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Strategic application of convective cooling to maximize the thermal gradient and reduce heat stress response in dairy cows

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ABSTRACT

This study determined the effectiveness of convective cooling at different times of day when air temperature (T_a) was cycled from day to night. Mid-lactation Holstein cows (n = 12) were placed in 3 environmental chambers (4 cows per chamber) and acclimated to T_a 19.9°C (thermoneutral; TN) for 7 d followed by an incremental increase over 3 d to a heat stress (HS) condition. Conditions were maintained for 11 d at high and low daily T_a of 33 and 23°C, respectively. To determine adaptive HS response, the HS period was divided into early (E: d 11 to 14) and late (L: d 17 to 20) periods. During HS, cows were exposed to continuous fan (convective) cooling (CC), 8-h day fan cooling (1100 to 1900 h; DC), or 8-h night fan cooling (2300 to 0700 h; NC). Compared with DC, the NC treatment maximized the thermal gradient during the convective cooling. Each animal received all treatments within 3 trials using a repeated 3 × 3 Latin square design. Cows were fed a total mixed ration and milked twice daily. Thermal status was assessed by using thermal conductance and average daily values for mean, minimum, and maximum rectal temperature (T_{re}), skin temperatures, and respiration rate. Percent reduction in dry matter intake from TN to HS was less for CC than DC and NC, with no change from E to L periods. The DC group exhibited the greatest trend for a percent reduction in total milk yield below CC due to the significantly lower morning milk production. All values for total daily milk production decreased from E to L periods, with E to L reductions in both morning and afternoon milk production. Minimum T_{re} for CC and NC cows was 0.4°C below DC. In contrast, maximum T_{re} was similar for NC and DC groups, at 0.5 to 0.6°C above the CC group. Skin temperature for CC cows was always less than DC cows. Skin temperature for NC cows was equal to CC for minimum skin temperature, but exceeded both CC and DC cows for maximum skin temperature. Average skin temperature decreased from E to L, which suggested heat adaptation. The thermal advantage of night (lowest T_a and greatest thermal gradient) versus day cooling (greatest T_a and lowest thermal gradient) was increased heat transfer via thermal conductance with NC. The higher thermal strain of DC cows caused a larger percent decrease in morning milk yield than for NC cows. In contrast, use of convective cooling at night in the absence of elevated humidity could sufficiently reduce heat strain beyond DC to maintain milk production at a level that is closer to that of CC cows.

Key words: heat stress, thermal conductance, dairy cow

INTRODUCTION

Summer heat stress and the resultant hyperthermia are important challenges facing the dairy industry that result in an estimated annual loss of $897 million dollars (St-Pierre et al., 2003). The traditional losses include reduced milk yield (Kadzere et al., 2002), lower reproductive rates (Wolfenson et al., 1997; Wilson et al., 1998), and depressed immune function (Elvinger et al., 1992). Core body temperature, which is the potential direct stimulus for these impaired functions, is dependent on the balance between the rates of heat gain and heat loss (Beede and Shearer, 1991). The increased heat load in the dairy cow, associated with greater milk production, has increased its thermal strain during periods of elevated ambient temperature (Kadzere et al., 2002). The housing environment and management approach must be modified, therefore, to increase heat loss and minimize thermal strain.

Modern dairy housing systems have been designed with 2 primary objectives relative to heat stress (Smith and Harner, 2012). First, the facilities should reduce exposure to external heat loads such as solar radiation. In addition, housing and milking systems have been designed to facilitate heat loss of cows with increased thermal loads associated with greater levels of milk production and concomitant increases in heat increment. Fan cooling systems have been used for many years to increase convective heat loss in these environments

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(Turner et al., 1992; Bray et al., 1994). The amount of convective heat transfer is dependent on the magnitude of the thermal gradient between exchange surfaces. One would expect, therefore, that the largest gradient for convective heat transfer exists during the night when the air temperature (**T_a**) is typically lowest and the air-to-body temperature gradient is typically the largest. Kabuga (1992) stated that nighttime release of body heat accumulated during daily exposure to heat stress is extremely important for thermal balance in lactating dairy cows. Akari et al. (1987) noted that the effect of heat stress on lactating dairy cows is ameliorated when night ambient temperatures fall. It has been suggested, in fact, that night temperature is more important than day temperature in determining the effect of summer heat on the productivity of dairy cows (Igono et al., 1992). Heat-stressed cows consume two-thirds of their total feed intake during the cooler night hours (Mallonee et al., 1985). A study of yearling beef steers demonstrated that night cooling resulted in a greater overall DMI than day cooling, and lowered mean daily respiration rate (**RR**) and rectal temperature by 35 breaths per minute (**bpm**) and 0.5°C, respectively (Gaughan et al., 2008).

To our knowledge, no study has evaluated the benefit of strategically cooling dairy cows when the air-to-body temperature gradient is the largest (typically at night) under controlled environment conditions. This experiment was conducted, therefore, to measure thermal balance and production responses of dairy cows exposed to strategic fan cooling when the gradient for convective heat transfer was either the greatest (nighttime cooling) or the least (daytime cooling) and to compare these responses to continuously cooled cows.

MATERIALS AND METHODS

Animals

Twelve mid-lactation Holstein cows (145 ± 21 DIM) were moved from the Foremost Dairy Farm at the University of Missouri–Columbia to 3 environmental chambers (6.1 × 9.1 m) in the Brody Environmental Center. The study was conducted in 3 trials that ran from February 10 to May 3. The selected time of year was to avoid the variance associated with introducing animals at different stages of heat acclimation or recovery. It was also at a time when there was an increase in daylight. Animals were housed in tiestalls within the chambers, with 4 animals per chamber. They were positioned approximately 1.2 m apart to avoid interference between animals and loosely restrained to the front of the tie stall with a chain attached to a halter. Although animals could not turn around in the stalls, they did have the ability to stand up or lie down so as not to create restraint stress. They were returned to the same chamber for each of the 3 trials used in this study. Each chamber was set to provide one experimental condition during a single trial and was then adjusted to create a new condition for each of the remaining trials. Using this approach, each chamber had each experimental condition, Animals were provided water using individual bowl waters and fed a daily diet (Table 1) for ad libitum consumption. All animal management procedures and experimental protocols were approved by the University of Missouri Animal Care and Use Committee.

Experimental Design

Twelve cows were randomly assigned to 1 of 3 fan treatments within 4 replicated 3 × 3 Latin square experimental designs. A total of 3 fan treatments were used in 3 trials (Figure 1). Each animal received each fan treatment during the consecutive trials. All animals

Table 1. Ingredients and chemical composition of diet fed to dairy cows

Item	Amount (% as fed)
Feed ingredient	
Corn silage	32
Alfalfa silage	11
Chopped alfalfa hay	16.2
High-moisture shelled corn	12.8
Soybean meal, 48%	5
Soybean hulls	6
Corn gluten feed	9.6
Fish meal	0.5
Hydrolyzed animal fat[1]	0.7
Ground corn	5.1
Dicalcium phosphate	0.3
Salt	0.1
Dynamate[2]	0.2
Limestone	0.3
Trace minerals[3]	0.1
Vitamins A, D, and E[4]	0.06
Vitamin E[5]	0.06
Chemical composition[6]	
OM %	92.1
CP %	16.6
ADF %	24.5
NDF %	40

[1] Manufactured by Southwest Byproducts (Springfield, MO).

[2] Trade name for mineral supplement containing guaranteed minimum analysis of 22% sulfur, 18% potassium, 11% magnesium produced by IMC Agrico (Mundelein, IL).

[3] Mineral mixes were formulated to contain 12% Ca, 10% Fe, 8% Mn, 8% Zn, 2% $CuSO_4$, 200 mg/kg of Co, 10,000 mg/kg of Se.

[4] Contained 88,200,000 IU/kg of vitamin A, 1,764,000 IU/kg of vitamin D_3, and 2,646 IU/kg of vitamin E.

[5] Contained 44,100 IU/kg of vitamin E.

[6] Mean dietary DM content was 56.4 ± 2.8%.