Physiological Responses in Thermal Stressed Jersey Cows Subjected to Different Management Strategies

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ABSTRACT

The effects of cooling and recombinant bovine somatotropin (rbST) on milk yield, reproductive performance, and health of Jersey cattle during summer thermal stress were measured for 2 yr. Cows were assigned to one of two groups based upon days in milk (DIM), parity, and genetic index. Year 1 and year 2 control cows ($n = 143$, $n = 183$, respectively) were housed in a pen with only shades. Cooled treatment cows each year ($n = 142$, $n = 180$) were housed with a spray and fan system for evaporative cooling. Cows were assigned at various days postpartum, not before d 63, coincident with commencement of rbST injections. One half of cows in each group received rbST on d 63 postpartum. Cows were assigned to the shade trial ranging from d 63 to 190. Cooled versus noncooled DIM were similar at the start of the trial. Trials began on July 1, 1999, and July 1, 2000, and concluded on September 30, 1999, and September 25, 2000. The ANOVA of daily milk weight data was conducted utilizing a 2×2 factorial design with cooling and rbST treatments as main effects. Cooling in combination with rbST increased milk yield compared with no cooling and no rbST for 1999 and 2000 (25.5 versus 21.8 kg/d, and 23.7 versus 20.5 kg/d, respectively). In general, cooling improved health and reproductive performance. (**Key words:** thermal stress, cooling, bovine somatotropin, Jersey)

Abbreviation key: rbST = recombinant bST; THI = temperature-humidity index.

INTRODUCTION

Intense summer heat is common in many parts of the United States that are becoming major milk production areas. In the southern group of states, Jersey cattle are

more popular because, during times of high environmental thermal stress with temperature humidity indices (THI) above 78, their milk production and reproductive efficiencies are not as depressed as Holstein cattle (McDowell et al., 1976). Jersey cow numbers increased in Arizona from 2.5% of the cows in 1975 to 13.4% in 2000 (D. Armstrong, personal communication).

Several research projects have shown that housing systems in hot climates can be modified with the use of evaporative cooling to improve both milk production and reproductive efficiency of Holstein dairy cattle (Armstrong et al., 1988, 1993a, 1993b; Flamenbaum et al., 1986; Ryan et al., 1992; Smith et al., 1993). Another study (Daugherty, 1993) used information from those trials in an investment analysis of dairy cattle cooling systems to show that the rate of return on investment in cooling equipment was profitable under several levels of milk production and ambient temperature ranges. Research data show that Jersey cattle are more adaptable than Holstein cattle to high temperatures for both lactating cows and young calves (Brody et al., 1954; Collier et al., 1981; Hernandez and Castellanos, 1983; McDowell, 1985). Feed intake data for both Jersey and Holstein cattle housed on a dairy farm that utilized a shade evaporative cooling showed feed intake average for Jersey cows to be 16.1 kg/d (range, 14.9 to 17.0 kg) during the summer months, with Holstein cattle averaging 20.2 kg (range, 17.1 to 22.9 kg; Allen, 1993, personal communication). Milk production on a per-cow basis was not available, but a decline of feed intake in hot weather is associated with a decline in milk production (Brody et al., 1954; El-Koja, 1979).

The first objective of the trial was to evaluate the effects of evaporative cooling on high-producing Jersey cattle subjected to thermal stress. The second objective was to evaluate the effects of recombinant (rbST) (Posilac, Monsanto, St. Louis, MO) on heat-stressed Jersey cattle and evaluate possible interactions between the two treatments.

MATERIALS AND METHODS

The trial was conducted over a 2-yr period in a commercial Jersey dairy operation milking 1100 head in Litch-

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field Park, Arizona. The rolling herd average was 305-d mature equivalent 8505 kg of milk, 385 kg of fat, 315 kg of protein. Days open and calving interval for the entire herd were 110 and 12.88, respectively, based upon calendar year 1999.

Cows were housed in open corrals with 5.5 m high metal shades providing 2.3 m²/cow. One pen was not cooled (control), and one was cooled. Cooled pens were equipped with 10 (0.76 m) oscillating fans placed on shade support poles at a height of 3.6 m, providing 425 m³/min of air movement and delivering 3.8 l/min of water at an initial cost of \$200/cow. The cooled and noncooled cows had misters at the roofline of all shades. Both the cooled and noncooled cows had evaporative cooling twice daily in the holding pen before milking, for approximately 30 min. Cows were milked twice daily starting at 0300 and 1500 h. Cows were assigned to the trial at various days postpartum, but no cow was assigned before d 63, coincident with commencement of rbST injections. Half of the cows in each group were assigned to receive rbST on d 63 postpartum. Health outcomes were recorded by the farm staff to include new incidences of mastitis and metabolic disorders, which included laminitis, hoof problems, off-feed, and any illness affecting milk production not related to mastitis. Two pens were fed identical rations as balanced by a nutritionist, consisting of typical southwestern dairy ingredients: corn, barley, alfalfa, corn silage, and whole cottonseed. The NE_L was 1.82 Mcal/kg with 19.1% CP and 5.52% fat. The pens were new the first year of the trial with a separate water and electrical meter for determining utility costs.

Milk weights were collected daily via the farm's S.A.E. Afikim (Israel) dairy records tracking system. Cows were bred solely on activity reports from pedometer readings taken on a daily basis.

Experiment 1

Cows were assigned randomly to one of the two pens described above. At the beginning of the trial, the control cows (n = 143, average DIM = 113.2, range 63 to 280 d, average daily milk = 25.7 kg) were divided into two groups, those receiving rbST (n = 87, average DIM = 121) or not receiving rbST (n = 56, average DIM = 99). The other treatment (cooled) cows (n = 142, average DIM = 114.3, range 63 to 280 d, average daily milk = 25.6 kg) were also divided into two groups, those receiving rbST (n = 86, average DIM = 120) or not receiving rbST (n = 56, average DIM = 107). Cows were assigned to one of the two pens 1 mo before the start of the trial, with daily milk weights collected to perform a covariate adjustment for milk weight analysis. The trial started on July 4, 1999, and ended September 30, 1999.

Experiment 2

Cows were assigned randomly to one of two pens described above. At the beginning of the trial, the control cows (n = 184, average DIM = 164, range 63 to 280 d, average daily milk = 25.7 kg) were divided into two groups, those receiving rbST (n = 84, average DIM = 194) or not receiving rbST (n = 101, average DIM = 146). The other treatment (cooled) cows (n = 185, average DIM = 167, range 63 to 280 d, average daily milk = 25.6 kg) were also divided into two groups, those receiving rbST (n = 86, average DIM = 195) or not receiving rbST (n = 99, DIM = 144).

Cows were assigned to one of the two pens 1 mo before the start of the trial, with daily milk weights collected to perform a covariate adjustment for milk weight analysis. The trial started on July 10, 2000, and ended September 25, 2000. Milk production, health, reproductive and farm high-low temperature and humidity data were collected daily by the farm personnel and transferred electronically on a weekly basis to a database at the University of Arizona. Respiration rates, external udder temperature, and under-shade environmental data were collected weekly. External udder temperatures were recorded with a laser thermometer (Raynger model RAYMX4PU, Raytek, Inc., Berlin, Germany) so that cows wouldn't be disturbed from their normal position. Environmental temperatures and humidity data were collected using a Barnant-Tri Sense-PAM (Barrington, IL) with attached probe.

Statistical Analyses

Milk data were analyzed using the mixed procedure of SAS. Data were analyzed similarly but separately for each experiment. The statistical design was a 2 × 2 factorial with cooling and rbST as main effects. Categorical data of health and reproductive events at the end of the trial each year were tested with chi-square. Milk production data were analyzed with DIM as a variable with treatment effect being noncooled, no rbST; cooled, no rbST; noncooled, rbST; and cooled, rbST. Environmental, and cow physiological data between July 10 and September 25, 2000 were analyzed for means within pens only.

RESULTS

Experiment 1

Daily THI at 1500 h ranged from 80 to 88. Throughout the trial period the THI was in the severe stress zone of THI index tables (Armstrong et al., 1993b Figure 1). The maximum temperature was 45°C, and the minimum high temperature was 27°C, showing a wide fluctuation

Figure 1. Temperature-humidity index (THI) maximum and minimum; 1999 (A) and 2000 (B).

over the trial period (Figure 1). High temperature and humidity resulted in thermal stress conditions over the entire trial period for experiment 1, with the exception of a drop in the nighttime THI to below 78, the severe stress zone, on August 12, 1999. Cows were able to maintain milk production with high daytime temperatures, as long as night THI were below 75; however, once nighttime THI went above 75, there was a precipitous drop in daily milk production (2.8 kg) and DMI (Figures 2 and 3).

Average daily milk production was higher in cooled (24.6 kg) compared with noncooled (23.0 kg) pens ($P < 0.01$). The average daily milk yield differed among all treatments except for the noncooled, rbST, and the cooled, no rbST treatments. Therefore, it was beneficial either to cool the cows or to give rbST, but it was clearly most beneficial to cool cows during high thermal environmental stress when utilizing rbST (Table 1; Figure 3).

The incidences of mastitis in the noncooled, no rbST ($n = 16$) treatment were significantly higher than noncooled, rbST ($n = 8$), and cows in both cooled treatments, 5 and 5, respectively ($P < 0.05$; Table 1). Reproductive

Figure 2. Total mixed ration intakes (DMI) 1999 (A) and 2000 (B).

events were difficult to evaluate because the trial included cows of various reproductive condition and gestation length of pregnant cows; however, embryonic death loss appeared higher ($P < 0.05$) in the noncooled, rbST cows when compared with noncooled, no rbST, and the cooled, no rbST treatments (Table 2). Interestingly, the number of abortions in the cooled rbST treatment was decreased significantly ($P < 0.05$) over the noncooled, rbST treatment, 5 versus 11, respectively (Table 2).

Experiment 2

During year 2, the highest THI 1500 h was 89, on July 18 and 19, and August 11, 2000, with a range of 78 to 89. Every day throughout the trial period the THI was in the severe stress zone of the THI index tables (Figure 1). The maximum temperature was 49.6°C on July 18 and July 19, 2000, and the minimum high temperature was 33.2°C on August 29, 2000, showing a wide fluctuation over the trial period (Figure 1). Elevated temperature and humidity created thermal stress conditions over the entire trial period for experiment 2, with a drop in the nighttime THI giving relief to the cows on August

Figure 3. Effects of bST (—, with rbST and ---, without rbST) on daily milk production for noncooled (top panel) and cooled (bottom panel) cows in 1999.

30, 2000. Again, the cows were able to maintain DMI and milk production with high daytime temperatures; however, once nighttime THI went above 75 there was a precipitous drop in both milk production and DMI. The average daily milk production was 24.6 kg/d for cooled pens versus 23.0 kg/d for noncooled pens ($P < 0.01$). The average daily milk among all treatments was different except between the noncooled, rbST and the cooled, no rbST treatments, demonstrating in the second year that it was beneficial either to cool the cows or to give rbST, but it was most beneficial to cool cows during high thermal environmental stress when utilizing rbST (Table 1, Figure 4).

The incidences of mastitis in the noncooled, no rbST ($n = 1$) treatments were lower than noncooled, rbST ($n = 4$), and cows in both cooled treatments (3 and 3, respectively; Table 1).

As with experiment 1, reproductive events were difficult to evaluate, because the trial included cows of vari-

Figure 4. Effects of cooling (—) or not cooling (---) on daily milk production for cows not receiving bST (top panel) or receiving bST (bottom panel) in 2000.

ous reproductive condition and gestation length of pregnant cows and the large variation in DIM between treatments.

Environmental modifications, as described in Materials and Methods, led to improvements in the temperature under the shade but did increase the humidity considerably. Temperature and humidity means were 29.1°C and 59.3% (THI = 78), and 32.8°C, 40.3% (THI = 80) for cooled and noncooled treatments, respectively (Table 3). This small difference in THI had a dramatic effect on physiological responses of the cows. The outside environmental THI was the same as the THI under the shade in the noncooled treatments; however, it was two index points lower in the cooled treatments (Tables 3 and 4). The effect was, however, an increase in both respiration rate and external forehead temperature of 80 breaths/min, 35°C and 102 breaths/min, 37.2°C for cooled and noncooled, respectively (Table 4). This increase in respiration rate would adversely affect DMI overall. The DMI actually increased as DIM increased

Table 1. Milk production and health outcomes of cows in experiments 1 (1999) and 2 (2000).

Treatments	Group (n)		Avg milk (kg) ^f		Mastitis		Metabolic disorders	
	1999	2000	1999	2000	1999	2000	1999	2000
Noncooled								
No rbST	56	101	21.8 ^a	20.5 ^a	16 ^d	1 ^d	7 ^d	2 ^d
rbST	87	82	23.7 ^b	21.0 ^a	8 ^e	4 ^e	7 ^d	7 ^e
Cooled								
No rbST	56	97	23.1 ^b	22.4 ^b	5 ^e	3 ^e	8 ^d	7 ^e
rbST	86	83	25.5 ^c	23.7 ^c	5 ^e	3 ^e	2 ^e	6 ³

^{a,b,c}Differs within column ($P < 0.01$).

^{d,e}Differs within column ($P < 0.05$).

^fAvg. pooled SE = 0.14 kg.

over the trial and was confounded by the rbST and no rbST cows grouped in the same pen (Figure 2). The impact on increased external udder temperature would undoubtedly affect both udder health and milk synthesis. As in experiment 1, whenever the nighttime THI dropped below 75, the following day there was an increase in DMI (Figures 1 and 2). No statistically significant difference emerged from analysis of replicate year. Rather than pooling data for the two years, results were compiled separately to illustrate that beneficial effects from cooling and bST occurred in early, mid, and late lactation.

Tables 5 through 8 show a partial budget indicating expected return on investment for \$14-, \$12.49, and \$10-per-hundred-weight milk, portraying values of 6%, 0%, and -10%, respectively, when utilizing both evaporative cooling and rbST.

DISCUSSION

In both experiments, cooled cows receiving rbST produced more milk than cows on the other three treatments ($P < 0.01$). The three treatments—cooled cows receiving rbST, cooled no rbST, and noncooled without rbST—resulted in fewer incidences of mastitis than did the noncooled, no rbST cows in experiment 1 ($P < 0.01$). Metabolic disorders, which included hoof problems, were lower in the cooled, rbST treatments when compared

with other treatments (Table 2; $P < 0.05$). The DIM of the treatment cows rbST and no rbST differed between years. The first year DIM were 113.2 and 114.3 for noncooled versus cooled cows, whereas DIM were 164 and 167, respectively, for the second year.

A comparison of the two experiments was not practical, because different environmental conditions existed between the two years as well as DIM from parturition through the treatment intervals. However, several inferences can be drawn from the data collected in both experiments. The most obvious and beneficial factor was the increased milk production when both rbST and evaporative cooling were utilized (Table 1; Figures 3 and 4). There was an economic benefit above \$12.49/cwt when viewing financial outcomes of utilizing both cooling and rbST (Tables 5 through 8). Very little research has been done on health benefits from utilizing cooling, but Table 1 shows in experiment 1, during the earlier part of lactation the number of cows with mastitis and metabolic disorders was reduced.

The amount of milk produced per cow/d from cooling and rbST was greater than the additive responses of rbST or cooling as separate treatments, indicating a synergistic effect (Table 1). As the animal's internal temperature stays closer to the thermoneutral zone of comfort, the effects of rbST are maximized. Once the internal temperature is compromised, with blood flow being di-

Table 2. Reproductive results for experiment 1.

Treatment	Group (n)	Number pregnant at start of trial	Number pregnant at end of trial	Embryonic loss
Noncooled				
No rbST	56	26	54 ^b	2 ^a
rbST	87	28	58 ^b	11 ^c
Cooled				
No rbST	56	25	56 ^b	1 ^a
rbST	86	26	70 ^a	5 ^b

^{a,b,c}Numbers with different superscripts within columns differ ($P < 0.05$).

Table 3. Environmental conditions for Experiment 2.

Date (2000)	Cooled			Noncooled		
	Barn temp. (C°)	Barn humidity (%)	THI ¹	Barn temp. (C°)	Barn humidity (%)	THI
6/19	24.1	78.8	76	33.7	34.5	80
6/27	26.8	78.2	78	32.5	38.2	79
7/03	29.7	36.6	76	33.3	23.9	78
7/11	30.6	44.9	79	35.6	24.7	80
7/18	28.8	45.4	76	36.8	19.0	80
7/25	32.3	46.5	80	38.1	20.9	82
8/01	32.9	50.5	81	31.9	54.5	82
8/08	27.3	84.1	78	34.2	39.9	82
8/18	27.8	84.7	80	31.4	47.2	80
8/22	31.3	44.7	79	34.3	33.5	81
8/29	26.0	61.3	75	26.0	60.1	75
9/05	30.9	45.5	79	31.7	33.8	79
9/12	29.7	52.1	78	30.7	63.2	82
9/20	29.7	77.6	82	29.6	70.8	82
Average over trial	29.1	59.3	78	32.8	40.3	80

¹THI = Temperature-humidity index.

verted to peripheral circulation in attempts to cool, and DMI is reduced, the benefit of rbST is reduced. The increased milk production was similar for years 1 and 2 (3.7 kg versus 3.2 kg, respectively). This translates into a 14.5 and 13.5% increase in milk production from the cows in the experiments receiving both cooling and rbST, for 1999 and 2000. In experiment 2, the external udder temperature of the cows cooled receiving rbST did not differ from the cows cooled not receiving rbST, 34.5 versus 34.7°C, respectively; however, the cooled cows' versus the noncooled cows' external udder temperature was sig-

nificantly different (34.5 versus 37.5°C, respectively; $P < 0.01$).

The added income from both rbST and cooling could improve the financial status on a Southwestern dairy operation during the summer months if used together. The additional feed cost from utilization of those options could be calculated as the cooled-treatment cows consumed on average 0.75 kg of DM (unpublished data) more than noncooled cows. If the added intakes for the increased daily milk production from rbST were similar, then an extra intake of 1.5 kg would translate into an

Table 4. Environmental conditions and physiological responses of cows in experiment 2.

Date (2000)	Envir. temp. (C°)	Envir. (humidity (%))	THI ¹	Respiration rate (breaths/min)		External udder temp. (C°)	
				Cooled (C°)	Not cooled (C°)	Cooled (C°)	Not cooled (C°)
6/19	27.1	60	75	60	96	34.2	36.0
6/27	32.7	74	86	89	114	35.1	37.0
7/03	32.3	32	78	67	90	35.5	37.0
7/11	40.0	16	82	86	100	36.4	37.1
7/17	34.7	12	76	83	106	35.9	38.7
7/25	40.3	13	82	74	116	36.4	39.5
8/01	34.2	34	81	80	108	36.7	38.6
8/08	34.0	68	85	95	112	37.1	34.4
8/18	31.0	43	82	63	98	34.4	37.3
8/22	26.0	48	80	99	111	36.8	38.7
8/29	35.0	61	75	83	88	36.2	37.0
9/05	38.0	43	83	79	89	34.0	37.5
9/12	38.0	19	82	82	97	34.3	37.4
9/20	29.4	38	75	78	101	32.2	34.9
Average over trial	33.3	40	80	80 ^a	102 ^b	35.4 ^c	37.2 ^d
SEM				±1.4	±1.4	±0.3	±0.2

^{a,b,c,d}Differs between columns ($P < 0.05$).

¹THI = Temperature-humidity index.

Table 5. Partial budget—input.

Item	Amount (\$)
Cow cooling system	40,000.00 ¹
Investment per cow	200.00
Repairs per cow	2.00
Energy cost per cow	4.13
Water cost per cow	2.08
Marketing per cow	0.012
Feed cost per cow	0.28

¹Includes installation and labor investment.

Table 6. Negative effects (\$ per cow/yr).

Added costs	Profitability	Cash flow
Fan system annual recovery cost (ACRC)	13.77	
Fan taxes and insurance	0.90	0.90
Fan repair and maintenance	2.00	2.00
Increased feed	28.56	28.56
Increased electric	4.13	4.13
Increased water	2.08	2.08
rbST injections	40.95	40.95
Milk hauling, advertising, and marketing	4.26	4.26
Total added cost	96.64	82.87

Table 7. Partial budget outcome (\$ per cow/yr).

	\$14 milk	\$12.49 milk	\$10 milk
Change in annual profit			
Total positive effects			
Minus	108.39	96.66	77.42
Total negative effects	96.64	96.64	96.64
Average annual rate of return on investment			
Annual profit or loss			
Divided by	11.75	0.02	-19.22
Dollars invested	200.00	200.00	200.00
Return on dollars invested, %	6	0	-10

Table 8. Cash available for annual retirement of principal (per cow/yr).

Item	\$14 milk	\$12.49 milk	\$10 milk
Total positive effects			
Minus	108.39	96.66	77.42
Total negative effects	82.87	82.87	82.87
Total cash available for debt retirement	25.52	13.79	-5.45

extra cost, attributed to increased milk from the treatments, of 28¢/cow per day consuming 17 kg of DM. The benefit of utilizing these management options on a dairy operation over a 120-d period of heat stress would translate into an additional income of \$13.79 per cow with milk priced at \$12.49/cwt (Table 8). This could be used to cover equipment investment costs.

CONCLUSIONS

Dairying in areas where high thermal stress is experienced must utilize environmental modifications such as shade and cooling to maintain profitability. The benefit was demonstrated in both experiments 1 and 2 with increased income over costs (above \$12.49/cwt). Respiration rates and external fore udder temperatures, which affect both milk production and reproduction, were reduced in environmental modifications that included evaporative cooling similar to other trials. The combined effect of higher peak milk production and increasing lactation persistency with minimal cost, as reported in numerous studies utilizing rbST and cooling, demonstrates that a dairy operation can improve responses in both milk production and reproduction. In our studies, cooling coupled with the use of rbST led to economically improving milk production in early-, mid- and late-lactation cows. Therefore, any modification that reduces heat stress will potentially improve milk production and reproduction.

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