Heat Stress Effects on Fertility: Consequences and Possible Solutions

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SUMMARY

- Heat stress can occur nearly everywhere; what varies among locations is its duration
- Negative effects of heat stress on reproduction can occur within days
- Evaporative cooling for dry cows may improve not only milk production but reproduction during summer heat stress
- Heat stress can negatively effect all aspects of reproduction and proper cooling is still the best way to improve fertility during heat stress
- Additional reproduction protocol changes can be made to help circumvent the fertility reduction seen during summer
- Opportunities such as embryo and genetic manipulation, nutraceuticals and managerial changes may exist to improve summer fertility

INTRODUCTION

Animal agriculture in the United States loses an estimated $2 billion to the negative impacts of heat stress (HS), with the dairy industry accounting for $900 million of this loss. Factors such as global warming, population growth in more temperate climates, and an increase in number of food production animals in hotter climates further increases the susceptibility of the dairy industry to HS related issues (Hulme, 1997; Roush, 1994). Lastly, the dairy industry has continued to focus on selecting for production traits which, in turn, may increase the dairy cow's susceptibility to HS.

Heat stress does not have to last for months to have profound negative impacts, but can occur in days, even in temperate climates. For example, during a heat wave in 2006, California dairy producers lost an estimated $1 billion in milk and animals. In 1999, during a severe heat wave, Nebraska producers lost more than $20 million in cattle deaths and performances losses. Between July 11 and 12, 1995, a combination of heat and humidity caused the deaths of over 3,700 cattle in a thirteen county area of western Iowa (Collier and Zimbelman, 2007). This economic loss is a direct result from HS reducing such things as milk production, reproductive performance, milk quality, heifer growth, and increasing cow and calf mortalities and health-care costs.

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). For example, body temperatures of lactating dairy cows are significantly increased with rising ambient temperature compared to nulliparous heifers (Sartori et a., 2002; Figure 1). Generally, it is assumed that a cow becomes more sensitive to HS as milk production increases due to elevated metabolic heat production. Selectively breeding dairy cows for increased milk yield has increased the cows' susceptibility to HS thereby compromising summer production and reproduction. In addition, selecting for milk yield reduces the thermoregulatory range of the dairy cow (Berman et al., 1985) and magnifies the seasonal depression in fertility caused by HS (Al-Katanani et al., 1999). Consequently, strategies should be initiated to lessen the severity of HS on reproduction in both the dry and lactating dairy cow.

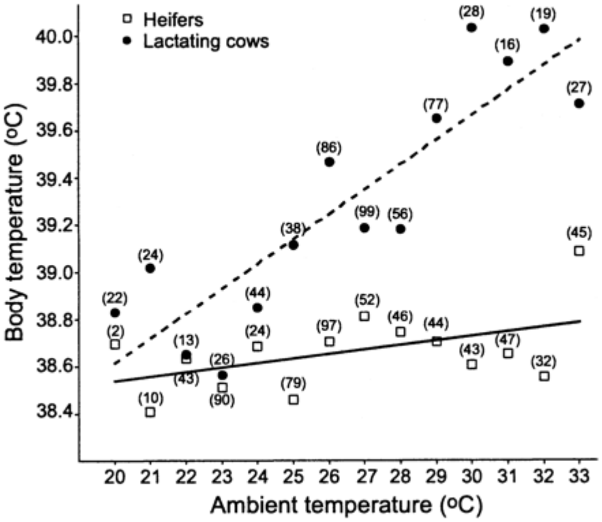


Figure 1. Relationship between ambient temperature (AT) and body temperature (BT) in lactating cows and nulliparous heifers. Values within parentheses represent the number of observations of BT for each group evaluated for each degree of AT. Calculated linear regression for cows was BT = 0.11AT + 36.49 (dashed line) and for heifers was BT = 0.02AT + 38.05 (solid line). Adapted from Sartori et al., 2002.

PREPARTUM HEAT STRESS EFFECTS ON SUBSEQUENT REPRODUCTION

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. Prepartum HS may decrease thyroid hormones and placental estrogen levels, while increasing non-esterified fatty acid concentrations in blood; all of which can alter growth of the udder and placenta, nutrients delivered to the unborn calf, and subsequent milk production (Collier et al., 1982a). Collier et al. (1982b) reported that dairy cows experiencing HS during late gestation had calves with lower birth weights and produced less milk than cows not exposed to HS. This was associated with a reduction in circulating thyroxine, prolactin, growth hormone, and glucocorticoid concentrations. Other researchers have suggested that cooling dry cows may increase birth weights, improve colostrum quality, decrease calving related health disorders and increase subsequent milk production. (Avendano-Reyes et al., 2006; Wolfenson et al., 1988). Feed intake and metabolic rate are adversely affected by HS during the immediate prepartum period, and this may adversely affect the ability of the dairy cow to ramp up production postpartum.

Few studies have investigated effects of cooling dry cows on subsequent fertility postpartum. Florida researchers demonstrated that postpartum cows with shade during the dry period had increased blood levels of prostaglandin F metabolite, ovarian volume, diameter of the largest follicle and corpus luteum, and percentage of ovaries with a corpus luteum compared to cows with no shade (Lewis et al., 1984). However, days to first ovulation and estrus, days open, and services per conception were unaltered by prepartum HS. Another study also concluded that there was no difference in services per conception, days open, or days to first estrus for dry cows either with prepartum shade or no shade (Collier et al., 1982b).

Many studies reporting a negative effect of HS on subsequent fertility were published over 20 years 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. 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, and increased milk yield 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 concentrations. In this study, reproductive parameters were not measured; however, 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; Table 1). One point I might add, is that the $8.92/cow/yr return is probably greatly underestimated for two reasons: One is that they did not collect reproduction information so they could not estimate the added benefits and two is the shade structures in this study were positioned in a north-south orientation so there would not have been shade over the feed line during the late morning and mid-afternoon. Therefore, if the feed line orientation had been in an east-west longitudinal position, the shade structure would probably have provided additional shade time over the feed line and the difference between the two groups in all likelihood would have been much greater than reported.

Table 1. Projected economic returns for dry cow pen fans, sprinklers, and shades vs. sprinklers only based on marginal milk production for the first 60 d into lactation for dry multiparous Holstein cows enrolled from June to October 2002. Adapted from Urdaz et al., 2006.

Period (yr.)	5
Fans used, no.	7
Cows cooled/summer	239
Interest rate (cost capital)	7.00%
Cows culled in first 60 d (%)	10.00%
Median DIM at culling	25
Net no. of cow-days to benefit	13,504
Capital costs:	
Fans, shade cloth, frame, etc..	$7,040.00
Residual value of capital equipment after 5 yr	$1,500.00
Annual capital costs	**$1,456.15**
Operating costs (per yr):	
Maintenance and electricity for operation	$450.54
Marginal feed for dry cows	$326.24
Annual operating costs	**$776.78**
Total Annual Costs	**$2,232.93**
Returns:	
Additional milk over 60 DIM, kg/day	1.4 kg/d
Marginal milk price for additional milk	$0.23
Total Annual Benefit (milk returns)	**$4,363.66**
Profit per year (based on milk only)	**$2,130.72**
Profit per cow	**$8.92**
Percentage profit per dollar spent per year	95%

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 months 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.

POSTPARTUM HEAT STRESS EFFECTS ON REPRODUCTION

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) despite a similar reduction in DMI (11 lb/d vs. 13 lb/d, respectively; Rhoads et al., 2007). 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). However, unlike NEBAL in thermal-neutral conditions, HS induced NEBAL didn't result in elevated plasma non-esterified fatty acids 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 heat stressed, 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 non-esterified fatty acids 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 where 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 above, HS induces negative energy balance 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.

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 vs. 8.6 mounts per estrus 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). Possible reasons for reduced estrous expression are from suppressed endocrine hormones such as luteinizing hormone and estradiol, important for follicle growth and triggering estrous behavior (Rensis and Scaramuzzi, 2003). However, it is unclear as to the effects HS has on endocrine function. To further exacerbate the problem, another possible reason for the reduction in expression of estrus is from reduction in physical activity, as a response to limit heat production.

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 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 explained 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 potential to be compromised.

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. In contrast, Sartori et al., (2002) showed a significant reduction in the summer for fertilization rate, embryo quality, and nuclei/embryo in lactating cows vs. nulliparous heifers. 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 and Embryo Loss

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 $F_{2\alpha}$; 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 prostaglandin $F_{2\alpha}$ 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 prostaglandin $F_{2\alpha}$ and embryo secretion of prostaglandin E_2 increased in response to HS by 72 %. Wolfenson et al. (1993) observed that secretion of prostaglandin $F_{2\alpha}$ was increased *in vivo* when heifers were exposed to high ambient temperatures. 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.

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 days 21 – 30 of gestation (Figure 2).

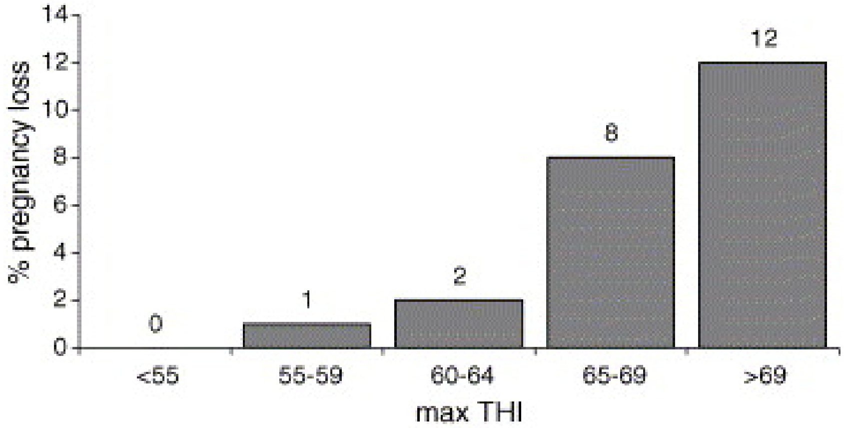


Figure 2. Pregnancy loss rates for different maximum temperature-humidity indices during days 21 – 30 of gestation. Adapted from Garcia-Ispierto et al., 2006.

A reduction in the amount of growth factors due to an increased level of milk production and (or) decline in nutritional status due to HS, may reduce the amount of necessary embryotrophic growth factors. Secretion of embryotrophic growth factors into the uterine lumen may be controlled by nutritional status of the cow since embryo transfer pregnancy rates were reduced in recipients with low BCS (Mapletoft et al., 1986). 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 negative energy balance. 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.

Uterine Environment and Immune Function

The reproductive organ can be compromised during HS providing a suboptimal uterine environment for fertilization, embryo growth, and implantation. Heat stress causes redistribution of blood flow from the visceral organs to the periphery resulting in decreased availability of nutrients and hormones, ultimately compromising uterine function. The increase in uterine blood flow caused by injection of estradiol-17β was reduced in cows not exposed to shade in summer compared with those receiving shade (Thatcher and Collier, 1986). Also, as mentioned earlier, prostaglandin production is increased and embryo growth and interferon-tau produced by the embryo are reduced due to heat shock exposure.

The effect HS has on immune function has not been evaluated in detail, especially in agriculturally important species. However, the incidence of some health problems certainly appears to increase during the summer months as increased rates of mastitis, retained placenta, metritis, and ketosis have been reported (Collier et al., 1982a). Several epidemiological studies reveal a reduction in fertility for cows affected by disorders of the reproductive tract, mammary gland, feet, and metabolic diseases such as ketosis, milk fever, and left-displaced abomasums. Retained placenta, metritis, and ovarian cysts are risk factors for conception. Cows had lower conception rates of 14 % with retained placenta, 15 % with metritis and 21 % for those with ovarian cysts (Grohn and Rajala-Schultz, 2000). Mastitis also significantly reduces fertility in lactating dairy cattle (Hansen et al., 2004). In addition, general *stress* enhances glucocorticoid levels, which reduces neutrophil function. Therefore, HS induced increases in cortisol levels may partially explain the negative effects HS has on health.

An additional cause of compromised immune function may be negative energy balance (NEBAL). NEBAL in early lactation is associated with a variety of health and reproductive issues (Drackley, 1999). The HS cow also enters NEBAL and thus (probably not surprising) experiences many of the same health problems and reduced reproductive parameters as *transitioning* cows. The calculated NEBAL during HS (approx. -5 Mcal/d) is not as severe as in early lactation (i.e. approx. d 7:approx. -15 Mcal/d), but it almost certainly is not a coincidence that both situations have increased rates of similar disorders.

STRATEGIES FOR REDUCING NEGATIVE EFFECTS OF PRE- AND 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. Below are several strategies to potentially help reduce the negative impacts of HS on reproduction in lactating dairy cows.

Cow Comfort and Cooling

The greatest opportunity to reduce the negative effects of HS during both the pre- and postpartum periods is through cooling. As mentioned above, cooling dry cows with feed line sprinklers, fans and shades proved to be beneficial for reducing services per conception, days open, and increasing milk yield with a significant return on investment compared to cows with either shades alone or feed line sprinklers alone (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.

Identifying 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 two 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/day) when cows where 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.

Estrous detection

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. Peralta et al., (2005) showed significant improvement in heat detection efficiency and subsequent conception rates when estrus was detected with a combination of heat detection methods versus using only one.

Bull Breeding

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.

Timed AI programs

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).

GnRH Injection at Estrus

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 injected with GnRH at the first signs of standing estrus during the summer and autumn months in Israel had increased conception rates compared to untreated controls (41 % to 56 %, respectively; Kaim et al., 2003).

FUTURE SOLUTIONS FOR IMPROVING SUMMER FERTILITY

Embryo Manipulation and Transfer

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 made in the *in vitro* embryo production techniques, embryo freezing, timed embryo transfer, and lowering cost of commercially available embryos before this becomes a feasible solution.

Recent developments in improving embryo resistance to heat stress through the use of both genotype manipulation and addition of survival factors, such as insulin-like growth factor-1 which protects cells from a variety of stresses, may further improve pregnancy rates with embryo transfer (Block and Hansen, 2007)

Genetic Manipulation

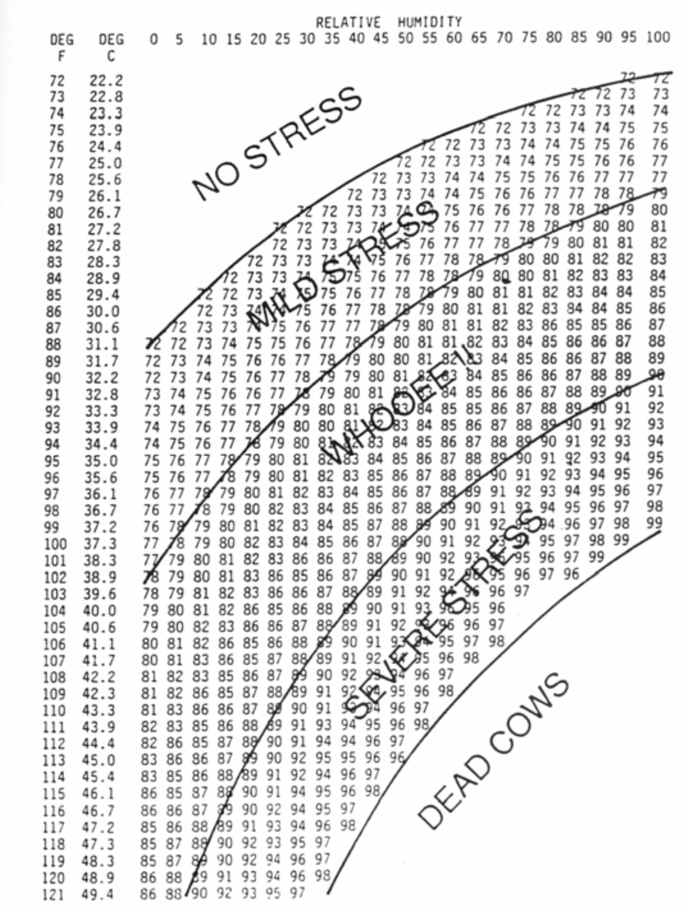
Selecting particular genes that control traits related to thermotolerance make it possible to select for thermal resistance without inadvertently selecting against milk yield (Hansen and Arechiga, 1999). Traits that could possibly be selected for include coat color, genes controlling hair length, and 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.

Nutraceuticals

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). 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.

Reevaluation of the Temperature-Humidity Index

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; Figure 3). 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 index 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.



DEG F	DEG C	RELATIVE HUMIDITY																				
		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
72	22.2																				72	72
73	22.8																		72	72	73	73
74	23.3																72	72	73	73	74	74
75	23.9														72	72	73	73	74	74	75	75
76	24.4												72	72	73	73	74	74	75	75	76	76
77	25.0											72	72	73	73	74	74	75	75	76	76	77
78	25.6										72	73	73	74	74	75	75	76	76	77	77	77
79	26.1									72	73	73	74	74	75	76	76	77	77	78	78	79
80	26.7							72	72	73	73	74	75	75	76	76	77	78	78	78	79	80
81	27.2						72	72	73	73	74	75	75	76	77	77	78	78	79	80	80	81
82	27.8						72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82
83	28.3					72	73	73	74	74	75	76	77	78	78	79	80	80	81	82	82	83
84	28.9				72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84
85	29.4			72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
86	30.0			72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84	85	86
87	30.6		72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	86	85	85	86	87
88	31.1	72	72	73	74	75	75	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88
89	31.7	72	73	74	75	76	76	77	78	79	80	80	81	82	83	84	85	86	86	87	88	89
90	32.2	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
91	32.8	73	74	75	76	76	77	78	79	80	81	82	83	84	85	86	86	87	88	89	90	91
92	33.3	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92
93	33.9	74	75	76	77	78	79	80	80	81	82	83	84	85	86	87	88	89	90	91	92	93
94	34.4	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	35.6	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96
97	36.1	76	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95	96	97
98	36.7	76	77	78	79	80	82	83	84	85	86	87	88	89	90	91	93	94	95	96	97	98
99	37.2	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	96	97	98	99
100	37.3	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	
101	38.3	77	79	80	81	82	83	86	86	87	88	89	90	92	93	96	95	96	97	99		
102	38.9	78	79	80	81	83	86	85	86	87	89	90	91	92	96	95	96	97	96			
103	39.6	78	79	81	82	83	86	86	87	88	89	91	92	94	96	96	97					
104	40.0	79	80	81	82	86	85	86	88	89	90	91	93	96	95	96						
105	40.6	79	80	82	83	86	86	87	88	89	91	92	94	96	96	97						
106	41.1	80	81	82	86	85	86	88	89	90	91	93	94	95	97	98						
107	41.7	80	81	83	86	85	87	88	89	91	92	94	95	96	98							
108	42.2	81	82	83	85	86	87	89	90	92	93	94	96	97								
109	42.3	81	82	86	85	87	88	89	91	92	94	95	96	98								
110	43.3	81	83	86	86	87	88	90	91	93	94	96	97									
111	43.9	82	83	85	86	88	89	91	93	94	95	96	98									
112	44.4	82	86	85	87	88	90	91	94	94	96	97										
113	45.0	83	86	86	87	89	90	92	95	95	96	96										
114	45.4	83	85	86	88	89	91	92	94	96	97											
115	46.1	86	85	87	88	90	91	94	95	96	98											
116	46.7	86	86	87	89	90	92	94	95	97												
117	47.2	85	86	88	89	91	93	94	96	98												
118	47.3	85	87	88	90	92	93	95	97													
119	48.3	85	87	89	90	92	94	96	97													
120	48.9	86	88	89	91	93	94	96	98													
121	49.4	86	88	90	92	93	95	97														

Figure 3. Temperature-humidity index table for dairy producers to estimate HS for dairy cows. Deg = Degrees. Relative humidity expressed as a percentage. Adapted from Frank Wiersma, 1990, Department of Agriculture Engineering, The University of Arizona, Tucson.

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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