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Production and physiological responses of heat-stressed lactating dairy cattle to conductive cooling

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ABSTRACT

The objective of this research was to test the effectiveness of conductive cooling in alleviating heat stress of lactating dairy cows. A conductive cooling system was built with waterbeds (Dual Chamber Cow Waterbeds, Advanced Comfort Technology Inc., Reedsburg, WI) modified to circulate chilled water. The experiment lasted 7 wk. Eight first-lactation Holstein cows producing 34.4 ± 3.7 kg/d of milk at 166 ± 28 d in milk were used in the study. Milk yield, dry matter intake (DMI), and rectal temperature were recorded twice daily, and respiration rate was recorded 5 times per day. During wk 1, the cows were not exposed to experimental heat stress or conductive cooling. For the remaining 6 wk, the cows were exposed to heat stress from 0900 to 1700 h each day. During these 6 wk, 4 of the 8 cows were cooled with conductive cooling (experimental cows), and the other 4 were not cooled (control cows). The study consisted of 2 thermal environment exposures (temperature-humidity index mean ± standard deviation of 80.7 ± 0.9 and 79.0 ± 1.0) and 2 cooling water temperatures (circulating water through the water mattresses at temperatures of 4.5°C and 10°C). Thus, a total of 4 conductive cooling treatments were tested, with each treatment lasting 1 wk. During wk 6, the experimental and control cows were switched and the temperature-humidity index of 79.0 ± 1.0 with 4.5°C cooling water treatment was repeated. During wk 7, waterbeds were placed directly on concrete stalls without actively cooling the water. Least squares means and *P*-values for the different treatments were calculated with multivariate mixed models. Conductively cooling the cows with 4.5°C water decreased rectal temperature by 1.0°C, decreased respiration rate by 18 breaths/min, increased milk yield by 5%, and increased DMI by 14% compared with the controls. When the results from the 2 cooling water temperatures (4.5°C and 10°C circulating water) were compared, we found that the rectal temperature from 4.5°C cooling water was 0.3°C lower than the rectal temperature with 10°C cooling water, but the other measurements (respiration rate, milk production, and DMI) did not show a statistically significant difference between the cooling water temperatures. Placing waterbeds on concrete stalls without additional cooling did not have a measurable effect in alleviating the heat stress of the cows.
Key words: heat stress, conductive cooling, waterbed, production response, physiological response

INTRODUCTION

Heat stress occurs when cows are exposed to ambient conditions of high heat, high humidity, or both, resulting in problems with disposing of excess metabolic heat. A cow may start to show signs of heat stress beginning at a temperature-humidity index (**THI**) of around 68 (Zimbelman et al., 2009). When a cow is heat stressed, her rectal temperature (**Tre**) and respiration rate (**RR**) will increase, and she will usually spend less time lying down (Cook et al., 2007). Dry matter intake and milk yield will decrease, and reproductive performance as well as immune function may decrease (Liu et al., 2014). Cows at any production level will show an inverse relationship between milk yield and heat stress (Ravagnolo et al., 2000; West, 2003). Higher-producing cows are more affected by heat stress than lower-producing cows because a higher milk yield requires a higher DMI and thus generates more metabolic heat (West et al., 2003). Heat stress costs the US dairy industry—a $40 billion industry in 2013 (USDA, 2014)—an estimated 4 to 7% revenue loss per year (St-Pierre et al., 2003; USDA, 2006).

Lingering physiological effects of heat stress may cause economic losses that exceed those encountered during the actual heat stress event. The decrease in milk yield is partly due to endocrine changes, not just the immediate effects of having less available energy when DMI decreases (Rhoads et al., 2010). In many cases, cows do not return to their level of milk yield before the heat stress event, and under severe heat stress, cows may abort a pregnancy or even die (Stull et al., 2008; Norman et al., 2012). Climate change could exacerbate these losses by making the climate warmer

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or more variable (Crescio et al., 2010). Heat-stress episodes caused by variable climate can be especially challenging for cows to cope with because it may take weeks for a cow to fully adapt to heat-stress conditions (Cook et al., 2007).

Current practices for heat-stress relief include the provision of shade and various sprinkler, mister, and fan systems. Under hot and humid conditions, shades and fans alone are insufficient to alleviate heat stress. Mister systems use fine water molecules to cool the air, and thus are more effective in arid climates but less effective in high humidity conditions (Armstrong, 1994). Collier et al. (2006) reported that sprinkling cows can be effective even in high humidity conditions, but excess moisture from sprinkler systems may lead to hygiene problems and increased risk of disease (Stull et al., 2008). Furthermore, fans consume electricity and sprinkler or mister systems consume water. For example, a sprinkler system tested by Frazzi et al. (2002) consumed on average 15,500 L/cow per 120-d cooling season.

Most US dairies with 500 or more cows use sprinklers or misters to mitigate heat stress (USDA, 2010). The resulting high water consumption is especially a problem in the western United States, where water can be scarce. Systems requiring considerable energy consumption also rely on currently inexpensive electrical energy, but energy prices may rise in the future (Collier et al., 2006). Although air conditioning has been tested as a cooling mechanism, it is not an economically feasible option (Hahn et al., 1969). Conductive cooling systems have the potential to conserve water, be more hygienic than evaporation-based cooling systems, and provide more effective heat stress relief than fan-only systems. The pioneering study by Bastian et al. (2003) on conductive cooling demonstrated that a waterbed filled with continuously cooled water may be an effective way to relieve heat stress in dairy cows.

Concurrently with this study, Ortiz et al. (2015) evaluated the effectiveness of conductive cooling of lactating dairy cows under controlled environmental conditions (hot and dry, hot and humid, and thermoneutral). Heat exchangers with running water at 7°C were buried 25 cm below the stall surface to remove metabolic heat from the cows. Ortiz et al. (2015) used sand and dried manure as the bedding material in their conductive cooling system. They reported that use of the heat exchangers did not decrease RR or increase feed intake for either bedding type. However, for sand bedding, the Tre of the cooled cows was reduced under both of the heat-stress conditions. Milk yield increased for the cooled cows under hot and humid conditions but was not significantly different between cooled and control cows for the hot and dry conditions. For the dried manure bedding, the use of conductive cooling did not affect milk yield and only lowered Tre under hot and humid conditions. The highest measured heat flux from the cow to the stall surface was 28.65 W/m^2 for a hot and humid environment with sand bedding and the heat exchanger on. This small heat transfer was attributed to the deep bedding (25 cm) used in the study to keep the cows comfortable and protect the heat exchanger (Ortiz et al., 2015). The study concluded that more work is needed to increase the efficiency of conductive cooling.

The use of cooled waterbeds in stalls has the advantage of providing cushioning for the cow and allowing almost direct contact between the skin surface and the cooled waterbed surface and thus allowing substantial heat flow. The objective of this research was to assess the effectiveness of a conductive cooling system using continuously cooled waterbeds to alleviate heat stress of high-producing, lactating dairy cattle.

MATERIALS AND METHODS

The experiment was conducted in the Large Animal Research and Teaching Unit (LARTU) at Cornell University using 8 primiparous Holstein cows that produced 34.4 ± 3.7 kg/d of milk at 166 ± 28 d in milk (mean ± SD). Cows were confirmed pregnant before the start of the study. Two identical climate-controlled rooms with tiestalls housed 4 cows each. The conductive cooling system used DCC waterbeds (Dual Chamber Cow Waterbeds, Advanced Comfort Technologies Inc., Reedsburg, WI), with some modifications as described in the Cooling System Design section. The experimental protocol and students involved in the study were approved by the Institutional Animal Care and Use Committee (IACUC) at Cornell University.

The cows were milked twice daily at 0600 and 1800 h, and milk weights were recorded at each milking. Before the morning milking, the cows were moved into the climate-controlled rooms at 0530 h. Experimental heat stress was imposed from 0900 to 1700 h, and all cows stayed in waterbed stalls during the daytime. Two identical, adjacent, climate-controlled rooms were used in this study. In each room, 2 experimental (conductively cooled) cows were housed on one side of the room and 2 control (not cooled) cows were housed on the other side of the room. All cows faced in the same direction. At 1900 h after evening milking, the cows were placed individually and left loose in a night pen so that they could exercise. All the night pens were in a large and well-ventilated room.

All the cows were fed a wet (moisture content ~58% wet basis) TMR formulated for primiparous, mid-lactation Holsteins (Table 1). Fresh feed was mixed daily