Managerial and Nutritional Strategies to Minimize Lactational and Reproductive Losses in Heat-Distressed Dairy Cows

Armagan Hayirli

Department of Animal Nutrition and Nutritional Disorders, Faculty of Veterinary Medicine, Atatürk University, Erzurum 25240 Turkey.
E-mail:ahayirli_2000@yahoo.com

Abstract

Heat stress (HS) is a welfare issue and has detrimental effects on lactation and reproduction. When environmental temperature exceeds 25 °C or when thermal-humidity index exceeds 75, cows exhibit HS signs. Feed intake, milk production, and fertility decrease and immune system is compromised in heat-distressed dairy cows. Managerial approaches cover barn design (stocking density, ventilation, shading, and sprinkling water) and animal's handling and mating (synchronization and timed-artificial insemination), which are intended to cool down the cow. Nutritional approaches are intended to reduce heat production by the body and covers access to unlimited clean and fresh water, feeding at night, increasing feeding frequency, feeding fat, reducing forage percentage and increasing concentrate, K, Na, and Mg percentages in the ration, balancing protein fractions, modifying particle size, formulating alkaline diet, and supplementing cow with buffer and yeast cultures. In conclusion, both managerial and nutritional approaches help maintain body temperature so that lactation and reproduction potential can be achieved during hot weather.

Key words: dairy cow, heat stress, lactation, management-nutrition, reproduction

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Introduction

Heat stress (**HS**) is a costly problem in dairy operations because of its deleterious effects on performance, lactation, and reproduction in dairy cows. It is also an important welfare issue. Managerial approaches are intended to cool the cow and nutritional approaches are intended to compensate reduced dry matter intake (**DMI**). Environmental modifications to minimize HS, coupled with an appropriate nutritional program are necessary to maintain intake and minimize lactational and reproductive losses. The purpose of this review is to emphasize managerial and nutritional strategies to reduce adverse effects of ambient environmental temperature on performance and productivity in dairy cows.

Heat Stress

All animals have a thermal comfort zone (**TCZ**), which refers to a range of temperature that allows the animal to exhibit normal physiological status. This range for the dairy cows is between -13 to 25ºC with a body temperature of 38.5-39.3ºC. Environmental temperatures below and above this zone is a significant stressor to the cattle and interfere with expression of their genetic potentials. Temperature-humidity index (**THI**) reflects the combined effects of ambient temperature and relative humidity, which is calculated as follows:
THI = T_{air} - [0.55 - (0.55 x RH / 100)] x (T_{air} - 58.8), where T_{air} = air temperature (^{o}F), RH = relative humidity (%) or **THI = 0.72 x (W+D) +40.6, where W = wet bulb temperature (**°C) and D = dry bulb temperature (°C).

The THI values less than 70 are considered comfortable, 71-80 mild and 81-90 moderate stressful, and a value greater than 90 causes extreme distress with cows being unable to maintain thermo regulatory mechanisms or normal body temperatures (Table 1). When temperatures exceed 25°C or when THI exceeds 70, cows experience HS, which is accompanied by reduced dry matter intake (**DMI**), lower milk production, decreased milk fat percentage, decreased fertility, depressed immune system, and reduced activity as well as increased maintenance requirement, body temperature (> 39.3 °C), and risk for mastitis and laminitis. These can vary by 1) severity of the environmental conditions 2) level of milk yield and quantity of feed consumed 3) stage of lactation, 4) size of the cow, 5) cooling management, 6) exercise requirements, and 7) breed and color.

For the cow, there are two sources of heat: the environmental temperature and the heat produced internally from basal nutrient metabolism. Heat produced from nutrient metabolism is lesser factor than environmental heat sources. Solar radiation and elevated ambient air temperature are primary environmental heat sources. Environmental temperature is aggravated by high relative humidity and lacking air movement.

Table 1. Temperature-humidity index for dairy cows

^{o}C	Relative humidity (%)													Stress level
	40	45	50	55	60	65	70	75	80	85	90	95	100	
23.9	No stress					72	72	73	73	74	74	75	75	Mild
26.7	73	3	74	74	75	76	76	77	78	78	79	79	80	Medium
29.4	76	77	78	78	79	80	81	81	82	83	84	84	85	
32.2	79	80	81	82	83	84	85	86	86	87	88	89	90	Severe
35.0	83	84	85	86	87	88	89	90	91	92	93	94	95	
37.8	86	87	88	90	91	92	93	94	95	97	98	99		
40.6	89	91	92	93	95	96	97							

Mechanisms by which the dairy cow dissipates body heat and maintain body temperature include conduction, convection, radiation and evaporation. The first three depend on a relatively large differential between body and environmental temperatures, and the last one depends on relative humidity. When the environmental temperature is close to the body temperature, especially in the presence of high relative humidity, all the cooling mechanisms are compromised.

Adverse Effects of Heat Stress on Lactation and Reproduction

Heat-distressed dairy cows exhibit altered acid-base status resulting from panting (> 80 breaths/min) and sweating, ways of evaporative cooling. Sweating and panting are accounted for two and one-thirds of evaporative water loss, respectively. Increased the loss of CO_2 via respiration reduces the blood concentration of H_2CO_3 and consequently, increases blood pH (*respiratory alkalosis*). Compensation for the respiratory alkalosis involves increased urinary HCO_3^- excretion, leading to a decline in blood HCO_3^- concentration. At 35°C, water loss by sweating is estimated to be 150g/m^2 body surface/h.

Reticulo-rumen motility decreases. Consequent decrease in the rate of digesta passage is associated with lower production of volatile fatty acid, with a high percentage of acetate. While blood flow to digestive tract and other internal tissues decreases, blood flow to the skin surface increases. In general, urine volume increases.

The effect of high environmental temperature on cow performance is mediated through the body temperature. Decreased productivity is linked mostly to depressed DMI (Table 2), which is an attempt to reduce heat production from the digestion and metabolism of nutrients. Intake for Holstein and Jersey cows is negatively correlated with minimum and maximum daily THI (-0.63 and -0.62, Holsteins; -0.62 and -0.55, Jerseys). In NRC prediction model (1981), DMI for a 600-kg cow producing about 27 kg of milk will decline by 8.2% (18.2 kg at 20°C to 16.7 kg at 35 °C) and maintenance requirement will increase by 20% (Table 2). At 40 °C, maintenance increases by 32% and DMI decreases by 56% as compared to cows reared in TCZ. Briefly, a 0.56°C increase in temperature above 38.61°C causes 1.8 and 1.4 kg decreases in milk yield and total digestible nutrients.

Even under TCZ, reproductive performance of dairy cows is low due to increased milk production associated with prolonged and severe negative energy balance (**NEBAL**). The adverse of effects of HS on reproduction is related directly to the increase in body temperature and development of NEBAL. Infertility is one of the most important obstacles for sustainable dairy production in tropical and subtropical countries. Development of NEBAL and existence of catabolic profile (low blood glucose, insulin, insulin-like growth factors, and growth hormone concentrations and high non-esterified fatty acids, β-hydroxybutyrate, and glucagon) lead to silent and/or short estrus and impair folliculogenesis, which eventually result in reduced conception rate and prolonged calving interval.

Heat stress suppresses synthesis of reproductive hormones, reduces quality of oocytes, and interferes with folliculogenesis. Damaged somatic cells within the follicles interfere with decrease estradiol synthesis that influences expression of estrus through increased secretion of ACTH, ovulation, and the corpus luteum. Heat stress, in general, does not dramatically influence days to first ovulation and estrus, but prolongs days open and increases services per conception (> 2.5) due to early embryonic loss and/or reduced conception rate (< 40%). Also, 1^{o}C increase in rectal temperature is associated with 20-30% reduction in blood flow to uterus. Undernourished uterine tissues and increased uterine temperature (> 40^{o}C, normally 38.6^{o}C) compromise embryo survival (Figure 1). In case of successful pregnancy in heat-distressed dairy cows, the result is a delivery of calves with low birth weight.

Table 2. Effect of environmental temperature (^{o}C) on performance of dairy cows

Temperature	Prediction				
	Maintenance (% of requirement at 10 ^{o}C)	DMI needed (kg/d)	DMI (kg/d)	Milk yield (kg/d)	Water intake (l/d)
-20	151	21.3	20.4	20.0	51.1
-10	126	19.8	19.8	25.0	57.9
0	110	18.8	18.8	27.0	64.0
10	100	18.2	18.2	27.0	64.0
20	100	18.2	18.2	27.0	68.1
25	104	18.4	17.7	25.0	73.8
30	111	18.9	16.9	23.0	79.1
35	120	19.4	16.7	18.0	120.0
40	132	20.2	10.2	12.0	106.0

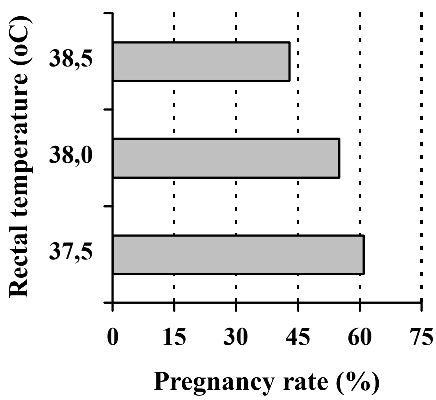

Figure 1. Pregnancy rate of dairy cows that have different rectal temperature at time of breeding

Managerial Strategies

Modifying the environment is the most effective way to reduce HS. Providing shade is the cheapest and best way to decrease radiant energy, but it does not decrease air temperature. Shade with a 2.5 cm-insulation (3.7-4.6 m^2/head) should be installed on 2.1-4.4 m away from the cow. It is shown that total heat load can be reduced by 30-50% with well-designed shade and that there is a 10% gain in milk yield simply by shading cows. As compared with cows in no shade, shaded cows have lower rectal temperature (38.9 and 39.4 ºC) and less respiratory rate (54 and 82 breaths/min), and produce 10% more milk (Table 3).

During periods of high temperature and/or humidity, however, shade alone is rarely enough. Thus, additional evaporative systems, such as ventilating and sprinkling are needed. Using fans and sprinklers improve DMI by 7-9% and milk yield by 8.6-15.8% and reduce rectal temperature by 0.44-0.56 °C and respiration rate by 17.6-40.6%. Sprinkling cows helps reduce body temperatures by increasing evaporative cooling (Figure 2) and ground temperature, as well. Intermittent sprinkling is suggested to not to cause humidity, sprinkling of 2-3 min every 30 min.

Table 3. Effect of shading on performance of dairy cows

Measurement	Shade	No shade
Rectal temperature (°C)	39.2	40.8
Respiration (count/min	83	133
Dry matter intake (kg/d)	20.7	16.8
Milk yield (kg/d)	19.4	17.0

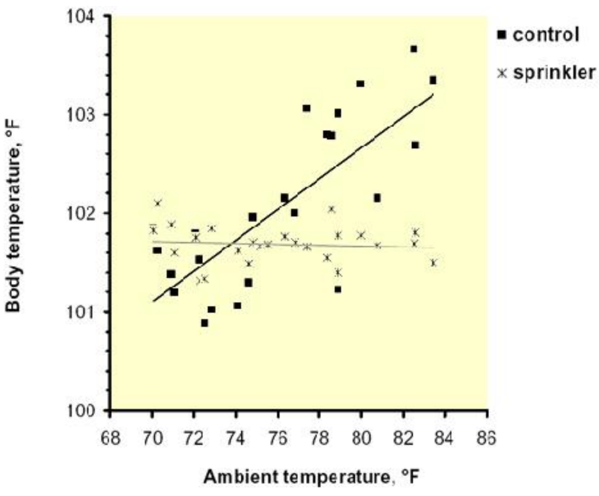

Figure 2. Relationship between body temperature and ambient temperature for cows that are not cooled and are sprinkled for 90 min before afternoon milking

Cows should not be handled in hot weather, especially after 10:00 hr because handling increases the body temperature about 0.5-3.5 °C. If needed, cows should be handled between midnight and 08:00 hr. Holding and processing areas should have shade and sprinklers.

Nutritional strategies to maintain reproductive performance seem less effective than managerial strategies. A number of reports show that cooling and shading increase estrus duration and pregnancy rate and reduce calving interval and percentage of cows with silent estrus by 50%. Thus, before and after artificial insemination, cows must be kept as cool as possible. Through estrus synchronization and timed-artificial insemination, breeding season should be switched to cooler days of the year in order to minimize reproductive losses.

Nutritional Strategies

The need for water increases sharply as the temperature increases (Table 2) because of water loss from sweating and panting. Provision of unlimited quantity of clean, fresh, and cool water to the cow is the most important nutritional strategy. Normally, a cow consumes 2-3 L of water for each kg DMI and an additional 3-5 L of water for each kg of milk yield. As the environmental temperature increases from 4.5 to 26.7 °C, the water consumption increases from 23 to 31 L in dry cows, 60 to 100 L in cows producing 18 kg milk, and 98 to 170 L in cows producing 30 kg milk. Although cooling water to below 15°C helps dissipate body heat, offering water at 20-27°C is recommended during hot weather. Waterers should be placed under shade and on the way to milking parlors.

The heat production of metabolic functions accounts for about 31% of the energy intake in a 600-kg cow producing 36 kg 4% fat-corrected milk. Heat production increases as DMI and milk yield increase. Energy expenditure for maintenance during hot weather increases. Metabolic heat production increases after feeding, at different levels depending upon feedstuffs in ration. Heat increment during metabolism accounts for two-thirds of endogenous heat production. The order of heat increment for nutrients, from the lowest to highest, is fat < concentrate < fiber. When heat production is reduced, less is going to be dissipated and energy utilization efficiency is improved. Thus, during hot weather diets should be formulated to contain fat (5-6%), high quality (digestible) fiber (a bit reduced rate), and concentrate (a bit increased rate). That is, *the ration should be heated up to cool the cow down* in order to maintain intakes of nutrients due to depressed DMI (Table 4).

In order not to cause acidosis, milk fat depression, off-feed conditions, and laminitis, diets should contain more than 55-60% concentrate. The percentages of nonstructural carbohydrates (**NSC**), acid detergent fiber, and neutral detergent fiber should be 33-38% at maximum, 19% at minimum, and 30% at minimum, respectively. Nonstructural carbohydrates can be increased to 40% when the diet contains

Table 4. Dietary modifications during hot weather*

Dry matter intake (% depression)	0	5	10	15	20
Respiration rate (count/min)	< 75	80	85	90	95
Dry matter intake (kg/d)	24.1	22.9	21.7	20.5	19.3
Energy (NEL, Mcal/kg)	1.59	1.70	1.81	1.92	2.00
Mcal/d	38.4	38.9	39.4	39.5	40.4
Crude protein (CP, %)	17.4	18.1	18.9	19.8	20.8
Rumen undegradable protein (% of CP)	39.4	42.7	45.7	48.7	51.7
Neutral detergent fiber (%)	35.0	31.0	28.0	26.0	25.0
Fat (%)	0.0	1.0	2.0	3.0	4.0
Minerals (%)					
Ca	0.46	0.70	0.73	0.78	0.82
P	0.41	0.43	0.45	0.49	0.51
Mg	0.25	0.27	0.28	0.30	0.31
K	1.00	1.15	1.30	1.45	1.60
Na	0.18	0.23	0.28	0.33	0.38
S	0.20	0.21	0.22	0.23	0.24

*Estimated for a 650 kg cow producing 45 kg milk with 3.6% fat and 3.2% protein.

high quality forage. In particle size separator, long (> 1.90 cm), medium (0.79-1.90 cm), and short (< 0.79 cm) particles should constitute 6-10, 30-50, and 60-60%, respectively.

Both deficient and excess crude proteins have detrimental effects on fertility. Both cases also cause an increase in body heat production resulting from reduced digestibility in association with reduced rumen motility and excessively formed NH_3 in association with a more than 60% ruminally degradable fraction, respectively. Excessive NH_3 requires additional energy for hepatic detoxification.

Through sweating cows lose K (human does Na). Thus, K requirements increase during hot weather. Supplementing heat-distressed cows with K (1.5-1.6% DM), Na (0.5-0.6% DM), and Mg (0.35-0.4% DM) is suggested. Providing alkaline diet reduces HCO_3^- loss and compensates K loss, suggesting that dietary cation-anion difference (Na + K - Cl - S) should be positive. Due to lowering fiber/increasing NSC in the ration, supplementing heat-distressed cow with $NaHCO_3$ (150-200 g/day/head or 0.75-1.0% of DM), niacin (6 g/d), yeast cultures, and fungal products (*Aspergillus oryzae*) is recommended. These supplements stabilize rumen fermentation and reduce risk for milk fat depression and other fermentation related disturbances through increasing fiber digestion, volatile fatty acid production, turnover rate of lactic acid, and numbers of cellulolytic bacteria as well as minimizing variations in rumen pH and ammonia formation.

Effectiveness of excessive supplemental vitamins A and E in heat-distressed dairy cows is controversial. Trace minerals (Zn and Cu) should be increased to minimize oxidative stress and boost immune potency. Other nutritional approaches to alleviate heat stress include 1) provision of total mixed ration, 2) feeding at night and after milking, 3) increasing feeding frequency to provide fresh and cool ration, and 4) adding water to ration.

Conclusion

Heat stress has detrimental effects on lactation and reproduction, which are major income sources in dairy operations. Managerial and nutritional strategies should be applied simultaneously to cool the cow down and reduce body heat production and maintain intakes of nutrients.

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