.4	1.8
1600 h	92.9	92.2	88.7	85.7	93.0	86.8	3.1
BT, C							
0800 h[b,c,d,e,f,g]	38.7	38.6	38.6	39.5	38.9	38.7	.1
1600 h[b,c,d,e,f,g]	38.9	38.6	38.9	40.6	40.3	39.7	.1
Entire trial[b,c,d,e,f,g]	39.0	38.7	38.9	40.2	39.7	39.3	.1

---

[a] Cattle were fed ad libitum (HE) or approximately 90% of ad libitum (RE) a 6% roughage diet, or fed ad libitum a 28% roughage diet (HR) while being exposed to thermoneutral (TNL) or hot (HOT) environmental conditions.

[b] ENV effect ($P<0.05$).

[c] HE vs RE ($P<0.05$).

[d] Diet effect ($P<0.05$).

[e] HE vs HR ($P<0.05$).

[f] ENV by diet interaction ($P<0.05$).

[g] ENV by HE and HR interaction ($P<0.05$).

TABLE 7. Mean daily dry matter (DMI), metabolizable energy (MEI), and water (WTI) intake[a].

	TNL			HOT			
Variable	HE	RE	HR	HE	RE	HR	SE
DMI, kg/d[b,c,d]	7.13	6.52	7.17	6.06	6.22	5.88	0.18
MEI, mcal/d[b,c,d,e,f]	21.30	19.47	19.56	18.11	18.58	16.03	0.52
DMI, % BW[b,c,d]	2.00	1.80	1.99	1.67	1.75	1.67	0.03
MEI, % BW[b,c,d,e,f]	5.98	5.38	5.42	4.99	5.23	4.55	0.10
WTI,							
l/d[e,f,g]	21.31	25.56	25.75	19.63	27.19	24.81	1.27
l/kg DMI[b,e,f,g]	3.04	3.78	3.46	3.02	4.36	4.27	0.22
l/mcal MEI[b,e,f,g]	1.02	1.27	1.27	1.01	1.46	1.57	0.08
Feces, % DM[b]	26.7	27.1	25.8	28.4	28.5	27.6	0.5

---

[a] Cattle were fed ad libitum (HE) or approximately 90% of ad libitum (RE) a 6% roughage diet, or fed ad libitum a 28% roughage diet (HR) while being exposed to thermoneutral (TNL) or hot (HOT) environmental conditions.

[b] ENV effect ($P<0.05$).

[c] ENV by diet interaction ($P<0.05$).

[d] ENV by HE and RE diet interaction ($P<0.05$).

[e] Diet effect ($P<0.05$).

[f] HE vs HR ($P<0.05$).

[g] HE vs RE ($P<0.05$).

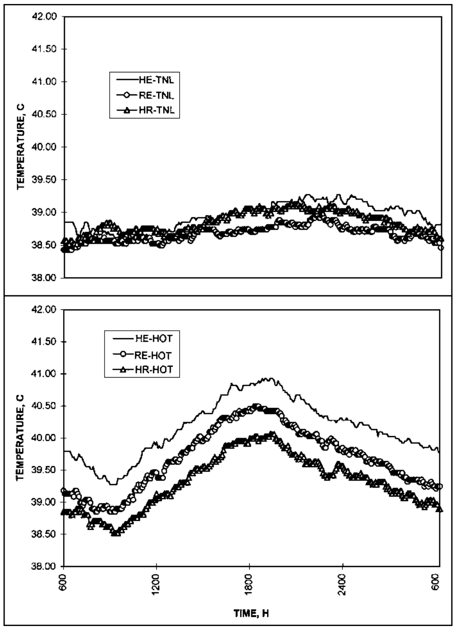

Figure 3. Rectal temperatures for steers fed a high energy diet, ad libitum (HE) or restricted (RE), or fed a 2% roughage diet (HR) under hot (HOT) or thermoneutral (TNL) conditions.

Water intake was greater (*P*<0.05) for RE and HR steers than for HE steers; only in the RE groups did HOT conditions tend to enhance WTI. Similar trends were found with WTI expressed per unit of DMI and MEI; in addition, ENV effects (HOT>TNL) were found (*P*<0.05). Fecal scores were also obtained in this trial. No differences in scores were apparent. However, ENV effects were noted for fecal DM with greater (*P*<0.05) fecal DM found in the HOT than in the TNL cattle group.

Total heat production is the amount of energy that is transferred from the animal to the environment and consists of many components: fasting metabolism, heat associated with voluntary activity, heat of product formation, heat of thermal regulation, heat of digestion and absorption, heat of waste formation and excretion, and heat of fermentation (7, 20, 32, 33). The bulk of the heat production attributed to fasting metabolic rate is believed to be associated with processes that include protein and lipid turnover, maintenance of ion gradients, vascular circulation, and muscle tone (24).

Evidence exists that a reduction in energy intake in cattle is followed by a reduction in metabolic rate (44). The lowered intensity of heat production is due to decreased maintenance heat production. A further effect of limited food intake is a change in the diurnal range in BT (10), with the lower range of BT typically extended. Such diurnal change in BT in response to food deficits is an appropriate strategy to conserve energy during drought (9). In the study reported herein, the range in BT tended to be greater under HOT conditions. However, under HOT conditions, RE and HR cattle had lower maximum and minimum BT than HE cattle.

If cattle are already experiencing heat stress, the heat of fermentation adds to the animals' total heat load and increases the energy expenditure needed for heat dissipation. Slightly increased respiration from heat stress can increase the maintenance energy expenditure by 7%, and heavy, labored panting can increase the maintenance energy cost by 11 to 25% (32). Data suggest that, during the summer, cattle limit-fed in the evening convert feed to gain more efficiently (*P*<0.06) than those fed in the morning (38), although Gaughan et al. (14) found no benefit from afternoon feeding when limited night-time cooling occurs.

Old and Garrett (35) observed that restricted feeding (0, 15, or 30%) affected fasting heat production (FHP) and that efficiency of ME use for gain (kilograms) was lower (*P*<0.05) when cattle consumed feed ad libitum. In a series of experiments, Hicks et al. (19) found that limit feeding tended to improve feed efficiency of feedlot steers but reduced rate of gain. Specific reasons for this improvement were not determined. Reduced liver size, reduced animal activity, reduced feed waste, or increased diet digestibility were not detected. Fluharty and McClure (11) suggested reasons for the improved feed efficiency with restricted feeding, which included reduced feed wastage, increased diet digestibility, reduced animal activity, and reduced visceral organ size, which reduce maintenance requirements. Fluharty and McClure (11) did find that restricted feeding reduced visceral organ mass compared with allowing lambs ad libitum access to feed. The reduction in visceral organ mass appears to be partly responsible for lowered maintenance energy requirements.

Carstens et al. (6) found that feed-restricted steers had lower heat production than ad libitum control steers and that it took restricted steers 3 wk of realimentation to increase heat production to control levels. Yambayamba et al. (47) concluded that the changes in thyroid secretion rates and resting metabolic rate patterns in restricted heifers were an indication of a reduced energy requirement for maintenance during the restriction period and the initial phase of the realimentation period. Such changes contribute to the animal's ability to utilize energy and protein more efficiently during realimentation (12). Fox et al. (12) further noted that a reduced maintenance requirement during feed restriction and the first part of realimentation would result in a greater proportion of the total energy consumed being used for growth than would normally be expected.

Purwanto et al. (37) reported increases in body heat production were found to peak 3 h after morning and afternoon feedings in high producing dairy cows. Pulse rate followed a pattern similar to heat production. In the present study, afternoon (1600 h) PR averaged nearly 10 beats per minute greater than morning (0800 h) PR. Also, although no ENV effect was noted, cattle fed HE diets had a greater pulse rate than cattle fed RE and HR diets (0800 h only). In general, these data support conclusions of Purwanto et al. (37) that diurnal heat production and, to a certain degree, heart rate pattern depend on feeding time and total feed intake. These data also support findings by Olbrich et al.

(34), who reported higher respiration rates for cattle consuming high concentrate diets vs cattle consuming high roughage diets (10 vs 55% cottonseed hulls).

The greater WTI for RE cattle was unexpected, although Yang et al. (48) reported that pigs consumed more water when food was restricted. Water was consumed for abdominal fill and overdrinking (polydripsia) was a behavioral response to hunger (49). Greater fecal DM under HOT conditions agree with findings of Beede (1), who reported that loss of water through feces lessens in dairy cattle as water losses through respiratory tract and skin increase.

Amount and time feed is consumed, in relation to environmental conditions, appears to influence BT and, ultimately, the ability of the animal to cope with EHL. Therefore, under ad libitum feeding conditions, BT, RESP, and PR vary with both MHL and EHL. Data suggest that under HOT, cattle fed higher roughage diets and(or) restricted in ME intake individually fed cattle maintain lower BT. Furthermore, cattle being adapted from 55 to 10% roughage diets and exposed to EHL were able to maintain intake up to the 25% roughage diet, even though BT was slightly elevated. A portion of the increase in BT found in cattle as they were stepped up from 55 to 10% roughage diets appears to be attributed to an increase in MEI under both TNL and HOT conditions. Recovery periods with THI approximately 74 or less are needed for cattle exposed to EHL. For cattle exposed to a limited heat load, as occurs under TNL conditions, the need for a recovery period is less critical.

Cattle managed for the most rapid and efficient gains present unique challenges during environmental extremes. In particular, high temperatures and humidities add to the problems of cattle fed high energy diets. Diet step-up and feeding programs should be managed to account for thermoregulatory responses associated with environmental challenges. Allowing for reduced DM and ME intakes or reducing feed offered is essential for cattle to maintain homeostasis when exposed to excessive heat load.

Literature Cited

1. Beede, D. K. 1992. Water for dairy cattle. In: Large Dairy Herd Management. H. H. Van Horn and C. J. Wilcox, (Eds.). p 260. Management Services, Am. Dairy Sci. Assn., Champaign, IL.

2. Berman, A., and Morag, M. 1971. Nychthermal patterns of thermoregulation in high-yielding dairy cows in a dry near-natural climate. Aust. J. Agric. Res. 22:671.

3. Bitman, J., A. Lefcourt, D. L. Wood, and B. Stroud. 1984. Circadian and ultradian temperature rhythms of lactating dairy cows. J. Dairy Sci. 67:1014.

4. Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrott. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. J. Anim. Sci. 68:1201.

5. Brosh, A., Y. Aharoni, A. A. Degen, D. Wright, and B. A. Young. 1998. Estimation of energy expenditure by heart rate measurements in cattle maintained under different conditions. J. Anim. Sci. 76:3054.

6. Carstens, G. E., D. E. Johnson, and M. A. Ellenberger. 1989. Energy metabolism and composition of gain in beef steers exhibiting normal and compensatory growth. In: Energy Metabolism of Farm Animals. Eur. Assoc. Anim. Prod. Publ. No. 43. p 131. Lunteren, The Netherlands.

7. Curtis, S. E. 1981. Environmental Management in Animal Agriculture. Animal Environment Services, Mahomet, IL.

8. DeDios, O. O., and G. L. Hahn. 1993. Thermoregulation of growing bovines during fall transitional environments. p 289. Proc. Int. Livest. Envir. Symp. Am. Soc. Agric. Eng., St. Joseph, MI.

9. Finch, V. A. 1986. Body temperature in beef cattle: its control and relevance to production in the tropics. J. Anim. Sci. 62:531.

10. Finch, V. A., and J. M. King. 1982. Energy-conserving mechanisms as adaptation to undernutrition and water deprivation in the African zebu. In: Use of Tritiated Water in Studies of Production and Adaptation in Ruminants. p. 167. Int. Atomic Energy Agency, Vienna, Austria.

11. Fluharty, F. L., and K. E. McClure. 1997. Effects of dietary energy intake and protein concentration on performance and visceral organ mass in lambs. J. Anim. Sci. 75:604.

12. Fox, D. G., R. L. Preston, B. Senft, and R. R. Johnson. 1974. Plasma growth hormone levels and thyroid secretion rates during compensatory growth in beef cattle. J. Anim. Sci. 38:437.

13. Friend, T. H. 1991. Behavioral aspects of stress. J. Dairy Sci. 74:292.

14. Gaughan, J. B., T. L. Mader, D. Savage, and B. A. Young. 1996. Effect of feeding regime on feed intake of cattle exposed to heat. Aust. Soc. Anim. Prod. 21:223.

15. Hahn, G. L. 1989. Body temperature rhythms in farm animals: A review and reassessment relative to environmental influences. In: Proc. 11th Int. Soc. Biometeorology Congr. D. Driscoll and E. O. Box (Eds.). p 325. SPB Publishing, The Hague, The Netherlands.

16. Hahn, G. L. 1994. Environmental requirements of farm animals. In: Handbook of Agricultural Meteorology. J. F. Griffiths (Ed.). p 220. Oxford University Press, New York, NY.

17. Hahn, G. L. 1995. Environmental influences on feed intake and performance of feedlot cattle. In: Symp.: Intake by Feedlot Cattle. F. N. Owens (Ed.). p 207. Oklahoma State Univ., Stillwater, OK.

18. Hahn, G. L., and T. L. Mader. 1997. Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. Proc. 5th Int. Livest. Environ. Symp. p 563. Am. Soc. Agric. Eng., St. Joseph, MI.

19. Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, and C. A. Strasia. 1990. Effects of controlled feed intake on performance and carcass characteristics of feedlot steers and heifers. J. Anim. Sci. 68:233.

20. Houpt, T. R. 1968. Heat production of bovine ruminal ingesta. Am. J. Vet. Res. 29:411.

21. Kelley, K. W. 1985. Immunological consequences of changing environmental stimuli. In: Animal Stress. G. P. Moberg, (Ed.). p 193. Am. Physiol. Soc., Bethesda, MD.

22. LCI. 1970. Patterns of transit losses. Livestock Conservation Inst., Bowling Green, KY.

23. Lefcourt, A. M., and W. R. Adams. 1996. Radiotelemetry measurements of body temperatures of feedlot steers during summer. J. Anim. Sci. 74:2633.

24. MacRae, J. C., and G. E. Lobley. 1982. Some factors which influence thermal energy losses during the metabolism of ruminants. Livest. Prod. Sci. 9:447.

25. Mader, T. L., L. R. Fell, and M. J. McPhee. 1997. Behavior response of non-brahman cattle to shade in commercial feedlots. Proc. 5th Int. Livest. Envir. Symp. p 795. Am. Soc. Agric. Eng., St. Joseph, MI.

26. Mader, T. L., G. L. Poppert, and R. A. Stock. 1993. Evaluation of alfalfa type as a roughage source in feedlot adaptation and finishing diets containing different corn types. Anim. Feed Sci. Technol. 42:109.

27. McLean, J. A., A. J. Downie, C.D.R. Jones and D. P. Stombaugh. 1983. Thermal adjustments of steers (Bos taurus) to abrupt changes in environmental temperature. J. Agric. Sci. (Camb.) 100:305.

28. Merck Veterinary Manual. 1991. A handbook of diagnosis, therapy, and disease prevention and control for the veterinarian. (7th Ed.). Merck & Co., Inc., Rahway, NJ.

29. Murphy, T. A., and S. C. Loerch. 1994. Effects of restricted feeding of growing steers on performance, carcass characteristics, and composition. J. Anim. Sci. 72:2497.

30. Murphy, T. A., S. C. Loerch, K. E. McClure, and M. B. Solomon. 1994. Effects of restricted feeding on growth performance and carcass composition of lambs. J. Anim. Sci. 72:3131.

31. NOAA. 1976. Livestock hot weather stress. Operations manual letter C-31-76. NOAA, Kansas City, MO.

32. NRC. 1981a. Effect of environment on nutrient requirements of domestic animals. National Academy Press, Washington, DC.

33. NRC. 1981b. Nutritional Energetics of Domestic Animals and Glossary of Energy Terms. National Academy Press, Washington, DC.

34. Olbrich, S. E., F. A. Martz, and E. S. Hilderbrand. 1973. Ambient temperature and ration effects on nutritional and physiological parameters of heat and cold tolerant cattle. J. Anim. Sci. 37:574.

35. Old, C. A., and W. N. Garrett. 1987. Effects of energy intake on energetic efficiency and body composition of beef steers differing in size at maturity. J. Anim. Sci. 65:1371.

36. Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1996. A new look at acidosis. In: Proc. Southwest Nutrition and Management Conference. p 1. Univ. of Arizona, Tucson, AZ.

37. Purwanto, B. P., Y. Abo, R. Sakamoto, F. Furumoto, and S. Yamamoto. 1990. Diurnal patterns of heat production and heart rate under thermoneutral conditions in Holstein Friesian cows differing in milk production. J. Agric. Sci. (Camb.) 114:139.

38. Reinhardt, C. D., and R. T. Brandt. 1994. Effect of morning vs evening feeding of limited-fed Holsteins during summer months. p 38. Kansas State Univ. Cattleman's Day Rep. Kansas State Univ., Manhattan, KS.

39. Sainz, R. D., F. De la Torre, and J. W. Oltjen. 1995. Compensatory growth and carcass quality in growth-restricted and refed beef steers. J. Anim. Sci. 73:2971.

40. SAS. 1994. SAS/STAT[7]. User's Guide (Version 6.10). SAS Inst. Inc., Cary, NC.

41. Scott, I. M., H. D. Johnson, and G. L. Hahn. 1983. Effect of programmed diurnal temperature cycles on plasma thyroxine level, body temperature, and feed intake of Holstein dairy cows. Int. J. Biometeor. 1:47.

42. Stock, R., and R. Britton. 1993. Acidosis in feedlot cattle. In: Scientific Update on Rumensin/Tylan for the Professional Feedlot Consultant. Elanco Animal Health, Indianapolis, IN.

43. Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedeken. 1990. Effects of grain type, roughage level, and monensin level on finishing cattle performance. J. Anim. Sci. 68:3441.

44. Turner, H. G., and C. S. Taylor, St. 1983. Dynamic factors in models of energy utilization with particular reference to maintenance requirements of cattle. Wld. Rev. of Nutr. and Diet. 42:135.

45. Webster, A.J.F. 1983. Energetics of maintenance and growth. In: Mammalian Thermogenesis. L. Girardier and M. J. Stock, (Eds.). p 178. Chapman and Hall, London, UK.

46. Wester, T. J., R. A. Britton, T. J. Klopfenstein, G. A. Ham, D. T. Hickok, and C. R. Krehbiel. 1995. Differential effects of plane of protein or energy nutrition on visceral organs and hormones in lambs. J. Anim. Sci. 73:1674.

47. Yambayamba, E. S. K., M. A. Price, and G. R. Foxcroft. 1996. Hormonal status, metabolic changes, and resting metabolic rate in beef heifers undergoing compensatory growth. J. Anim. Sci. 74:57.

48. Yang, T. S., B. Howard, and W. V. Macfarlane. 1981. Effects of food on drinking behaviour of growing pigs. Appl. Anim. Ethol. 7:259.

49. Yang, T. S., M. A. Price, and F. X. Aherne. 1984. The effect of level of feeding on water turnover in growing pigs. Appl. Anim. Ethol. 12:103.

50. Young, B. A. 1993. Implications of excessive heat load to the welfare of cattle in feedlots. In: Recent Advances in Animal Nutrition in Australia. p 45. Univ. of New England, Armidale, N.S.W., Australia.

51. Yousef, M. K. 1985. Stress Physiology in Livestock: Volume I. Basic Principles. CRC Press, Boca Raton, FL.