Effects of Heat Stress on Production, Health and Reproduction of Dairy Cattle

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The combined effects of high ambient air temperature, relative humidity, and solar radiation have profound effects on milk yield, growth, reproduction, and cow health. In the lactating cow, total body heat load is significantly escalated by an increase in metabolically-derived heat associated with milk production. Whenever heat gain is greater than heat loss body temperature rises, heat stress results and performance is proportionally reduced.

Effects of Prepartum Heat Stress

Considering the increase in internally-derived body heat from the higher metabolic rate associated with milk production it is not surprising that the lactating cow is particularly sensitive to heat stress. The rapid decline in feed intake and milk yield during periods of thermal stress are readily apparent. Consequently, much of the attention in heat stress management is (and has been) focused on the lactating cow. Reality is that the effects of thermal stress on cows in late gestation are just as devastating, if not more so. High environmental temperatures during late pregnancy alter blood flow and maternal-fetal hormone concentrations resulting in lower birth weight of calves and reduced milk yield in the subsequent lactation.[1–5]

Gestation length of the bovine ranges from 270–292 days and is divided into three periods: 1) the period of the ovum, blastula, or early embryo (from fertilization to day 10–12), 2) the period of the embryo and organogenesis (from day 10 to day 45), and 3) the period of the fetus and fetal growth (from day 45 to parturition).[6] In terms of greatest sensitivity to elevated temperatures, the period of the early embryo and last trimester of the fetal growth period are the most important.

Logically, uterine growth precedes placental growth, which in turn, precedes growth of the fetus. Approximately 60% of bovine fetal growth occurs during the last 90 days of pregnancy. Near term the unborn calf is increasing in weight by 1.1 to 1.5 pounds per day.[7] Prolonged exposure to high temperatures during this crucial period can have dramatic effects on placental and fetal growth as well as fetal viability. In a study by Bell et al. chronic exposure to elevated temperatures during gestation in ewes retarded placental growth by 54%, fetal growth by 17%, and was responsible for fetal death in three of six heat stressed ewes.[8] Head et al. found similar effects on placental growth of dairy cattle where summer heat stress significantly reduced placental dry weights.[9]

Effects of prepartum heat stress on calf birth weight are reported in two studies by Collier et al. and one by Wolfenson et al. Using a large data set comprised of 975 Holstein calves born over 23 years, Collier et al. found a seasonal trend in calf birth weight observing that calves born during mid to late summer weighed 10% less than those born during the winter months.[2] This effect on birth weight was reaffirmed in a follow-up study in which prepartum cows were housed in either a shade or no shade group. Mean birth weight of calves born to cows assigned to a shade group was 87.3 lbs. compared to 80.5 lbs. (8% reduction in weight) for calves assigned to a no shade group (Table 1).[3] No difference in length of gestation was detected between the shade and no shade group. A similar study in Israel by Wolfenson et al., observed that calf birth weight increased an average of 5.7 lbs. for calves born to cows assigned prepartum to a shade structure equipped with sprinklers and fans for cooling.[4] Calf birth weight differences in the latter study were greatest for cows in their fourth or greater lactation.

Milk yield was related to calf birth weight in all three studies; larger calf birth weights were associated with higher subsequent milk yield. In the shade/no shade experiment by Collier et al., postpartum 305-day predicted milk yield was reduced by 12% in the group with no access to shade prepartum (Table 1).[3] Cooling prepartum increased daily milk production by an average of 7.7 lbs. through 150 days postpartum in the study by Wolfenson et al.[4] Similar results were reported from a study on three dairies in Central Saudi Arabia where prepartum cooling of cows from two of three herds studied significantly increased milk production at peak lactation over cows not

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cooled prepartum.[5] On the basis of these observations, it's clear that strategies for cooling cows during the prepartum period should be a high priority.

TABLE 1. Effect of heat stress prepartum on calf birth weight and maternal milk yield postpartum (adapted from Collier et al.).[3]

Trait	Shade	No Shade	Difference	(%)
Calf birth weight	87.3[a]	80.5	6.8	(8%)
100-d milk yield (lbs)	5,878.4	5,623.2	255.2	(4%)
305-d milk yield[b] (lbs)	14,867.6	13,085.6	1782.0	(12%)

[a] significant ($P < .05$)
[b] 305-d predicted yield adjusted for age, month of calving, and Estimated Relative Producing Ability (ERPA).

Effects of Peripartum Heat Stress

The process of labor and delivery is an arduous task for the cow under any circumstances but particularly so when complicated by intense solar radiation, elevated ambient air temperature, and high humidity. Cows calving during daylight hours without the benefit of shade for protection from solar radiation are especially subject to hyperthermia, heat stroke, and possibly dystocia. The problem is not uncommon to Florida dairymen in the spring when northern heifers close to parturition are imported as herd replacements to Florida dairies. They normally arrive with thick haircoats and often have difficulty acclimating to hot weather.[10] Under such circumstances these animals are particularly vulnerable to hyperthermia or heat stroke. These animals can become rapidly distressed and if unnoticed eventually collapse and progress to a comatose state that ultimately ends in death.

Field observations of pregnant ewes exposed to chronic heat stress indicate that such conditions often lead to the delivery of small lambs with poor viability.[11,12] This would appear to be the case in cattle as well, however, specific data on the relationship between heat stress and neonatal viability are limited. Mortality data from a Florida dairy for calves which died within 24 hours of birth are displayed in Table 2. Overall mortality of calves near parturition was 6.1%. This agrees with Bellows et al., which states that approximately 6.4% of calves die near parturition.[13] Of those that die near parturition most (72%) die from dystocia.[14] Since several of the calves listed as stillbirths in the Florida study were likely the result of dystocia, our data would support this view. Although an association between dystocia and seasonality has not been reported, clinically, severe heat stress appears to impair or delay parturition when cows become hyperthermic. If this clinical impression is accurate heat stress on the cow at parturition may be expected to increase the likelihood of dystocia (or prolonged delivery) and consequently the rate of dystocia/slow delivery-related calf mortality.

TABLE 2. Pregnancy rates of embryo recipient and artificially inseminated lactating dairy cows, determined by milk progesterone concentrations (Day 21 post-estrus) and by rectal palpation (40-60 days post-estrus) (adapted from Putney et al.).[41]

	Pregnancy Rate %					
	Embryo Transfer Group			Artificial Insemination Group		
Number	Day 21	Day 40	(n)	Day 21	Day 40	(n)
637	47.6	29.2	(113)	18.0	13.5	(524)

Day 21 pregnancy rate difference significant ($p < 0.001$).
Day 40 to 60 pregnancy rate difference significant ($p < 0.001$).

Seasonal effects on the failure of passive transfer in calves lend further support to a negative effect of environmental stress on the calving and neonate. Studies on large numbers of calves in Florida's subtropical climate have found that the concentration of serum immunoglobulins in neonates 2–10 days of age is highest during the winter months of January through March and lowest during the summer months of July and August.[15,16] There are at least two possible explanations for the observed seasonal effect on rates of passive transfer in warm climates. First, an Arizona study that found an increase in serum corticosteroids from heat stressed neonates which was suggested to be responsible for a reduction in permeability of the small intestine to immunoglobulin absorption by calves.[17] Secondly, a study of colostral immunoglobulin content at the first postpartum milking which suggested a reduction in the natural suckling response during periods of peak heat and environmental stress.[18] In contrast, the pattern of immunoglobulin absorption in temperate or cooler climates is poorer during winter months and improved during the more moderate summer months.[19] It would appear that factors associated with environmental stress may negatively influence passive transfer in calves by physical as well as physiological means.

In addition to dystocia, one of the most frequent calving-related problems is retained placenta. Specific causes for retained fetal membranes are numerous but nutritional imbalances, fat cow syndrome, peripartum disease, twinning, and dystocia are considered some of the more important redisposing factors. Incidence rates of 10–12% are generally accepted as normal. However, frequency is higher whenever gestation is shorter than normal (a common consequence of induced parturition). A seasonal increase in the incidence of retained placenta associated with heat stress has been reported. Incidence of retained fetal membranes and metritis increased from an average of 12% during moderate weather to 24% during the hotter stressful period of May through September.[20] Days open was lengthened by 32 days for cows having retained placenta/metritis and by 24 days as a result of calving during the warmer months. Length of gestation for cows with retained fetal membranes was 5.25 days shorter than for cows which did not retain their placentas. In contrast, a Florida study by Martin et al., failed to show an effect of season on fetal membrane retention, however, days to first service, days open, and services per conception were all extended by the occurrence of retained placenta.[21]

Effects of Postpartum Heat Stress

Milk Yield

The environmental temperature range most conducive to optimal milk production is between 41 and 77°F. The lower limit (lower critical temperature) of this range is flexible and dependent upon age, diet, and other factors. On the other hand, in the lactating dairy cow the upper limit (upper critical temperature) is fairly rigid such that feed intake and milk production are measurably affected whenever temperatures approach 78–80°F. At a temperature of 104°F feed intake is reported to be only 60% of normal intake rates.[22] A Florida study in which cows were housed in either a shade or no shade environment found that cows with no shade consumed 56% less feed during daytime hours. Cows in this study compensated some over night by increasing feed consumption by 19% compared with cows in shade. Overall, feed intake was reduced by 13% for cows with no shade compared to cows having access to a shade structure.

Thatcher et al., observed an increase of 9.6% in 4% fat corrected milk for cows maintained in an air conditioned environment compared to cows housed under natural heat-stressing environmental conditions.[23] Another study comparing the effect of shade versus no shade on lactational performance found an increase of 10.7% for cows house and fed under a shade structure compared with no shade controls.[24] Finally, Schneider et al., observed a 23% improvement in daily feed intake and a 19% increase in milk production cows in shade compared to cows with no shade.[25] Clearly, feed intake and therefore lactational performance are improved by the attenuation of heat stress.

Udder Health

Somatic cell counts and incidence of clinical mastitis in the southeast region increase during the summer months.[26–28] These observations suggest that heat stress may amplify susceptibility to intramammary infection by decreasing host resistance and/or increasing host exposure to pathogens created by conditions which favor their growth and propagation in the cow's environment.

Evidence for a direct effect of elevated temperature on the immune system is limited and based primarily on in vitro studies. An indirect effect on immunity may occur as a result of decreased feed intake and consequently deficient uptake of essential nutrients important to optimal immune function. Vitamin E and the selenium-containing enzyme, glutathione peroxidase, are antioxidants which protect body cells and tissues from oxidative attack by free radicals released during the respiratory burst associated with bacterial killing in neutrophils and macrophages. Neutrophils obtained from cows deficient in Vitamin E and selenium had reduced intracellular bacterial killing.[29] A study by Smith et al., found that the prevalence of intramammary infection at calving in heifers supplemented with Vitamin E and selenium was reduced by 42% compared to unsupplemented controls.[30]

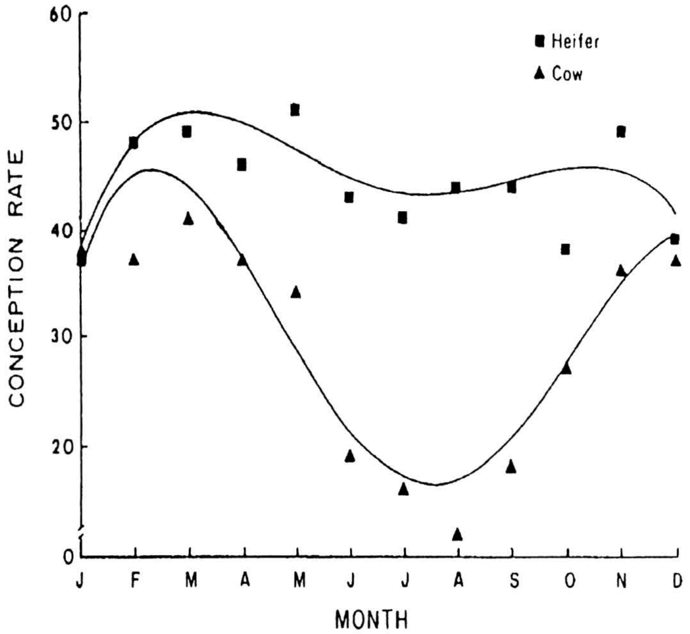
Postpartum Reproductive Performance

Heat stress negatively impacts conception rate, estrus detection efficiency, and embryo survival/development. The resultant seasonal depression in reproductive performance is one of the most serious problems of the dairy industry in the southern United States as well as subtropical and tropical countries throughout the world.

Conception Rates

Conception rates plummet during periods of extreme high temperature and humidity. Rates as low as 10% following artificial insemination have been recorded.[31] As a result some dairies choose to avoid breeding cows during the hotter months. Badinga et al., in a large study involving 6,555 inseminations in a Florida dairy over a three-year period with three breeds represented, made several key observations.[32] Heifers had higher conception rates (47%) compared to lactating cows (32%). The discrepancy in conception rate for heifers versus cows is most likely due to the inability of lactating cows to maintain normal body temperature during periods of heat stress because of an increase in metabolically-derived heat associated with milk production. The most significant decline in conception rate occurred during the summer months of June through August and recovery was slow requiring an additional two months before achieving pre-heat stress rates (see Figure 1). The decrease in conception rate was accelerated when environmental temperatures rose above 86°F. Differences by breed were: Jersey 45%, Brown Swiss 41%, and Holstein 39% and reflect differences in milk production and thermoregulatory responses to heat stress.

FIGURE 1. Least square means for monthly conception rates (%) in heifers and cows, unadjusted for environmental effects (adopted from Badinga et al.).[32]



The most common causes of reproductive inefficiency in dairy herds are: 1) inadequate estrus detection, or the absence of expressed estrus and 2) infertility, some of which is due to embryonic mortality.[33] Heat stress does not prevent the occurrence of normal estrus cycles. It does, however, amplify the problem of heat detection by reducing the length of the estrus period (from 18 hours down to 10 hours) and lowering the intensity of estrus behavior.[34] Thatcher et al., documented the magnitude of this effect on estrus detection in a large commercial dairy noting an increase in percent of undetected heats from normal annual rates of 66% to 80% during the hot summer months of July and August.[35] The combined effects of poor conception and reduced heat detection efficiency have a devastating effect on overall reproductive performance in dairy herds.

Early Embryo Survival and Development

Several studies have demonstrated that early stage embryos are especially sensitive to high environmental temperature.[36-39] Heat stress occurring on the day of estrus or within 1–7 days post-estrus is particularly deleterious to embryo survival. Putney et al., studied the effect of acute short-term heat stress (107°F for 10 hours beginning with the onset of estrus) prior to ovulation in superovulated heifers. Heifers in the heat stress and thermoneutral group were maintained post-treatment in thermoneutral conditions until embryo collection and evaluation on day 7 following insemination. The objective was to determine the incidence of embryo abnormalities and mortality resulting from short-term heat stress on the day of estrus. Only 12% of the embryos recovered from heat stressed heifers were considered normal compared with 68.4% of the embryos from heifers assigned to the thermoneutral group (75°F). Furthermore, an appreciably higher level of embryo death occurred in the heat-stressed group.[39] A second study to determine the effect of thermal stress occurring from ovulation through day 7 had similar results with only 20.7% of embryos collected from stressed heifers being categorized as normal compared with 51.5% from thermoneutral controls.[40] Consequently, dairy cattle need to be protected from heat stress on the day of insemination and for at least 7 days following fertilization in order to avoid heat-induced embryo loss.

In an effort to circumvent problems associated with heat stress on early embryos, Putney et al., devised a scheme involving embryo transfer to bypass the period of greatest susceptibility.[41] Selected embryos collected from superovulated heifers on day 7 post insemination were nonsurgically transferred to 113 synchronized lactating Holstein dairy cows. An additional 524 lactating cows were artificially inseminated for comparison purposes. Pregnancy rates for the embryo transfer group were 47.6% and 29.2% compared with 18.0% and 13.5% for the artificial insemination group at day 21 (determined by milk progesterone) and 40, respectively (see Table 2.) This study supports the concept of extreme sensitivity of the early embryo to heat stress, and in addition points to a possible solution. As technological advances continue in the art and science of embryo transfer it is presumed that this may become one of the tools or options for dealing with the problem of early embryonic mortality associated with heat stress.

Susceptibility of the embryo beyond day 7 post insemination appears to be substantially lower. Biggers et al., studied the effects of high temperature on embryos between days 8 and 16 and observed that although pregnancy rates were not affected there was a trend toward higher embryonic mortality in heat stressed cattle.[42] It is worthy of note that there appeared to be significant embryo loss (embryo transfer group reduced by 18.4% from day 21 to day 40) beyond 21 days in the study by Putney et al., as well. Therefore, further study into the effects of heat stress on later stage embryos is warranted.

Summary

Heat stress, whether it occurs in the prepartum, peripartum, or postpartum period can have drastic affects on performance. In late gestation chronic hyperthermia can reduce calf birth weights, and decrease milk production in the subsequent lactation. Clinical observation suggests that under conditions of severe heat stress during the peripartum period, the natural course of parturition may be prolonged. This may result in the delivery of calves of suboptimal viability based on seasonal reductions in passive transfer and natural suckling by neonates. Finally, effects of heat stress on lactational and reproductive per formance can be particularly devastating. Optimal milk production requires feeding and management practices which will minimize internal heat production in combination with facilities which will prevent excessive heat load from the environment while assisting the dairy cow to dissipate surplus body heat. Heat stress markedly reduces conception rate and increases embryonic mortality. Since the early embryo is most susceptible to heat stress, the incorporation of cooling strategies for cows on the day of estrus and for 7 days thereafter would likely decrease embryo loss due to hyperthermia.

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