Thermal, Productive, and Reproductive Responses of High Yielding Cows Exposed to Short-Term Cooling in Summer

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ABSTRACT

Effect of cooling on body temperature, milk production, estrous behavior, and reproductive performance was examined in 66 estrous-synchronized, Israeli-Holstein dairy cows. Cooling was by an automated system, which actuated sprinkling (30 s) followed by forced ventilation (4.5 min) for 30-min periods. Cows were cooled 9 times/d between 0500 and 2100 h over 10 d, starting 1 d before expected estrus until d 8 post estrus. Cooling reduced typical diurnal rise of body temperature in summer heat-stressed cows by .5 to .9°C, and body temperature was maintained close to normothermic temperature (38.6°C). Milk production of cooled cows was 2.6 kg/d (+8%) above control at end of the cooling period. More cooled cows than noncooled exhibited standing estrous behavior; in noncooled cows, silent ovulations or anestrus were more frequent. Conception rate of cooled cows did not differ from control, suggesting need for a longer than a 10-d cooling period for improvement of fertility. The cooling system has potential to alleviate heat stress in dairy cows and to improve their thermal balance, productive, and reproductive performances.

INTRODUCTION

Summer heat stress is generally known to affect productivity of dairy cows (8). The effect of relieving heat stress by different methods on thermal and productive responses of dairy cows has been examined in a number of studies as were the effects of shading (22), ventilation (3, 7), and sprinkling (11, 15). In general, various methods decreased body temperature (Tb), partially improved milk production, but did not totally eliminate seasonal reduction.

Most research on heat stress effects on reproduction has been focused on failure of fertilization and on early embryonic mortality (18, 22). High ambient temperature (Ta), on the day after insemination appeared to be detrimental to conception (2). The most critical period appeared to be from insemination and the following few days (21). Fertility was improved by cooling dairy cows during the first 10 d after insemination by means of spraying water (11). Mechanical refrigeration (21) of dairy cows during the first 6.5 d after insemination tended to improve fertility, but differences from control were small and not statistically significant. During hot weather, estrous behavior is also impaired. Cows in a hot climate had shorter estrus than cows held in cool conditions (10).

Sprinkling combined with forced ventilation was first examined by Seath and Miller in 1948 (20). Temperature of hyperthermic cows was reduced by wetting the skin with a hand sprinkler and fan ventilation for 1 h. Recently we described an automatically controlled system of cooling dairy cows that combines sprinkling and ventilation (6). Wetting the animal’s skin and coat provides water for evaporation irrespective of sweating, and forced...
ventilation enhances evaporation by sustaining the vapor pressure gradient between the animal's surface and the surrounding air. Body temperature was lowered by 1°C as a result of 30 min of cooling of cows at 31°C. However, four such cooling periods per day did not totally eliminate temporary rises of T_b in cows exposed to summer environment.

The objective of this study was to examine the effect of short-term cooling on thermal responses, reproductive performance, and milk production of dairy cows during summer.

MATERIALS AND METHODS

Animals

Sixty-six Israeli-Holstein dairy cows were paired according to lactation number and previous milk yield and randomly assigned to either cooled (C) or noncooled (NC) treatments. Cows were estrous-synchronized with PRID (progesterone-releasing intravaginal device, CEVA, France) and prostaglandin F_2α analogue, cloprostenol (Estrumate; ICI, England). Synchronization was obtained by insertion of PRID for 7 d with Estrumate injected intramuscularly 1 d before PRID removal. The experiment was carried out on four groups of synchronized cows during July to September. Groups were formed of cows that had calved within 3 wk, 16 cows per group on average. All cows in a group were estrous-synchronized on the same date. Environmental conditions were similar for all four summer groups; mean (and range) of minimal and maximal daily T_a and relative humidities during experimental periods (described later) for the four groups were: 20.4°C (20.2 to 21.7°C) and 31.8°C (31.5 to 32°C); 43% (40 to 48%) and 89% (89 to 90%). Cows were fed ad libitum a complete ration containing concentrates, cotton seeds, corn silage, vetch hay, and liquid whey. The ration (which included hay and silage as 25% of DM) comprised 17% CP, 14 to 15% crude fiber, and a caloric density of 1.78 Mcal/kg DM (NE_1).

Housing and Cooling System

The cows were kept in an open shed with access to a concrete floored, unshaded yard with shaded mangers for individual animals. Mangers had stanchions for individual animals. Space allowed per cow was 17 m². At cooling times C cows were tied in stanchions to be cooled, whereas NC cows were kept in the open shed. At the end of cooling, C cows were released from stanchions. Forced ventilation, about 5 m/s, was produced along the stanchions by two fans (Model DDQ-632-6, free flow 12200 m³/h, Ziehl-Abegg, 7118 Kunzelsau, FDR), spaced 5 m apart and 3 m high. Sprinkling was supplied by inverted static garden sprinklers (Model 943, Naan, Israel), spraying about 12 L/min, spaced 1.5 m apart along the stanchions at 1 m above the backs of the animals. A similar cooling system operated in the holding area (6). The C cows were cooled nine times per day at 0500, 0830, 1000, 1200, 1340, 1440, 1600, 1730, and 2100 h. Cooling times and their spacing were determined by daily routine on the farm, resulting in uneven intervals between coolings. Cows were cooled six times in the experimental area and three times in the holding area before milking times (0530, 1230, and 2130 h). Each cooling period lasted 30 min and consisted of repeated cycles of sprinkling (30 s) and forced ventilation (4.5 min). The cooling lasted 10 d; it started 1 d (d−1) before the expected synchronized estrus (d 0), and ended to d 8 postestrus. During this period, control cows were cooled twice during the day in the holding area, before morning and night milkings. Before and after the 10-d experimental cooling period, all cows were exposed to the usual farm cooling routine: three 20-min coolings in the holding area before milkings and two additional coolings before noon milking at 0900 to 1000 h and following this milking at 1500 to 1600 h.

Measurements

Ambient temperature and relative humidity were recorded continuously in the shed (Rustrack RH/Temperature Recorder Model 225, Gulton Industries Inc., East Greenwich, RI). Rectal temperature was measured to nearest .1°C with an interchangeable thermistor probe system (Model 46TUC Tele-thermometer, Yellow Springs Instruments, Yellow Springs, OH). To characterize thermal responses of C and NC cows, on d 4 T_b was measured throughout the day. For C cows, T_b was measured between 0700 and 1800 h, before, just after and 20 to 30 min after end of each cooling period. A total of 18 T_b measurements were recorded for each C group cow, whereas for each NC group cow, 12 measurements were sufficient to charac-
terize \( T_b \) pattern during daytime hours. This schedule of \( T_b \) measurements of C and NC cows was based on the results of previous experiment with the cooling system (6).

Daily milk yields (thrice daily milkings) were recorded at monthly intervals. Milk yields were also recorded before and after cooling treatment, on d -4 and d 8, respectively; the latter data served for analysis of cooling effect on milk yield. Milk yields of one group were deleted from data analysis due to milking machine problems.

Cows were observed for behavioral estrus four times daily for 4 wk starting 36 h after PRID removal. All cows were artificially inseminated 54 h following PRID removal, i.e., on day of expected estrus (d 0). Cows exhibiting estrous behavior after first AI or cows that did not exhibit estrus at all were re inseminated 72 h after PRID removal. Pregnancy was diagnosed by rectal palpation at 45 d postinsemination. In addition, cows that did not manifest estrus through d 28 (nonreturn cows) were recorded. Samples of blood from the jugular vein were collected at 0700 h on d -4, 0, 3, 6, 8, 11, 14, 17, and 24 post-AI, and the concentration of progesterone in plasma was determined by radioimmunoassay as described by Wolfenson et al. (24). Cows not exhibiting estrus between 36 h and 6.5 d after removal of PRID were defined as anestrus cows. Profiles of progesterone (not presented) were used to evaluate ovarian status of these cows. Anestrus cows in which plasma progesterone concentration declined from 2 ng/ml and above at 48 h before PRID removal to .5 ng/ml and below between d -1 and d 1 and increased within the following 2 to 5 d to 1 ng/ml and above, were considered as having undergone a silent ovulation. Those in which d 0 plasma progesterone was 3 ng/ml and above, or cows in which progesterone remained at 1 ng/ml or below until at least d 9 to 10, were regarded as cows that did not ovulate during the experimental period.

**RESULTS AND DISCUSSION**

**Effect of Cooling on Body Temperature**

Mean air temperatures during the experiment were 26°C at 0700 and 1900 h and peaked at 32°C at 1300 h. The effect of cooling on \( T_b \) is in Figure 1. The large increase in \( T_b \) that occurred in NC during the hotter hours of the day was typical of the hot season and was almost completely eliminated in C. Differences of .5°C up to .9°C were noted between C and NC cows (\( P<.01 \)). Temperature of NC cows reached 39.1°C at 1000 h and thereafter remained high with peak \( T_b \) of 39.4°C at 1500 h (\( P<.01 \) for treatment by time of day interaction). By this cooling method, \( T_b \) does not decrease immediately after beginning of a 30-min cooling period, but rather becomes maximal 20 to 30 min after its end. A detailed analysis of the effect of cooling on the \( T_b \) of cows within cooling postcooling cycle has recently been presented (6).

Comparing the efficiency of the present cooling method with other methods is difficult, because climatic conditions, milk yields, and other factors differ in the various studies. In other studies, \( T_b \) decreased between .1°C and 1.6°C. Shade reduced \( T_b \) by 1.6 from 40.8°C in cows exposed to solar radiation; however, \( T_b \) of shaded cows remained high at 39.2°C (19). Cooling shaded cows by different means was less efficient in \( T_b \) reduction during hot hours of the day. Reductions of \( T_b \) during hot afternoon hours of about .3°C were recorded in a few studies on shaded cows cooled by forced ventilation (3), roof sprinkling (9), and spray
cooling (15). Spray cooling in the tropics (11) and air misting and fan cooling (1) resulted in a .6°C reduction in T_b during the hot afternoon hours. Reductions of up to 1.0°C were reached by air conditioner zone cooling in Louisiana (12). Larger reductions (up to 2.0°C) were attained by maintaining cows in mechanically refrigerated closed barns (21). The latter are, however, rather expensive to operate.

In this study, animals were cooled nine times per day and average interval between two consecutive 30-min cooling periods was 1.5 h (range 1 to 2 h). Such a cooling regimen successfully decreased and leveled T_b at 38.5°C during day time (Figure 1) for a .3°C increase above that at 1300 h. This rise could be associated with activities related with milking (walking, crowding, etc.) during the hotter hours of the day. Mean T_b of cooled cows in this study (38.6°C) was similar to T_b recorded for high yielding Israeli-Holstein dairy cows in winter conditions [T_a range 10 to 25°C, (7)]. It should be noted that in our study mean maximum T_a did not exceed 32°C, which reflects a moderate summer. At T_a of 32°C and above, T_b increases to the 40°C range (3).

**Milk Production**

Curves at 150 d lactation of C and NC cows are in Figure 2. The 10-d cooling period was applied after peak lactation at an average 87 d postpartum. The lactation curve of cooled cows was transiently elevated. Cessation of intensive cooling was associated with a decline of the lactation curve to the precooling yields. Similarity between lactation curves of C and NC cows was noted thereafter.

Least squares analysis of the effect of 10-d cooling period on milk production is in Table 1.

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**TABLE 1. Least squares analysis of variance for milk production of cows in summer before and after 10-d cooling period.**

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>MS</th>
<th>Error term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group (G)</td>
<td>1</td>
<td>198.32a</td>
<td>C (G X T)</td>
</tr>
<tr>
<td>Treatment (T)</td>
<td>1</td>
<td>64.02</td>
<td>C (G X T)</td>
</tr>
<tr>
<td>G X T</td>
<td>2</td>
<td>73.67</td>
<td>C (G X T)</td>
</tr>
<tr>
<td>Cow (G X T)</td>
<td>42</td>
<td>63.98**</td>
<td>R</td>
</tr>
<tr>
<td>Time</td>
<td>1</td>
<td>.30</td>
<td>R</td>
</tr>
<tr>
<td>G X time</td>
<td>2</td>
<td>7.07</td>
<td>R</td>
</tr>
<tr>
<td>T X time</td>
<td>1</td>
<td>37.72*</td>
<td>R</td>
</tr>
<tr>
<td>G X T X time</td>
<td>2</td>
<td>2.28</td>
<td>R</td>
</tr>
<tr>
<td>Residual (R)</td>
<td>41</td>
<td>6.43</td>
<td></td>
</tr>
</tbody>
</table>

^a^P<.06.

1 Three groups of 16 synchronized cows from July to September.

2 Cooled vs. noncooled cows.

3 Milk production before (d -4) and at end (d +8) of 10-d cooling period.

*P<.02.

**P<.01.

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![Figure 1](image-url)  
**Figure 1.** Body temperature (°C) of cooled (0) and noncooled (*) cows in summer. Vertical broken lines mark beginning of 30-min cooling periods of cooled cows. Standard error of the means of cooled and noncooled data: .02, .03, respectively.
Average milk yield was slightly different \( (P<.06) \) among groups of cows. Group interactions with treatment or with treatment by time were not significant, indicating that groups did not differ in their response to cooling. Of physiological significance is the finding that treatment by time (pre- and postcooling milk yields) interaction was significant \( (P<.02) \), indicating different trends of milk yield change with time between two treatments. In the C group, milk yield increased by 1.2 kg/d over precooling yield, whereas in NC cows, yield decreased by 1.4 kg/d during the same period (Table 2). As a result, the cooled group produced about 3 kg/d more milk than the NC group at end of the cooling period.

The design of this experiment was determined partly by practical considerations of experimentation on a commercial farm. Consequently, during the experimental period C cows experienced a marked short-term reduction in heat stress, and NC cows experienced a short-term increase in heat stress. Overall net milk production differences between the two groups could have resulted from indirect effect of change in environmental conditions on feed consumption as well as from a direct effect of heat stress on production of milk. It is beyond the scope of this study to characterize the specific effect of the two elements on milk production. Further studies in which cows were cooled postpartum during summer months by a similar cooling system indicated similar increment of milk production (Wolfenson et al., unpublished data).

Provision of shade increased production by 2.4 kg/d above 17 kg/d for un-shaded animals (19). Attempts to improve summer milk yields of high producing multiparous shaded cows in Israel (35 kg/d) by forced ventilation increased daily milk production 1.9 kg (7). Installation of additional cooling systems for shaded cows in the US improved milk production; evaporative cooling increased production by .5 to 1.5 kg/d from mean control value of 22 kg/d (5), roof sprinkling improved production by .6 kg/d above a 21 kg/d control yield (9), and spray-cooled cows produced .7 kg/d more milk than the 23 kg/d control value (15).

Table 2. Daily milk yields\(^1\) of cooled and noncooled cows before and at end of a 10-d cooling period in summer.

<table>
<thead>
<tr>
<th>Group</th>
<th>No. cows</th>
<th>Milk production time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before cooling*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \bar{X} ) SE</td>
</tr>
<tr>
<td>Cooled</td>
<td>25</td>
<td>33.9 .5</td>
</tr>
<tr>
<td>Noncooled</td>
<td>23</td>
<td>33.5 .5</td>
</tr>
</tbody>
</table>

\(^{a,b}\)Means within column with different superscripts differ \( (P<.05) \).

* Treatment \times Time interaction \( (P<.02) \).
Estrous Behavior and Reproductive Performance

Use of a short, intensive cooling period during early pregnancy to improve reproductive performance could be practical on the dairy farm only if groups of cows at the same reproductive stage can be cooled at the same time. Estrous synchronization allows for such grouping. Synchronization treatment did not interact significantly with season (summer vs. winter) on conception rate (Y. Folman, personal communication) or affect milk production (D. Wolfenson, unpublished data). Thus, synchronization does not seem to confound the effect of cooling on the data set.

Effect of cooling on estrous behavior is in Table 3. In cows that manifested estrus, it was recorded on d −1, d 0, and d +1, i.e., 36 to 48, 49 to 72, and 73 to 96 h after PRID removal, respectively; one cow was detected in standing estrus on d +2. More C than N cows were observed in standing estrus. The occurrence of anestrus was more prevalent in the NC than in the C group. Of these, 2 C cows and 6 NC cows had silent ovulations (P<.10).

These results indicate that cooling heat-stressed cows affected estrous behavior, specifically increasing incidence of standing estrus. The results agreed with (10), which showed that summer heat stress reduces incidence of estrus, shortened its duration, and decreased its intensity in Holstein heifers. Multiparous cows in summer had, on average, a longer (30.8 d) estrous cycle than winter cows (24.7 d), whereas interval between ovulations did not differ between seasons; this suggested occurrence in summer of ovulations unaccompanied by standing estrus (8). Higher frequency of silent ovulations in heat-stressed cows was also reported (17). The higher proportion of anovulating cows in the NC group supports the suggestion that heat stress may prevent or delay ovulation (4), in this case, in estrous-synchronized cows.

The reproductive performance of cooled and noncooled cows is in Table 4. It includes only cows that manifested estrus prior to or at AI; the 15 anestrous cows of both groups, of which only 2 were found pregnant, were excluded. No difference between C and NC cows was found in percent cows not showing estrus through d 28, or in conception rate as diagnosed by rectal palpation on d 45 (31 and 36%, respectively). When anestrous cows were included, conception rate was 27 and 31% for C and NC cows.

The lack of improved conception rate by cooling the cows between d −1 to d 8 contrasts with the study by Gauthier (11), which showed a significant increase in conception rate of cows cooled by sprinkling for the first 10 d after AI. Nor, does it agree with the inverse relationship between conception rate and high Ta on the day postinsemination (2) or with pregnancy being particularly sensitive to heat stress during d 4 to d 6 post-AI (23). A possible reason for the discrepancy between studies could be that in the present study Tb of NC cows did not exceed 39.5°C, which represents a mild hyperthermia. In other studies, more severe hyperthermia prevailed. A relationship between conception rate and ambient heat stress during the 12 d preceding AI and especially on d −2, was suggested (16). The moderate conception rate in the two groups and the absence of postinsemination cooling effect may therefore

<table>
<thead>
<tr>
<th>Group</th>
<th>No. cows</th>
<th>Cows showing estrous behavior</th>
<th>Anestrous cows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Standing</td>
<td>Mounting</td>
</tr>
<tr>
<td>Cooled</td>
<td>33</td>
<td>23 a (70%)</td>
<td>6 (18%)</td>
</tr>
<tr>
<td>Noncooled</td>
<td>33</td>
<td>15 b (45%)</td>
<td>7 (21%)</td>
</tr>
</tbody>
</table>

a,b Means within column with differing superscripts differ (P<.05).
TABLE 4. Conception rate\(^1\) and nonreturn rate\(^2\) of summer cooled and noncooled cows showing estrus behavior.

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Cows</th>
<th>Nonreturn Rate</th>
<th>Conception Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooled</td>
<td>29</td>
<td>21 (72%)</td>
<td>9 (31%)</td>
</tr>
<tr>
<td>Noncooled</td>
<td>22</td>
<td>15 (68%)</td>
<td>8 (36%)</td>
</tr>
</tbody>
</table>

\(^1\) Diagnosed pregnant by rectal palpation on d 45.

\(^2\) Percent cows not showing estrus through d 28.

be due to preceding mild weather and to routines relieving heat stress prior to insemination.

All cows were cooled five times daily in the holding area, before and after the 10-d experimental period, according to the normal routine in the herd. Such a cooling regimen improved the thermal state of the cows, but it was less efficient compared with the experimental cooling regimen. Thus, following, termination of the experimental period on d 8, C cows were exposed to more stressful conditions whereas thermal status of NC cows was improved. Consequently, it is possible that the decreased cooling frequency of C cows increased embryo losses after d 8, and any benefit of increasing embryo survival rate in the 1st wk post-AI diminished afterwards. Occurrence of embryo losses at the 2nd and 3rd wk post-AI was suggested earlier (13). This underlines the difficulty in trying to assess the effect of short-term heat stress relief in field experiments on pregnancy maintenance.

In conclusion, cooling dairy cows for 10 d, from d -1 to d 8 post-AI, successfully prevented the typical diurnal increase in \(T_b\) during summer. Milk production of cooled cows at the end of cooling period was about 3 kg/d higher than in NC cows. More cooled than noncooled cows exhibited estrus. However, fertility was not improved by cooling cows, probably because of the short cooling period.

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REFERENCES

15. Igono, M. O., B. J. Steevens, M. D. Shanklin, and


