Economic feasibility of cooling dry cows across the United States

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ABSTRACT

Heat stress during the dry period reduces milk yield in the subsequent lactation of dairy cows. Our objectives were to quantify the economic losses due to heat stress if dry cows are not cooled and to evaluate the economic feasibility of dry cow cooling. We used weather data from the National Oceanic and Atmospheric Administration to calculate the number of heat stress days for each of the 50 US states. A heat stress day was declared when the daily average temperature-humidity index was ≥ 68 . The number of dairy cows in each state in 2015 was obtained from the USDA-National Agricultural Statistics Service. We assumed that 15% of the cows were dry at any time, a 60-d dry period, and a calving interval of 400 d. Only cows in their second or greater parity (65%) benefitted from cooling during the dry period of the previous parity. Milk yield decreased by 5 kg in the subsequent lactation (340 d) if the cow experienced heat stress during the dry period based on a review of the literature. The default marginal value of milk minus feed cost was \$0.33/kg of milk. The investment analysis included purchases of fans and soakers and use of water and electricity. Investment in a dry cow barn was considered separately. The average US dairy cow would experience 96 (26%) heat stress days during the year if not cooled and loses 447 kg of milk in the subsequent lactation if not cooled when dry. Annual losses would be \$810 million if dry cows were not cooled (\$87/cow per yr). For the top 3 milk-producing states (California, Wisconsin, New York), and Florida and Texas, the average milk losses in the subsequent lactation were 522, 349, 387, 1,197, and 904 kg, and reduced profit per cow per year would be \$101, \$68, \$75, \$233, and \$176, respectively. The average benefit-cost ratio and payback periods of cooling dry cows in the United States were 3.15 and 0.27 yr (dry cow barn already present) and 1.45 and 5.68 yr (if investing in a dry cow barn) in the default scenario. To reach positive net present values, 6 d (barn is present) and 55 d (barn

investment necessary) of heat stress annually were necessary (default assumptions). Other benefits of cooling, such as increased health and more productive offspring, were not considered. In conclusion, cooling of dry cows was profitable for 89% of the cows in the United States when building a new barn is required (under default assumptions) and very profitable when construction of a dry cow barn is not required (except for Alaska).

Key words: heat stress, temperature-humidity index, dry cow, economic feasibility

INTRODUCTION

Heat stress is a major factor affecting dairy cows across the United States. The effects of heat stress during the lactation on lactating cows have been extensively studied (e.g., West, 2003; Collier et al., 2006; De Rensis et al., 2015). St-Pierre et al. (2003) calculated that heat stress is responsible for annual losses of over \$1 billion in the dairy industry in the United States if lactating cows are not sufficiently cooled, mainly due to the negative effects on milk production, DMI, reproduction, and culling. Heat stress is the costliest problem that dairy farmers face during the summer (Baumgard and Rhoads, 2012). However, these studies did not include the losses associated with dry cows that experienced heat stress. Although many farmers cool their lactating cows during periods of heat stress, cooling of dry cows is often ignored.

The long-term consequences of heat stress during the dry period were first studied by Collier et al. (1982) and Thatcher et al. (1984) who showed the effects on calf birth weight and the seasonality of birth weight in Holstein calves. Wolfenson et al. (1988) observed negative effects on calf weight and milk production. More recent work at the University of Florida has further demonstrated the benefits of dry cow cooling on improved calf performance and cow health in the next lactation. Heat stress during the dry period results in impaired mammary growth and consequently leads to decreased milk production in the subsequent lactation (Tao and Dahl, 2013). Cows cooled with soakers and fans during the entire dry period of 46 d had greater milk production of 5 to 7.5 kg/d in the subsequent lactation compared

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with those cows that were under shade only (do Amaral et al., 2009; Tao et al., 2011, 2012). When cows were cooled only during the last 2 wk before parturition, the increase in milk production in the subsequent lactation was 1.4 kg/d (Urdaz et al., 2006). In all these studies, all cows were cooled during the lactation.

Other effects of heat stress during the dry period are also reported, such as decreased fertility in cows (Wiersma and Armstrong, 1988), decreased immunity and fertility (do Amaral et al., 2011; Thompson and Dahl, 2012), and reduced birth weights and growth rates in calves born out of cows that experienced heat stress when dry (Collier et al., 1982; do Amaral et al., 2011; Tao et al., 2012).

Given the negative and long-term consequences of heat stress during the dry period, cooling dry cows may have economic benefits. Typical cooling of dry cows requires investments in soakers and fans. In addition, a dry cow barn may have to be built if dry cows are housed outside, as is common in, for example, Florida. These costs are not dependent on the length of time that heat stress would be experienced. Other costs to cool dry cows depend on the length of time during the year when dry cows would experience heat stress, which varies by geographic location across the United States.

Dhuyvetter et al. (2000) and St-Pierre et al. (2003) provided economic analyses of the cooling of lactating cows. The available economic analyses of cooling dry cows are limited. Adin et al. (2009) calculated that the total cost of cooling a dry cow in Israel was equivalent to the net income from 80 kg more milk. In that study, cows that were cooled during the dry period produced 190 kg more milk in the first 90 DIM versus cows that were not cooled when dry. However, Adin et al. (2009) did not account for the increase in DMI by cows that produced more milk, nor did they include other factors such as investment in cooling technology and number of heat stress days. We did not find other economic feasibility analyses of cooling dry cows.

Therefore, our first objective was to quantify the economic losses from lost milk production across the United States if all dry cows would not be cooled. Our second objective was to provide an economic feasibility analysis of investments in soakers and fans as well as cooling barns for dry cows across the United States.

MATERIALS AND METHODS

Weather Data

One measure of heat stress is a temperature-humidity index (**THI**) above a threshold (West, 2003; Collier et al., 2006). We quantified heat stress across the United States by calculating the average THI per calendar day

for each of the 50 states. We used daily data provided by the National Oceanic and Atmospheric Administration for the years 2007 to 2013. The data set contained weather data including average daily temperature (°F) and dewpoint (°F). We averaged the data from all available weather stations within each state. Relative humidity (**RH**) was calculated as follows (NOAA, 2015):

$$RH = \left\{ \frac{[(173 - 0.1 \times T) + \text{dewpoint}]}{173 + (0.9 \times T)} \right\}^8,$$

where T = average daily temperature (°F). We calculated the THI according to the formula of Zimbelman et al. (2009):

$$THI = T - [0.55 - (0.55 \times RH) \times (T - 58)].$$

We declared a heat stress day when average daily THI ≥ 68 (Zimbelman et al., 2009). We calculated the number of heat stress days per state in each year and averaged those across the years.

Milk Production and Number of Dry Cows

We used data from USDA-NASS (2016) to obtain the total milk production and total number of dairy cows for each of the 50 states in the United States in 2015. We assumed that 15% of the total number of dairy cows were dry at any time during the year and the calving interval was 400 d. We also assumed that only cows in their second or greater parity (65%) benefitted from cooling during the dry period in the previous parity because we did not consider the benefits of cooling pregnant heifers during their later gestation period, although no evidence is present to indicate that they do not benefit. From this, we calculated the number of lactating cows that might benefit from cooling in the dry period.

Milk Losses

In Table 1, we summarized the results of 11 studies that documented the effects of heat stress during the dry period on milk loss in the subsequent lactation. Based on recent studies, we assumed a reduced milk production of 5 kg/d for 340 lactating days in her subsequent parity if the cow experienced heat stress during the dry period. Further, we assumed that the decrease in milk yield in a state was proportional to the number of heat stress days for that state. For example, 70% of the dry cows are under heat stress during the year if not cooled in Florida. Thus, without cooling, we assumed a loss in

Table 1. References, length of the preceding dry period, days of milk production measured in the subsequent lactation, and milk loss in the subsequent lactation of 11 studies that investigated the effect of dry cow heat stress on milk production in the subsequent lactation

Reference	Dry period length (d)	Milk production measured in the subsequent lactation (d)	Milk loss in the subsequent lactation (kg/d)
Collier et al. (1982)	60	100	1.2
Collier et al. (1982)	60	305 ¹	2.6
Wolfenson et al. (1988)	60	150	3.5
Avendaño-Reyes et al. (2006)	60	100	2.6
Urdaz et al. (2006)	28 ²	60	1.4
Adin et al. (2009)	60	90	2.1
do Amaral et al. (2009)	46	210	7.5
do Amaral et al. (2011)	46	140	2.3
Tao et al. (2011)	46	280	5
Tao et al. (2012)	46	294	6.3
Thompson et al. (2014)	46	280	3.8

¹305-d predicted yield adjusted for age, month of calving, and estimated relative producing ability.

²Cooling in the close-up period only.

milk production of $70\% \times 5 \text{ kg/d} = 3.5 \text{ kg/d}$ during the 340 d in their subsequent lactation for all second and greater parity cows. We only included losses in milk yield because those effects are better documented and easier to quantify than other effects such as reduced immunity, fertility, and calf performance.

Economic Analysis

Marginal Milk Income Minus Feed Costs. To calculate the extra milk income from cooling dry cows, we used as default a milk price of \$0.44 per kg of milk, based on the average of the all-US milk prices reported for 2010 to 2015 (Gould, 2016). We calculated increased milk income by multiplying the increased milk production from cooling dry cows by the milk price.

We assumed a cow consumes 0.71 Mcal to produce 1 kg more milk. One kilogram of DM of a well-balanced TMR contains 1.7 Mcal (NRC, 2001). Therefore, we assumed that a cow consumed 0.4 kg of DM per 1 kg more milk. We assumed a cost of \$0.28 per kg of DMI (Rollin et al., 2015). Thus, the default milk revenue minus feed cost was \$0.33 per kg more milk as a result of dry cow cooling.

Cooling Investment Costs. Cooling costs of dry cows consisted of investment in a barn (if needed) and in fans and soakers. Cooling costs further included expenses for electricity and water during heat stress days. All costs were prorated across 20 yr, which is equal to the assumed lifespan of the barn (IRS, 2016).

The default investment costs for building a barn were assumed to be \$2,500 per stall (Kammel, 2015). This does not include the investment costs of fans and soakers. We assumed a residual value of 10% for the barn after 20 yr.

We assumed that the cooling system within the barn was composed of fans (0.4 kW, 80 cm, 7 yr lifetime) and soakers including water pipe (5 yr lifetime). The cost of each fan was \$700 (Kammel, 2015). We assumed 5 dry cow stalls per fan based on the set up at the University of Florida Dairy Unit where most of the reviewed dry cow cooling studies have taken place. During the 20 yr period, fans were purchased at the start of yr 1, 8, and 15. We assumed a residual value of 10% and straight-line depreciation. Therefore, the remaining value per fan was \$160 in yr 20. The cost of the soakers was based on Dhuyvetter et al. (2000), adjusted for inflation (DOL, 2015), and was assumed to be \$8.19 per stall. Soakers were purchased 4 times during the 20 yr (years 1, 6, 11, and 16), and the remaining value was \$0.80 per stall.

Utilities. We calculated the fixed and variable costs of energy and water. Water and energy prices were taken from GRU (2015) and Dhuyvetter et al. (2000) corrected for inflation. Energy cost was divided in demand (fixed) and electricity (variable) charges, and they were set at \$37 and \$1.62 per fan per heat stress day, respectively. We assumed an energy efficiency of the fans of 0.75 kW and that a fan was used for all 24 h during a heat stress day. The cost of water was \$0.42 per 1,000 L, and we assumed 56.8 L of water per stall per heat stress day to cool a dry cow.

Maintenance. We assumed stall maintenance cost of sand as \$90/dry cow stall per yr, when a new barn was built. The maintenance cost of fans and soakers was set at \$15/fan per year based on the setup at the University of Florida Dairy Unit.

Investment Feasibility Analysis. Cash flow during the 20-yr period was discounted at an annual discount rate of 5%. We calculated the net present value

(NPV) of investment in dry cow cooling per cow per year. In addition, the benefit-cost (BC) ratio was calculated by dividing the sum of the present value of 20 yr of revenues by the sum of the present value of 20 yr of costs. We calculated the payback period as the time to when the cumulative annual net revenue from milk sales minus feed cost equaled the total 20 yr cost of the investment and utilities. We also calculated the internal rate of return (IRR), which is the discount rate when NPV equals \$0. The investment in cooling dry cows is worthwhile when $NPV > \$0$, BC ratio > 1 , payback period is short, and $IRR > \text{annual discount rate}$ (Higgins, 2001). Separate analyses were carried out for investments with and without building a barn.

We performed breakeven analyses for milk price, increase in milk production in the subsequent lactation, and barn investment cost per dry cow stall, for a payback period of 3 yr for the top 3 states with the most dairy cows (California, Wisconsin, New York), as well as Florida and Texas, which are among the top 25 states for number of dairy cows and have a high number of heat stress days per year. For each variable that we changed, we kept the other variables at their default values (i.e., \$0.44/kg milk price, 5 kg/d increase in milk production in the subsequent lactation, \$2,500/stall barn investment cost).

We also varied milk price (\$0.34, \$0.44, and \$0.54 per kg of milk), potential increase in milk production in the subsequent lactation (1, 3, and 5 kg/d), and investment costs per dry cow stall (\$1,500, \$2,500, and \$3,500) to determine their effect on the NPV per cow per year when the number of heat stress days was varied from 0 to 360. Again, one variable at a time was changed with all others at their default values as described above.

RESULTS

Heat Stress and Milk Losses Without Cooling

The USDA-NASS (2016) reported 9,322,400 dairy cows present in the United States in 2015. Of these, dry cows (15%) were assumed to be 1,398,360. These numbers have not changed much in the last decade. The numbers of dry and milking cows in the top 25 US states with the most dairy cows in 2013 are shown in Figure 1. Collectively, these 25 states had 8,805,000 (94.4%) dairy cows in 2015. With the exception of California, which is responsible for 19.6% of the milk produced in the United States (USDA-NASS, 2016), the other 4 major milk-producing states are in the cooler northern part of the United States. Significant milk producing states such as Texas, New Mexico, Arizona, Florida, and Georgia, that together produced 13.2% of the total

US milk production, are in regions with a large number of heat stress days per year.

Figure 2 shows the number of heat stress days and the milk lost per cow in the subsequent lactation if dry cows are not cooled for the 25 states with the largest number of dairy cows. Based on the weighted average of the number of cows across the 50 states and the number of heat stress days in each state, an average US dairy cow is under heat stress 96 d (26%) during the year. On average, 70% of the cows in Florida would experience heat stress during their dry periods if not cooled. In cooler northern states such as Washington and Maine, 12% of the dry cows still would experience heat stress if not cooled. In 23 out of 50 states, at least 30% of the dry cows would experience heat stress during the year. In the top 25 states with the greatest number of dairy cows (Figure 1), 26% of the dry cows (weighted average) would experience heat stress, and in California 31% of the dry cows experience heat stress if not cooled.

Each day of heat stress during the year equates to 4.66 kg lower milk yield in the subsequent lactation. An average US dairy cow would lose 447 kg of milk in the subsequent lactation if not cooled when dry. This assumes first parity cows have no milk losses. Of the top 25 states with the most dairy cows, the weighted average loss is 441 kg in the subsequent lactation. For the top 3 states with most dairy cows (California, Wisconsin, New York), Florida and Texas, the average milk losses in the subsequent lactation were 522, 349, 387, 1,197, and 904 kg. Per average cow (including first parity cows), these values are 339, 227, 251, 778, and 587 kg, respectively.

Weighted by the number of cows in each state, annual losses would be \$810 million if dry cows were not cooled (\$87/cow per year) using the default milk sales minus feed cost of \$0.33/kg of milk. In California, the total economic losses if dry cows are not cooled are \$181 million per year. For California, Wisconsin, New York, Florida, and Texas, the average annual losses would be \$101, \$68, \$75, \$233, and \$176/cow per yr, respectively. The weighted annual loss is \$162 million if we assumed that heat stress during the full dry period decreased milk production by only 1 kg/d in the subsequent lactation instead of 5 kg/d. When the milk price is reduced from \$0.44 to \$0.34 per kg, total weighted annual losses in the United States would be \$563 million without dry cow cooling.

Cooling Investment Analysis

An example of the economic feasibility analysis of cooling dry cows in Florida is shown in Table 2. With investment in the barn, the NPV per cow per year was

Figure 1. Total number of dairy cows in the top 25 states with the most dairy cows in 2015 (dry cows in dark gray, lactating cows in light gray). Source: USDA-NASS (2016). We assumed 15% of all cows were dry.

\$111, the BC ratio was 2.34, and the payback period was 1.87 yr. Under these conditions, the IRR was 53%. If only fans and soakers need to be purchased, those values would be \$139, 3.47, 0.10 yr, and 1,017%, respectively. For California, the results were \$31, 1.58, 4.72 yr, and 20% when investment in the barn was necessary and \$58, 3.22, 0.23 yr, and 440% without the barn investment, respectively.

Considering the weighted average number of heat stress days in the United States (96) and the default assumptions, the NPV, BC ratio, payback period, and IRR would be \$22, 1.45, 5.67 yr, and 16%, respectively (including building a dry cow barn). If the dry cow barn is already present, the values would be \$50, 3.15, 0.27 yr, and 376%. To reach an NPV > \$0, a minimum number of heat stress days of 6 and 9 d are necessary when a barn is not built when milk prices are \$0.44 and \$0.34, respectively. If investment in the barn is included, the minimum number of heat stress days would be 55 and 81 to reach a positive NPV, respectively. Of all US dairy cows, 89% are in states with at least 55

heat stress days per year. The only states in the top 25 with fewer than 55 d of heat stress per year are Washington, Oregon, and Idaho (43, 47, and 52 d of heat stress, respectively).

Assuming the default assumption for depreciation of barn, fans, and soakers, the NPV can be calculated as follows:

$$\begin{aligned}
 \text{NPV (\$ per cow per yr)} = & (-0.0075 \\
 & \times \text{barn cost per stall} - 0.0935 \\
 & \times \text{barn maintenance per dry cow per yr}) \\
 & + (-0.0032 \times \text{cost per fan} - 0.9721) \\
 & - (0.0216 \times \text{cost of soakers per stall}) \\
 & + (\text{number of heat stress days} \times \{-0.012 \\
 & \quad + [\text{kg increase in milk per day} \\
 & \quad \times (0.344 \times \text{price per kg milk} - 0.138 \\
 & \quad \times \text{price per kg of DM})\}]).
 \end{aligned}$$

For example, the NPV per cow per year equals \$35 when barn cost per stall is \$2,500, barn maintenance per dry cow per yr is \$90, cost per fan is \$700, cost of soakers per stall is \$8.19, the number of heat stress days is 90, increase in milk is 5 kg/d, price of milk is \$0.54/kg, and price of DM is \$0.28/kg (Figure 3). When the barn cost is \$0, the barn maintenance is also \$0, so the NPV per cow per year is \$62.

Figures 3 and 4 show the results of the sensitivity analysis for variations in milk price, reduction in milk yield in the subsequent lactation, and barn investment cost per dry cow stall. The number of heat stress days per year is varied from 0 to 360.

Figure 3 includes the barn investment cost. In 6 of the 7 scenarios shown, the number of heat stress days varied from 42 to 94 to create a positive NPV. This shows that cooling of dry cows including barn investment costs is profitable in most states in the United States. In Florida, with its 257 d of heat stress, the NPV was \$119/cow per yr when milk price was \$0.44/kg and barn investment cost was low (\$1,500). When

the loss in milk production was assumed to be only 1 kg at a milk price of \$0.44/kg and a barn investment cost of \$2,500, more than 305 heat stress days were necessary to reach a positive NPV. A combination of the higher milk price of \$0.54/kg, milk loss of 5 kg/d, and a barn investment cost of \$2,500/stall resulted in the greatest NPV of cooling dry cows. In this scenario, the NPV became positive with 42 heat stress days per year. Figure 4 does not include the barn investment cost, but only investment in fans and soakers. For all 5 scenarios, the NPV became positive between 5 and 35 heat stress days per year.

Table 3 shows the results of the breakeven analyses for the top 3 states with the greatest number of dairy cows in United States as well as Florida and Texas, assuming a payback period of 3 yr. When the barn investment cost was included, the results were more sensitive to the number of heat stress days. In Florida, the investment can be recovered in 3 yr even if the increase in milk production is 3.3 kg/d, or the milk price is as low as \$0.33/kg or the barn investment cost

Figure 2. Milk lost per cow in the subsequent lactation (340 d) and days under heat stress for the top 25 states with the most dairy cows. We assumed an average loss of 4.66 kg per 340 d for each day of heat stress.

Table 2. Economic feasibility analysis of cooling dry cows in Florida for a 100-cow herd

Item	Value
Number of lactating cows at any time during the year	85
Number of dry cows at any time during the year	15
Days with heat stress (average THI >68) during the year ¹ (%)	257 (70%)
Lactating days with benefit from cooling in subsequent lactation	340
Milk loss in subsequent lactation when full time heat stress (kg/d)	5
Cows in second and greater parity (%)	65
Milk price (\$/kg)	0.44
kg of DMI per kg more milk produced	0.4
Feed price (\$/kg of DM)	0.28
Number of dry stalls per fan	5
Investment cost of a fan (\$/fan)	700
Lifetime of a fan (yr)	7
Maintenance cost of a fan (\$/fan per yr)	15
Electrical demand charge (\$/fan per yr)	37
Electricity charge (\$/kWh)	0.06
Power of a fan's motor (kW)	0.4
Energy efficiency of fans (kW)	0.75
Hours fan is used per heat stress day	24
Investment costs of soaker line (\$/dry stall)	8.19
Lifetime of a soaker line (yr)	5
Soaker water usage (L/dry stall per heat stress day)	56.8
Cost of water (\$/1,000 L)	0.42
Investment cost of dry cow barn (\$/dry cow stall)	2,500
Lifetime of dry cow barn (yr)	20
Barn maintenance, sand (\$/dry cow stall per yr)	90
Present value of milk sales minus feed cost (\$/cow per heat stress day)	0.56
Present value of barn investment + maintenance (\$/cow per yr)	27.16
Present value of soakers, fans investment + maintenance (\$/cow per yr)	3.38
Present value of water and electricity use (\$/cow per heat stress day)	0.012
Including costs of fans, soakers, and barn investment	
Net present value (\$/cow per yr)	111
Benefit:cost ratio	2.34
Payback period of initial investments (yr)	1.87
Internal rate of return (%)	53
Including costs of fans, soakers only	
Net present value (\$/cow per yr)	139
Benefit:cost ratio	3.47
Payback period of initial investments (yr)	0.10
Internal rate of return (%)	1,017

¹THI = temperature-humidity index.

is as high as \$4,106 per dry cow stall. However, when the barn investment cost was not included, dairy farmers in Florida would recover their investments in fans and soakers in 3 yr with milk prices as low as \$0.13/kg (\$0.02 milk sales minus feed cost per kg of milk). A small increase in milk production in the subsequent lactation would be enough to pay the investment of cooling dry cows in 3 yr in these 5 states if investment in the dry cow cooling barn is not required.

DISCUSSION

Our objectives were to quantify the economic losses from milk not produced across the United States if dry cows experienced heat stress during their dry period, and to provide an economic feasibility analysis of investments in soakers and fans as well as cooling barns for dry cows. The results showed a loss of \$810 million

per year in the United States from lost milk production alone if dry cows were not cooled. It is not known how many dry cows actually experience heat stress as a result of a lack of cooling during periods of heat stress. Therefore, the opportunity value of further cooling dry cows is likely less than \$810 million annually.

Heat Stress Assumptions

We assumed that cows were either heat stressed every day of their dry period or did not experience any heat stress in their dry period. In most of the reviewed literature, cows experienced heat stress every day but not 24 h/d because nights were cool. In practice, cows might experience heat stress on some days and not others. Urdaz et al. (2006) reported increase in milk production in the subsequent lactation for cows that were cooled only in the last 28 d of their dry period. It

is not known if cooling during the entire dry period is necessary to obtain the benefits of cooling dry cows in the subsequent lactation.

The effects of cooling dry cows on milk production in the subsequent lactation, as reported in the literature review, were observed when lactating cows were not experiencing heat stress. It is not known what the effect of dry cow cooling is when the cow experiences some heat stress in the subsequent lactation, such as cows housed outdoors during summers without adequate access to heat abatement. We can expect that the majority if not all of the subsequent milk production occurs when the cow does not experience heat stress, however, either because she is actively cooled or because milk production happens in the cooler time of the year when no heat abatement is necessary anyway.

We used the average THI ≥ 68 to describe either the presence of absence of heat stress (Zimbelman et al., 2009). This measure was developed for lactating cows and ignores the severity of heat stress. Although the dry cow produces less metabolic heat than a lactating cow and has a higher heat dissipation capacity, her endocrine system is more sensitive to moderate heat

stress (Collier et al., 1982). Heat stress can reduce the concentrations of plasma thyroxin and placental estrogen, leading to an impairment in the growth and postpartum function of maternal tissues (Collier et al., 1982). A THI ≥ 68 might therefore be a realistic indication of heat stress for the dry cow. In addition, the dry cow is likely to not be under shade and thus more exposed to solar radiation. In this case, the actual black globe heat load the dry cow experiences might be more severe than a THI of 68.

Jordan (2003) stated that it would be important to measure the duration and intensity of heat stress to understand the full effect on cow performance. We ignored the heat load in a day, for example, as measured by the number of hours per day the THI was above a threshold (THI load) or under the temperature of 21°C, conditions that help cows alleviate heat stress through dissipation of heat load gained previously (Scott et al., 1983; Igono et al., 1992). Other measures of a heat stress could change the number of heat stress days across the United States.

A preferred measure of heat stress is rectal temperature (Kadzere et al., 2002). A strong and positive

Figure 3. Net present value per cow per year for 0 to 360 d of heat stress per year. The costs of fans and soakers and barn investment costs were included. Milk prices (\$/kg): 0.34, 0.44, and 0.54. Increase in milk yield (kg/d): 1, 3, and 5. Barn investment cost (\$/dry cow stall): 1,500, 2,500, and 3,500.

Table 3. Breakeven analysis for milk increase in subsequent lactation, milk price, and the barn investment cost, to obtain a payback period of 3 yr for the 3 states with the most dairy cows (California, Wisconsin, New York) and Florida and Texas¹

State	Barn + fans + soakers			Fans + soakers only	
	Milk increase (kg/cow per d)	Milk price (\$/kg)	Barn investment cost (\$/dry cow stall)	Milk increase (kg/cow per d)	Milk price (\$/kg)
CA	7.37	0.60	1,536	0.55	0.15
WI	10.96	0.83	880	0.77	0.16
NY	9.91	0.76	1,022	0.71	0.16
FL	3.28	0.33	4,106	0.30	0.13
TX	4.30	0.39	2,989	0.36	0.14

¹Default assumptions: \$2,500 barn investment cost per dry cow stall, \$0.44/kg milk price, 5 kg/d reduction in milk yield in the subsequent lactation if dry cows were not cooled. States and number of heat stress days: CA (112), WI (75), NY (83), FL (257), and TX (194). Variables were varied one at a time with the other variables set at their default values.

relationship is present between rectal temperature of dry cows in the afternoon and milk production in the subsequent lactation (Tao and Dahl, 2013). Under normal management, complete abatement of heat stress is unlikely, but active cooling could help decrease body temperature (Tao and Dahl, 2013).

We also assumed that the 15% of the herd is dry throughout the year, regardless of the season. Signifi-

cant seasonality in reproductive performance exists in the Southeastern United States (al-Katanani et al., 1999; Oseni et al., 2003; De Vries and Risco, 2005). Consequently, the calving pattern results in a seasonal dry pattern. More cows are dry in the warmer season of the year than the cooler season to encourage fall calving (Du, 2013), which increases the estimated total loss of milk not produced if cows are not cooled.

Figure 4. Net present value per cow per year for 0 to 360 d of heat stress per year. Only the costs of fans and soakers are included but not barn investment costs. Milk prices (\$/kg): 0.34, 0.44, and 0.54. Increase in milk yield (kg/d): 1, 3, and 5.

Investment Analysis

Generally, cooling of dry cows was found to be very profitable. Adin et al. (2009) found a breakeven milk yield of 80 kg in the subsequent lactation in Israel to pay for cooling dry cows. Those authors did not include the increase in DMI, but included the investments in cooling facilities, installation, and operation costs. The number of heat stress days in their experiment was approximately 120 d. When using our model with default prices and including the increase in DMI, our breakeven yield would be 265 kg of milk in each subsequent lactation to reach an NPV equal to \$0. At a response of 5 kg/d, this extra milk production is realized in 53 d. If a barn is not necessary, the breakeven yield would be 40 kg of milk in each subsequent lactation.

Other Effects of Heat Stress Not Included in This Study

This study included effects of heat stress on only milk production in the subsequent lactation. We assumed that cows survived at least 340 d in the subsequent lactation. In practice, approximately 20 to 50% of cows are culled in the subsequent parity and would only benefit from cooling in the previous dry period until they are culled. On the other hand, other benefits of cooling dry cows were not included in our analysis. For example, replacement heifers might benefit from cooling during later stages of their gestation and consequently milk production in the first parity would increase. Another factor not included is that when a cooling barn is built, dry cows are moved from alternative housing to inside the cooling barn. This would reduce the costs of the alternative housing and further increase the value of investment in a barn with cooling.

Various other effects of heat stress during the dry period on animal performance have been documented or are being discovered. Heat stress during the dry period shortens gestation length (Collier et al., 1982; Tao and Dahl, 2013), which has been associated with a decrease in milk production in the beginning of the subsequent lactation (Bremmer et al., 1999). In addition, an increase in the number of stillbirths (A. Vieira-Neto, University of Florida, Gainesville, personal communication), and an increase in the incidence of postpartum diseases (Adin et al., 2009) is reported. The immune function was compromised in cows that underwent heat stress during the dry period (do Amaral et al., 2011). Milk fat might also decrease (Avendaño-Reyes et al., 2006; do Amaral et al., 2009). Cows dry in hot months had an increase in the number of days to first insemination, number of inseminations, increased culling for reproductive failure (Wiersma and Armstrong,

1988), and days to pregnancy diagnosis during the first 150 DIM in the subsequent lactation relative to those dry in cool months (Thompson and Dahl, 2012). Calves born from cows exposed to heat stress during their dry period had lower birth weights (Collier et al., 1982; do Amaral et al., 2011; Tao et al., 2012) and compromised passive immune transfer (Tao et al., 2012). Some evidence is emerging that fertility and milk production through the first lactation are negatively affected if the female experienced heat stress around the time of her creation (Brown et al., 2016) and at the end of gestations before she was born (Monteiro et al., 2016). The economic consequences from these effects are not easily evaluated. Therefore, the economic benefits from cooling dry cows in this study appear to be conservative.

CONCLUSIONS

The average US dairy cow (including first lactating cows) would experience 96 heat stress days during the year if not cooled and lose 290 kg of milk in the subsequent lactation if not cooled when dry. Annual losses would be \$810 million if dry cows were not cooled. Cooling of dry cows was profitable for 89% of the cows in United States when building a new barn is needed (under default assumptions) and very profitable when construction of a dry cow barn is not required (except for Alaska).

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