Strategies to Improve Reproduction during Heat Stress

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INTRODUCTION

Heat stress (**HS**) negatively impacts all aspects of dairy cattle production. Milk production decline and reproduction losses during the summer substantially impact the economic potential of dairy farms. The annual economic impact of HS on American animal agriculture has been estimated at $2 billion, with the dairy industry alone accounting for $900 million of this loss.

Heat stress occurs over a wide combination of solar radiation levels, ambient temperatures, and relative humidity. This is further aggravated by metabolic heat production (generated by the cow herself). Generally, it is assumed that a cow becomes more sensitive to HS as milk production increases due to elevated metabolic heat production. The dairy industry continues to focus on selecting for production traits which, in turn, may increase the dairy cow's susceptibility to HS further intensifying the summer decline in milk production and reproduction. In addition, selecting for milk yield reduces the thermoregulatory range of the dairy cow (Berman et al., 1985).

Breeds predominantly used in the U.S. dairy industry were developed in temperate climates, and are most productive between the temperatures of 41 and 59º F. Cows experience a loss in production when temperatures increase from 59 to 77º F (Hahn, 1985). However, dramatic reductions are observed when the temperature exceeds 77º F. Consequently, strategies should be initiated to lessen the severity of HS on both reproduction and milk production to improve cow performance and farm profitability.

IMPROVING REPRODUCTION BY COOLING DRY COWS

Traditionally, dry pregnant cows are provided little protection from HS because they are not lactating; and it is incorrectly assumed they are less prone to HS. Additional stressors are imposed during this period due to abrupt physiological, nutritional, and environmental changes. These changes can increase the cows' susceptibility to HS and have a critical influence on postpartum cow health, milk production, and reproduction. The dry period is particularly crucial since it involves mammary gland involution and subsequent development, rapid fetal growth, and induction of lactation. Heat stress during this time period can affect endocrine responses that may increase fetal abortions, shorten the gestation length, lower calf birth weight, and reduce follicle and oocyte maturation associated with the postpartum reproductive cycle.

Many studies reporting subtle effects of HS on subsequent fertility were published over 20 yr ago when the average milk yield was much less than it is today. In addition, our cooling systems and knowledge of proper cooling (when, where, and to what extent) to reduce HS has increased substantially. A study conducted in Saudi Arabia on 3 different farms observed an improvement in peak milk production (90.9 vs. 87.2 lb), decreased services per conception (3.1 vs. 3.7 services), and reduced culling for reproductive failure (7.7 vs. 19 %) for dry cows evaporatively cooled vs. shade only (Wiersma and Armstrong, 1988). More recently, Avendano-Reyes et al. (2006) concluded that cooling dry cows with shades, fans, and water spray vs. cows with only shade decreased services per conception and days open, while milk yield increased during the postpartum period. In 2006, Urdaz et al. observed that dry cows with feed line sprinklers, fans, and shade compared to cows with only feed line sprinklers had an increased 60 d milk yield with no difference in body condition score (**BCS**) changes, incidence of postparturient disorders, or serum nonesterified fatty acid (**NEFA**) concentrations. Although reproductive parameters were not measured, cooling dry cows with shades, fans, and sprinklers compared with only sprinklers improved total 60 d milk production by 185.5 lb/cow, and increased estimated annual profits by $8.92/cow (based on milk only).

The problem of *carry over* effects from summer HS to fall fertility may be accentuated due to HS during the dry period. It is well known that a period of approximately 2 mos is needed for low autumn fertility to be restored to the level prevailing in the winter. It takes approximately 40-50 d for antral follicles to develop into large dominant follicles and ovulate (Roth et al., 2001). If HS occurs during this time period both the follicle and oocyte inside the follicle become damaged. Once ovulation occurs, the damaged oocyte has reduced chances of fertilizing and developing into a viable embryo. Cooling dry cows may reduce HS effects on the antral follicle destined to ovulate 40-50 d later, which coincides with the start of most breeding periods, and possibly increases first service conception rates.

The greatest opportunity to reduce the negative effects of HS during both the pre- and postpartum periods is through cooling. As mentioned previously, cooling dry cows with feed line sprinklers, fans, and shades proved to be beneficial for reducing services per conception, reproductive culls, and days open; as well as increasing milk yield with a significant return on investment compared to cows with either shades alone or feed line sprinklers alone (Wiersma and Armstrong, 1988; Avendano-Reyes et al., 2006; Urdaz et al., 2006). In addition to proper cooling, changing management decisions may help reduce the severity of HS in areas of intermittent heat waves. For instance, at dry-off, many cows receive vaccines that can cause a fever spike which, when coupled with HS, can cause body temperature to rise above normal (101.3-102.8 ºF). In the 2006 California heat wave, many cows died (not only in the fresh pen as expected) within the first few days of dry off (personal unpublished observations). Possibly, during severe heat waves it would prove beneficial to delay vaccinations at dry-off, if the dry pen does not contain adequate cooling.

IMPROVING LACTATING DAIRY COW REPRODUCTION DURING HEAT STRESS

As mentioned earlier, genetic selection for milk production has increased metabolic heat output per cow. This has considerably increased the lactating dairy cows' susceptibility to HS. In addition, the first several days to weeks following calving, the cow is vulnerable to infectious diseases and metabolic disorders. These stress factors, coupled with physiological, nutritional, and environmental changes occurring at calving, can reduce reproductive performance.

Energy Balance

Many experiments indicate HS reduces both feed intake and milk yield, and this decreased feed intake has been recognized as one of the main reasons for reduced milk yield. Recently, a series of studies conducted at the University of Arizona demonstrated Holstein cows subjected to HS in mid-lactation vs. cows housed in thermal-neutral conditions and pair-fed had a greater reduction in milk yield (31 lb/d vs. 13 lb/d, respectively; Figure 1) despite a similar reduction in DMI (11 lb/d vs. 13 lb/d, respectively; Rhoads et al., 2007; Figure 2). In a similar experiment, HS cows entered into and remained in negative energy balance (**NEBAL**; ~4-5 Mcal/d) for the entire duration of HS (Wheelock et al., 2006; Figure 3). However, unlike NEBAL in thermal-neutral conditions, HS induced NEBAL didn't result in elevated plasma NEFA; but increased glucose disposal (rate of cellular glucose entry) in HS compared to thermal-neutral pair-fed cows. These studies indicate the reduction in DMI can only account for approximately 40-50 % of the decrease in production when cows are HS, and approximately 50-60 % can be explained by other HS induced changes. In addition, as an adaptive mechanism glucose is utilized as an energy source instead of NEFA to maintain milk production and daily maintenance during HS. This may have implications on fertility since the oocyte, embryo, and conceptus utilize glucose as an energy supply. Leroy et al. (2006) showed that cleavage rate and blastocyst development were severely reduced *in vitro* in a low glucose environment vs. a physiologically normal glucose environment.

The changes in the endocrine system not only affect milk yield, but impact reproductive performance. The lactating dairy cow first directs nutrients to growth (2- to 3- year-old cows), maintenance, and lactation before supplying the reproductive organ with nutrients for ovarian function and embryo growth. As mentioned, HS induces NEBAL and several studies indicate that lactating dairy cows losing greater than 0.5 units BCS within 70 d postpartum had longer calving to first detected estrus and (or) ovulation interval (Butler, 2000; Beam and Butler, 1999). Garnsworthy and Webb (1999) reported the lowest conception rates in cows that lost more than 1.5 BCS units between calving and insemination. In addition, Butler (2000) reported that conception rates range between 17 and 38 % when BCS decreases 1 unit or more, between 25 and 53 % if the loss is between 0.5 and 1 unit, and is > 60 % if cows do not lose more than 0.5 units or gain weight.

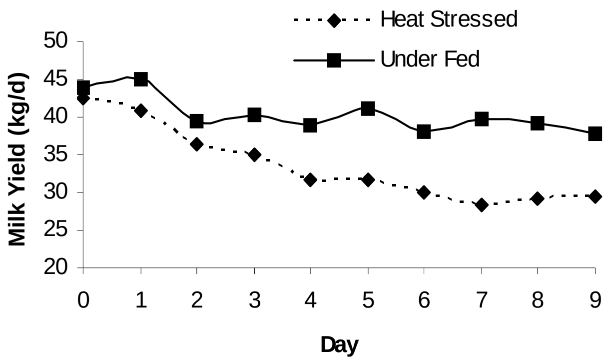

Figure 1. Effects of HS and pair-feeding thermal-neutral conditions on milk yield in lactating Holstein cows (adapted from Rhoads et al., 2007).

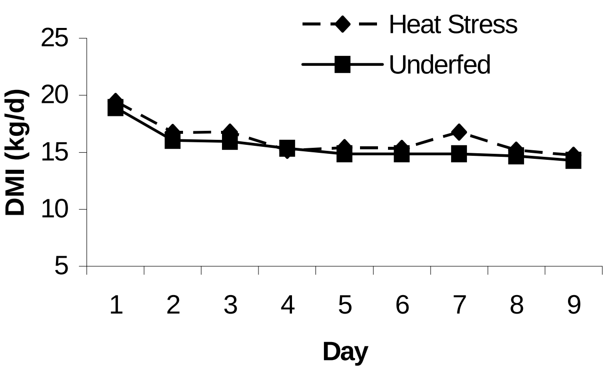

Figure 2. Effects of HS and pair-feeding thermal-neutral lactating Holstein cows on dry matter intake (adapted from Rhoads et al., 2007).

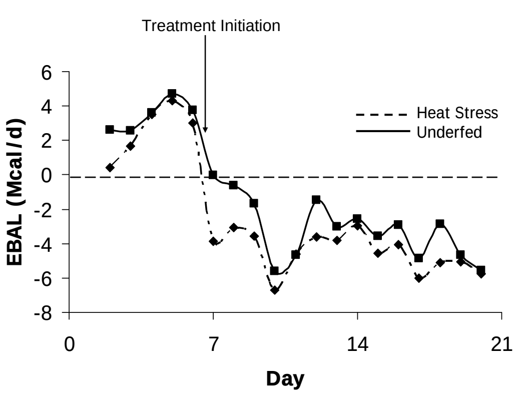

Figure 3. Effects of HS and pair-feeding thermal-neutral conditions on calculated net energy balance in lactating Holstein cows (adapted from Wheelock et al., 2006).

Interestingly, in addition to HS, another deterrent to dairy cow fertility is increased circulating plasma urea nitrogen concentrations. In terms of effects on fertility, most research has focused on the urea produced as a result of protein metabolism within the rumen. However, elevated urea concentrations are also a consequence of increased skeletal muscle breakdown. The end result of these physiological changes that occur during HS are elevated plasma urea nitrogen concentrations in HS cows compared to pair-fed cows in thermal-neutral conditions (Wheelock et al., unpublished). Therefore, elevated plasma urea nitrogen concentrations may be exacerbating the decrease in fertility that is frequently observed during periods of HS.

Estrous Activity, Hormone Function, and Follicular Development

Heat stress reduces the length and intensity of estrus. For example, in summer, motor activity and other manifestations of estrus are reduced (Hansen and Arechiga, 1999) and incidence of anestrous and silent ovulations are increased (Gwazdauskas et al., 1981). Nebel et al. (1997) reported that Holsteins in estrus during the summer had 4.5 mounts/estrus vs. 8.6 mounts for those in winter. On a commercial dairy in Florida, undetected estrous events were estimated at 76 to 82 % during June through September compared to 44 to 65 % during October through May (Thatcher and Collier, 1986).

Heat stress impairs follicle selection and increases the length of follicular waves; thus reducing the quality of oocytes and modulating follicular steroidogenesis (Roth et al., 2001). Summer HS has been shown to increase the number of subordinate follicles; while reducing the degree of dominance of the dominant follicle and decreasing inhibin and estrogen levels (Wolfenson et al., 1995; Wilson et al., 1998). The HS-induced increase in duration of follicular dominance has been associated with a reduced fertility in beef heifers (Mihm et al., 1994). Ryan and Boland (1991) observed an increase in twinning rates in dairy cows during summer vs. winter. Summer HS reduces follicular dominance allowing more than one dominant follicle to develop, explaining the increased twinning seen in summer months. As discussed earlier, the follicle destined to ovulate emerges 40-50 d prior to ovulation. Therefore, HS occurring at anytime during this period can compromise follicular growth and steroidogenic capacity. In addition, either due to direct actions of elevated temperature or alterations of follicular function, the oocyte has the potential to be compromised.

Oocytes, Fertilization, and Early Developing Embryos

During summer, HS reduces pregnancy and conception rates, which can carry-over into the fall months (Wolfenson et al., 2000). Oocytes obtained from dairy cows during the summer HS period had reduced developmental competence *in vitro* (Rocha et al., 1998). Rutledge et al. (1999) also reported a decrease in the number of Holstein oocytes that developed to the blastocyst stage during July and August compared to cooler months. In both of these studies, fertilization rate was not affected by season, but the lower development following fertilization during summer was indicative of oocyte damage. When superovulated donor heifers were exposed to HS for 16 h beginning at the onset of estrus, there was no effect on fertilization rate. However, there were a reduced number of normal embryos recovered on d 7 after estrus (Putney et al., 1988a). This illustrates that a brief HS can still affect oocyte competence within the preovulatory follicle. In addition, exposure of cultured oocytes to elevated temperatures during maturation decreased cleavage rate and the proportion of oocytes that became blastocysts (Edwards and Hansen, 1997).

Heat stress can also affect the early developing embryo. When HS was applied from d 1 to 7 after estrus there was a reduction in embryo quality and stage from embryos flushed from the reproductive tract on d 7 after estrus (Putney et al., 1989). In addition, embryos collected from superovulated donor cows in summer months were less able to develop in culture than embryos collected from superovulated cows during fall, winter, and spring months (Monty and Racowsky, 1987). Drost et al. (1999) demonstrated that transfer of *in vivo* produced embryos from cows in thermoneutral conditions increased pregnancy rate in HS recipient cows compared to that of HS cows subjected to AI. Embryos appear to have developmental stages in which they are more susceptible to the deleterious effects of HS as shown *in vitro*. *In vitro* HS at the 2- to 4-cell stage caused a larger reduction in embryo cell number than HS at the morula stage (Paula-Lopes and Hansen, 2002). An earlier study also showed that HS caused a greater reduction in embryo development when applied at the 2-cell stage than the morula stage (Edwards and Hansen, 1997) or at d 3 following fertilization than at d 4 (Ju et al., 1999).

Latter Stages of Embryo Development

Not only can HS affect the oocyte and early embryo, it can also reduce embryo growth up to d 17, which is a critical time point for embryo production of interferon-tau. Adequate amounts of interferon-tau are critical for reducing pulsatile secretion of prostaglandin $F_{2\alpha}$ (**$PGF_{2\alpha}$**); thus blocking CL regression and maintaining pregnancy. Biggers et al. (1987) indicated that HS reduced weights of embryos recovered on d 17 from beef cows. This reduction in embryo size was associated with reduced interferon-tau available to inhibit $PGF_{2\alpha}$ pulsatile secretion, which causes CL regression. Putney et al. (1988b) incubated embryos and endometrial explants obtained on d 17 of pregnancy at thermoneutral (39 °C, 24 h) or HS (39 °C, 6 h; 43 °C, 18 h) temperatures. The HS conditions decreased protein synthesis and secretion of interferon-tau by 71 % in embryos; however, endometrial secretion of $PGF_{2\alpha}$ and embryo secretion of PGE_2 increased in response to HS by 72 %. Collectively these studies demonstrate that both the embryo and the uterine environment can be disrupted due to HS inhibiting the embryo's ability to secrete interferon-tau (signal to block CL regression) and maintain pregnancy and (or) manipulating production of important proteins from the uterine lining.

Plasma concentrations of insulin, insulin-like growth factor-1, and glucose are decreased in summer compared to winter months; most likely due to low DMI and increased NEBAL. This reduction in important growth factors and nutrients for reproduction hampers the embryo's ability for normal growth and production of interferon-tau. Bilby et al. (2006) reported that supplementing lactating dairy cows with recombinant growth hormone at the time of AI and 11 d later increased growth factors, conceptus lengths, interferon-tau production, and pregnancy rates in lactating dairy cows compared to cows without bST supplementation. Possibly increasing availability of important growth factors during HS may improve embryo growth and survival.

Embryo loss is another important factor that effects fertility and is increased during HS. Dairy cows conceiving with singletons or twins are 3.7 and 5.4 times more likely to lose their embryo, respectively, during the hot versus cool season (Lopez-Gatius et al., 2004). In addition, the likelihood of pregnancy loss has been shown to increase by a factor of 1.05 for each unit increase in mean maximum temperature-humidity index (**THI**) from d 21 – 30 of gestation (Figure 4).

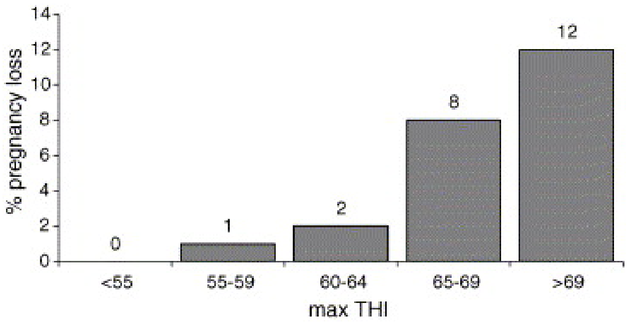

Figure 4. Pregnancy loss rates for different maximum temperature-humidity indices (THI) during d 21 – 30 of gestation (adapted from Garcia-Ispierto et al., 2006).

REDUCING NEGATIVE EFFECTS OF POSTPARTUM HEAT STRESS

Current and past research has resulted in dramatic improvements in dairy cow management in hot environments. Two primary strategies are to minimize heat gain by reducing solar heat load and maximize heat loss by reducing air temperature around the animal or increasing evaporative heat loss directly from animals. Following are several strategies to potentially help reduce the negative impacts of HS on reproduction in lactating dairy cows.

Cow Comfort and Cooling

Locating where HS is occurring on the dairy facility by identifying *hot spots* is key to implementing the proper cooling or management strategy to eliminate these hot spots. Temperature devices have been used to monitor core body temperatures in cows by attaching a temperature monitor to a blank continuous intravaginal drug release (**CIDR®,** Pfizer Animal Health, New York, NY) device for practical on-farm use. The device is inserted into the cow's vagina, measuring core body temperature every minute for up to 6 d. This allows monitoring of the cow's body temperature and identification of where the cow is experiencing HS.

Providing enough shade and cow cooling is vital for proper cow comfort. There should be at least 38 to 45 sq ft of shade/mature dairy cow to reduce solar radiation. Spray and fan systems should be used in the holding pen, over feeding areas, over the feeding areas in some freestall barns, and under shades on drylot dairies in arid climates. Exit lane cooling is an inexpensive way to cool cows as they leave the parlor. Providing enough access to water during HS is critical. Water needs increase 1.2 to 2 times during HS conditions. Lactating cattle require 35 to 45 gal of water/d. Access to clean water troughs when cows leave the parlor, at 2 locations in drylot housing, and at every crossover between feeding and resting areas in freestall housing is recommended. Keep in mind milk is approximately 90 % water; therefore water intake is vital for milk production and to maintain thermal homeostasis.

The holding pen is often an area of elevated HS conditions. Cows are crowded into a confined area for several minutes to hours. Cows should not spend more than 60 to 90 min in the holding area. In addition, provide shade, fans, and sprinklers in the holding pen. An Arizona study showed a 3.5 ºF drop in body temperature and a 1.76 lb increase in milk/cow/d when cows were cooled in the holding pen with fans and sprinklers (Wiersma and Armstrong, 1983). Cattle handling such as sorting, adding cattle to the herd, vet checks, and lock-up times should be completed in the early morning. The cow's warmest body temperature occurs between 6 p.m. and midnight. Reducing lock-up times can also reduce HS, especially in facilities with little or no cooling above head locks.

Nutritional Modifications

The nutritional impacts on reproduction are well documented. Reducing metabolic diseases will further enhance our ability to improve reproduction during the summer months. Some simple feeding and nutritional strategies can be implemented to reduce the negative effects of summer HS on reproduction.

The maintenance requirement of lactating dairy cows increases substantially as environmental temperature increases. When possible, increase the number of feedings and (or) push-up times in order to increase DMI. In addition, feed during cooler parts of the day and increase moisture content in the ration from an average of 35 to 40 % to an average of 45 to 50 %.

The HS cow is prone to rumen acidosis and many of the lasting effects of warm weather (laminitis, low milk fats, etc.) can probably be traced back to a low rumen pH during the summer months. As a consequence, care should be taken when feeding *hot* rations during the summer. Obviously fiber quality is important all the time, but it is paramount during the summer as it has some buffering capacity and stimulates saliva production. Furthermore, dietary HCO_3^- may be a valuable tool to maintain a healthy rumen pH.

Feeding dietary fat (rumen inert/rumen bypass) remains an effective strategy of providing extra energy during a time of negative energy balance. Compared to starch and fiber, fat has a much lower heat increment in the rumen; thus provides energy without a negative thermal side effect.

Wheelock et al. (2006) previously demonstrated that maximizing rumen production of glucose precursors (i.e. propionate) may be an effective strategy to maintain production during HS. However, due to the rumen health issue, increasing grains should be conducted with care. A safe and effective method of maximizing rumen propionate production is with monensin (approved for lactating dairy cattle in 2004). In addition, monensin may assist in stabilizing rumen pH during stress situations. Proplyene glycol is fed typically in early lactation, but may also be an effective method of increasing propionate production during HS. With the increasing demand for biofuels and subsequent supply of glycerol, it will be of interest to evaluate glycerol's efficacy and safety in ruminant diets during the summer months.

Having a negative dietary cation-anion difference (**DCAD**) during the dry period and a positive DCAD during lactation is a good strategy to maintain health and maximize production. It appears that keeping the DCAD at a healthy lactating level (approx. +20 to +30 meq/100 g DM) remains a good strategy during the warm summer months (Wildman et al., 2007).

Unlike humans, cattle utilize potassium (K^+) as their primary osmotic regulator of water secretion from their sweat glands. As a consequence, K+ requirements are increased (1.4 to 1.6 % of DM) during the summer and this should be adjusted for in the diet. In addition, dietary levels of sodium (Na^+) and magnesium (Mg^+) should be increased, as they compete with potassium (K^+) for intestinal absorption.

Reproduction Protocol Changes

Improve estrous detection during summer by increasing the time and number of visual observations for estrus. Tail head paint is the most popular estrous detection aid and should be applied in adequate amounts with easily observable colors. This should be coupled with visual estrous detection.

There are several technologies available to improve identification of estrus. The HeatWatch® (CowChips, LLC, Denver, CO) system records the number and times mounted during estrus through the use of a radiotelemetric pressure transducer placed on the tail head to transmit information to a computer. Pedometers can also be used to measure the increased amount of activity associated with estrus.

Heat stress significantly impairs bull fertility in the summer. Semen quality decreases when bulls are continually exposed to ambient temperatures of 86 ºF for 5 wk or 100 ºF for 2 wk despite no apparent effect on libido. Heat stress decreases sperm concentration, lowers sperm motility, and increases percentage of morphologically abnormal sperm in an ejaculate. After a period of HS, semen quality does not return to normal for approximately 2 mo because of the length of the spermatic cycle, adding to the carry-over effect of HS on reproduction. It may prove beneficial to periodically check semen quality. In addition, many dairy producers use A.I. for a set number of breedings (i.e. 3 A.I. breedings) and then move the cow to the bull pen; however it may be advantageous to continue to A.I. for several more breedings to by-pass the deleterious effects described above during and immediately after periods of HS.

The use of fixed timed AI (**TAI**) to avoid the deleterious effects of reduced estrous detection has been well documented. Utilizing some type of TAI (i.e. Ovsynch, Cosynch72, or Ovsynch56), either coupled with or without estrous detection, can improve fertility during the summer. A study conducted in Florida during the summer months observed an increase in pregnancy rate at 120 d postpartum (27 % vs. 16.5 %, respectively) and a decrease in days open, interval from calving to first breeding, and services per conception in cows TAI versus inseminated at estrus (De la Sota et al., 1998).

Another possible way to improve fertility in the summer is through an injection of GnRH at estrus. Ullah et al. (1996) injected GnRH into lactating dairy cows at detected estrus during late summer in Mississippi and increased conception rate from 18 % to 29 %. In agreement with this study, lactating dairy cows were injected with GnRH at the first signs of standing estrus during the summer and autumn months in Israel, and conception rates increased compared to untreated controls (41 % to 56 %, respectively; Kaim et al., 2003).

POSSIBLE SOLUTIONS FOR IMPROVING SUMMER FERTILITY

Embryo transfer can significantly improve pregnancy rates during the summer months (Drost et al., 1999). Embryo transfers can by-pass the period (i.e. before d 7) in which the embryo is more susceptible to HS. Nevertheless, embryo transfer is not a widely adopted technique. Improvements need to be in made in the *in vitro* embryo production techniques, embryo freezing, timed embryo transfer, and lowering the cost of commercially available embryos before this becomes a feasible solution.

Selecting particular genes that control traits related to thermotolerance make it possible to select for thermal resistance without inadvertently selecting against milk yield (Hansen and Arechiga, 1999). Traits that could possibly be selected for include coat color, genes controlling hair length, and genes controlling heat shock resistance in cells (see review by Hansen and Arechiga, 1999). In addition, genetic modification or altering biochemical properties of the embryo before embryo transfer may be possible to improve thermal resistance and increase summer fertility.

There may be feed additives, which can partially alleviate HS through increased heat dissipation; thereby lowering internal body temperature. In several studies, fungal cultures in the diet decreased body temperatures and respiration rates in hot, but not cool, weather (Huber et al., 1994). A recent experiment in Arizona showed an increase in sweating rates and lower core body temperatures when encapsulated niacin was fed to lactating cows compared to thermal neutral controls (Zimbelman et al., 2007). A follow-up study was conducted on a commercial dairy farm during the summer months in AZ with rumen protected niacin being fed to late lactation dairy cows. Results showed similar effects with lower core body temperatures during the hot part of the day with an additional increase in fat- and energy-corrected milk (Zimbelman et al., 2008). Feeding unsaturated fatty acids to ewes has been shown to alter lipid composition of oocytes, improving thermotolerance (Zeron et al., 2002). The use of encapsulation techniques to by-pass the rumen, feed additives to improve heat loss, and (or) manipulating cellular biochemical composition may improve reproductive function during the summer months; however, more studies are warranted.

The THI is calculated using both ambient temperature and relative humidity. To date, researchers suggest that cows experience HS beginning at a THI of 72. The THI values were categorized into mild, moderate, and severe stress levels for cattle by the Livestock Conservation Institute (Armstrong, 1994). Berman (2005) pointed out that the supporting data for these designations are not clear. For example, the index is based on a retrospective analysis of studies carried out at the University of Missouri in the 1950's and early 1960's on a total of 56 cows averaging 34.1 lb of milk/d with a range of 5.9 to 69.9 lb/d. In contrast, average production per cow in the United States is presently over 60 lb/d with many cows producing over 100 lb/d at peak lactation. Current studies are underway at the University of Arizona to re-evaluate the THI utilizing modern-day high producing dairy cows. Most likely, the new THI interpretations may encourage use of cooling techniques at lower temperatures than currently recommended. The resulting management changes could reduce the negative effects of HS on reproduction.

CONCLUSION

Improved cooling is still the most profitable and effective way to improve both milk production and reproduction during the summer months. Even generally milder climates experience HS or heat waves that dramatically reduce fertility. Dry cows are also susceptible to HS and should be provided some type of cooling to improve subsequent fertility after calving. Postpartum HS can significantly decrease pregnancy rates with impacts lingering well into the fall months. Designing strategies to reduce negative effects of HS on fertility; such as enhanced cooling, ration adjustments, and reproductive protocol changes, will improve dairy farm profitability.

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