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Evaluation of conductive cooling of lactating dairy cows under controlled environmental conditions

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ABSTRACT

Cooling systems used to reduce heat stress in dairy operations require high energy, water usage, or both. Steady increases in electricity costs and reduction of water availability and an increase in water usage regulations require evaluation of passive cooling systems to cool cows and reduce use of water and electricity. A study was conducted to evaluate the use of heat exchangers buried 25 cm below the surface as components in a conductive system for cooling cows. Six cows were housed in environmentally controlled rooms with tie-stall beds, which were equipped with a heat exchanger and filled with 25 cm of either sand or dried manure. Beds were connected to supply and return lines and individually controlled. Two beds (one per each kind of bedding material) constituted a control group (water off), and the other 4 (2 sand and 2 dried manure) used water at 7°C passing through the heat exchangers (water on). The experiment was divided in 2 periods of 40 d, and each period involved 3 repetitions of 3 different climates (hot and dry, thermo neutral, and hot and humid). Each cow was randomly assigned to a different treatment after each repetition was over. Sand bedding remained cooler than dried manure bedding in all environments and at all levels of cooling (water on or off). Bed temperatures were lower and heat flux higher during the bed treatment with sand and water on. We also detected a reduction in core body temperatures, respiration rates, rectal temperatures, and skin temperatures of those cows during the sand and water on treatment. Feed intake and milk yield numerically increased during the bed treatment with sand and water on for all climates. No major changes were observed in the lying time of cows or the composition of the milk produced. We conclude that use of heat exchangers is a viable adjunct to systems that employ fans, misters, and evaporative cooling methods to mitigate effects of heat stress on dairy cows. Sand was superior to dried manure as a bedding material in combination with heat exchangers.

Key words: conductive cooling, heat stress, dairy cow

INTRODUCTION

A combination of genetics with good management techniques has steadily increased milk production per cow to the current level of 9,980 kg/cow (USDA, 2013). However, this increase in milk production also increased the amount of metabolic heat produced by a dairy cow (Kadzere et al., 2002). Higher metabolic heat production requires additional measures for cooling a cow during times of thermal stress (Collier et al., 2006).

Standard heat-abatement techniques used in the dairy industry rely on water and fans to either cool down the environment in which the cows are housed or apply water to increase the rate of evaporation that typically occurs from the skin of a cow.

Electricity usage of these cooling systems ranges between 0.71 and 1.76 kW/h depending on the intensity of the heat-abatement model used (St-Pierre et al., 2003). According to Harner et al. (2013), the amount of water needed for heat abatement in a dairy farm ranges between 56 and 75 L/cow per day during the heat-stress season (120 d). However, water consumption and availability pose major problems for today's dairy operators. The depletion of clean water supplies and the increasing cost of water and electricity in the United States are becoming limiting issues in some states. Additionally, regulations concerning water availability for livestock production will likely be more restrictive in future years. New passive methods for cooling livestock need to be investigated to maintain high levels of milk

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production while increasing the efficiency of water and electricity consumption.

Conductive cooling is 1 of 4 routes of heat exchange available to cows to transfer the metabolic heat they produce to the environment. It involves the flow of heat from the skin of a cow down a thermal gradient to a surface that has a lower temperature. The effectiveness of conductive cooling is directly related to the size of the temperature gradient between the 2 bodies, the thermophysical properties of the media, and the size of the contact area between these 2 bodies (Schmidt-Nielsen, 1964). Conductive temperature exchange has also been described as a product of the proportional relationship between the conductivity of materials and their bulk density (Esmay, 1969).

Little research has been done evaluating the effectiveness of conductive cooling on dairy cows. Only 20% of the surface area of a cow is available for exchanging heat via conduction. Bastian et al. (2003) analyzed the use of cooled waterbeds as a method for increasing the size of the thermal gradient and for increasing the heat flow between the cows and their beds. Results of this study demonstrated an increase in the heat flux between a water-filled mattress and cows when the water temperature decreased and the thermal conductivity of the bodies increased. To evaluate the ability of a conductive cooling system to alleviate heat stress when placed underneath the bedding material of a cow, Mondaca et al. (2013) developed a comprehensive model capable of simulating the conjugate heat and mass transfer of a dairy cow. The model predicts the amount of heat that will leave the animal as a result of conductive cooling, and it demonstrates the potential of heat exchangers buried below the bedding surface as an alternative way to increase the heat flow from cows to the environment. Accordingly, the present experiment was designed to measure the effectiveness of heat exchange through bedding material as a conductive cooling system.

In commercial dairy farms the bedding material is selected based on its economic feasibility, the physical comfort it will provide, and how well it can maintain the cleanliness and health of the udder. When choosing a bedding material, however, not many producers take into consideration the thermal comfort of the cow. Cummins (1998) stated that the bedding material on a dairy farm should be part of any heat-abatement strategy. Cummings reported lower temperatures in limestone (25.9°C) and sand (26.9°C), compared with wood shavings (28.6°C), at 25 mm below the surface. A more recent computational and experimental study showed that sand bedding had higher heat flux with cows when compared with straw and mattresses filled with rubber granules (Radoń et al., 2014). Two of the most frequently used bedding materials are sand and dried manure. In recent years producers have been trying to shift from using sand to dried manure because of cost and availability. Previous research had shown that sand and dried manure are both suitable as bedding materials (Cook et al., 2004; van Gastelen et al., 2011; Husfeldt et al., 2012).

The objective of this experiment was to evaluate the effects of these 2 types of bedding and their interaction with a bed heat-exchanger cooling system [cooling system + sand, cooling system + dry manure, and control (no water flowing through the heat exchanger in either bedding material)] operating during 3 different types of climates (thermo-neutral zone, hot and dry, and hot and humid).

MATERIALS AND METHODS

This experiment was conducted in the environmental rooms at the William J. Parker Agricultural Research Complex at the University of Arizona. To conduct the experiment, 6 multiparous Holstein dairy cows producing an average of 36.1 ± 5.5 kg/d of milk and 315 ± 20 DIM were purchased from a commercial dairy. The cows were housed in tie stalls and were fed and milked twice daily (0600 and 1800 h). The ration fed to the cows is shown in Table 1.

The trial was divided into 2 periods of 40 d each, and each period consisted of 3 repetitions of 3 different climates (hot and dry, thermo neutral, and hot and humid). At the beginning of each period an acclimation phase of 7 d was established. Each repetition consisted of 9 d (3 d per climate), and after each repetition,

Table 1. Ingredients and chemical composition of diet[1]

Item	Value
Ingredient, % of DM	
Alfalfa hay	65.0
Corn (steam flaked)	22.1
Whole cottonseed	7.28
Distillers grains	2.58
Supplement RS-1299[2]	2.04
MAXXER[3]	0.96
Chemical analysis	
CP, %	17
NDF, %	26.4
ADF, %	20.2
Fat, %	4.9
DM, %	53.0
NE_L, Mcal/kg of DM	1.76

[1]Diet DM averaged 53% by weight of DM, and water added was 47% by weight.

[2]The supplement contained 1.14% fat, 10.42% Ca, 4.49% P, 3.80% Mg, 0.49% S, 0.19% K, 15.83% Na, 7.52% Cl, 2,029.06 mg/kg of Zn, 1,991.82 mg/kg of Mn, 974.24 mg/kg of Fe, 583.45 mg/kg of Cu, 67.86 mg/kg of Co, 12.28 mg/kg of Se, 6.81 mg/kg of Mo, 43.68 mg/kg of I, 304.9 IU/g of vitamin A, 30.2 IU/g of vitamin D, and 1.0 IU/g of vitamin E (Tarome Inc., Eloy, AZ).

[3]Calcium salts of palm oil (Tarome Inc.).