Feed and Water Intake of Heat Stressed Cattle

Robert J Collier, Laun. H. Hall, Lance H. Baumgard, Rosemarie B. Zimbelman, Yao Xiao
University of Arizona, Intermountain Feed Company, Iowa State University, Dairy Nutrition Services, University of Florida
Email: rcollier@ag.arizona.edu

Introduction

Climate or the average weather conditions for a region is the most important ecological factor determining the growth, development, and productivity of domestic animals (Adams et al., 1998). Climate changes are known to impact the economic viability of livestock production systems worldwide (Klinedinst et al., 1993) through a variety of routes. These include changes in food availability and quality, changes in pest and pathogen populations, alteration in immunity and both direct and indirect impacts on animal performance such as growth, reproduction and lactation. Lack of prior conditioning (acclimatization) to sudden change in weather often results in catastrophic losses in the domestic livestock industry (Thornton et al., 2009)

Despite uncertainties in climate variability, the Intergovernmental Panel on Climate Change (**IPCC**) Fifth Assessment Report identified the ‘‘likely range” of increase in global average surface temperature between 0.3 ^{0} C and 4.8 ^{0} C by the year 2100 (IPCC, 2014). The risk potential associated with livestock production systems due to global warming can be characterized by levels of vulnerability, as influenced by animal performance and environmental parameters (Hahn, 1995). As production levels (e.g., rate of gain, milk production per day, eggs/day) increase, the sensitivity and tolerance to stress increases and, when coupled with an adverse environment, the animal is at greater risk.

Nationally, heat stress results in total economic losses ranging between $1.9 and $2.7 billion per year (St.-Pierre et al., 2003). Although projected increases in ambient temperatures will result in additional financial losses, the extra metabolic heat resulting from the projected increase in animal productivity will have far greater impact, which has been estimated at between 2 and 4 times as much as global warming (St.-Pierre et al; 2003, St.-Pierre, 2013).

Despite the enormous economic impact, there is little information on the heat stress (**HS**)-induced changes in metabolism and nutrient partitioning in lactating dairy cattle. An increased heat load decreases nutrient uptake in almost all species and the dairy cow appears extra sensitive as decreased DMI > 30% is not uncommon. It is traditionally assumed that decreased DMI is primarily responsible for reduced milk yield (West, 2003). However, Rhoads et al., 2008, demonstrated that inadequate nutrient intake accounts for only ~40% of the reduced milk yield and they hypothesized that changes in carbohydrate metabolism are responsible for a large portion of the remainder (Rhoads et al., 2009).

Acute Versus Chronic Effects of Heat Stress

Acute effects of heat stress are considered to occur during the first 3-6 days after the onset of the stress while chronic heat stress effects are considered to begin at the end of the first week of the stress and continuing to the end of the stress (Collier and Gebremedhin, 2015, Collier et al. 2017). Major changes in feed and water intake and milk yield occur during the acute phase and continue during the chronic period of the stress.

As shown in Figure 1, which summarizes data from 4 studies, as the temperature humidity index **(THI**) increases from 57 to 73 lactating dairy cows experience a decrease in feed intake of 7.5% over a 6-day period which remains the same for the remaining 14 days of the stress. Milk yield declines to heat stress however are delayed.

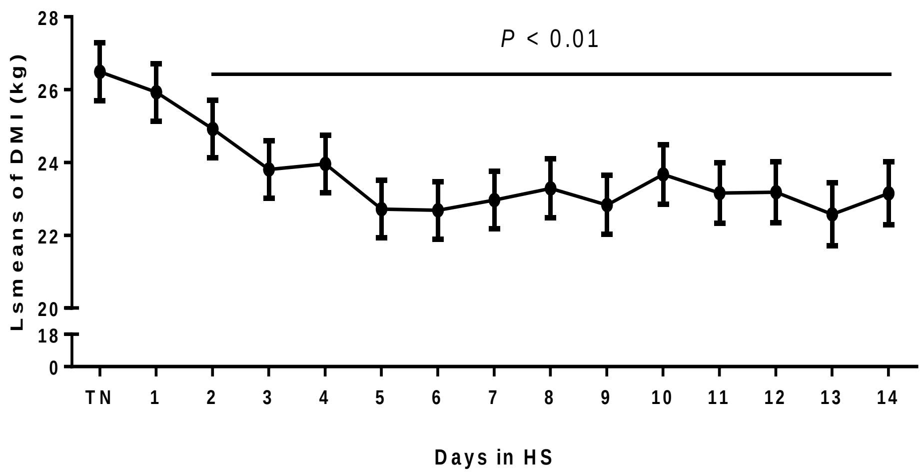


Figure 1. Feed intake responses following THI increase from 57 to 73. Data summarized from Zimbleman et al., 2010; Wheelock et al., 2010; Hall et al., 2015 and Hall et al., 2018.

This is demonstrated in Figure 2 which displays the milk yield responses in the same animals as Figure 1. As shown in Figure 2, milk yield declines beginning the second day of heat stress and does not reach a plateau until 10 days following the initiation of the stress. Therefore, the full effect of the increase in THI was not displayed until 4 days following the plateau in feed intake.

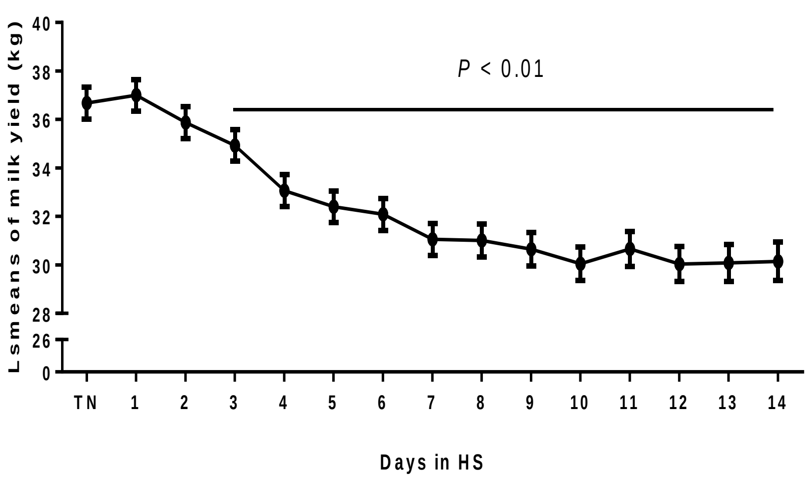


Figure 2. Milk yield responses following THI increase from 57 to 73. Data summarized from Zimbleman et al., 2010; Wheelock et al., 2010; Hall et al., 2015 and Hall et al., 2018.
Although heat stress has immediate effects on a number of physiological parameters such as respiration rate, water intake, feed intake and behavior the impacts on milk yield are delayed (Collier et al., 1981). When examining the effects of afternoon heat stress on that evening's milk yield there is essentially no change in milk yield, (Figure 3). However, the evening milk yield 24 and 48 hours later is progressively reduced with the maximum impact seen 48 hours following the stress, (Figure 3).

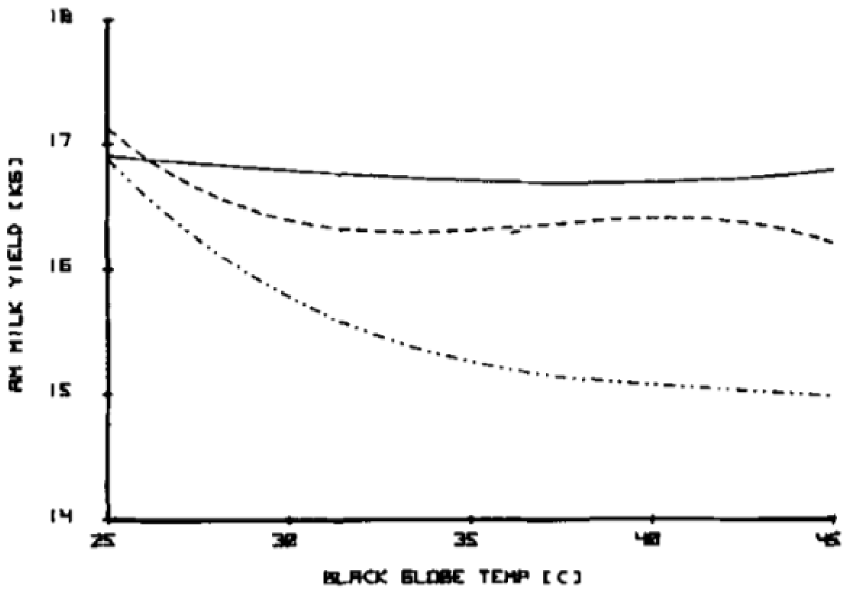


Figure 3. Least squares regressions of average afternoon Black Globe temperature 2 days prior to (···—·), 1 day prior to (--), or day of (-) a.m. milking on PM milk yield. From Collier et al. 1981. Data summarized from Zimbleman et al., 2010; Wheelock et al., 2010; Hall et al., 2015 and Hall et al., 2018.

This delayed effect of feed intake on milk yield was confirmed by West et al., (2003) who reported that THI 2 days prior was most predictive of reduced milk yield during heat stress. In heat stressed animals milk energy output decreases twice as much as digestible energy intake (McDowell et al., 1969). This was confirmed by Wheelock et al. (2010) who demonstrated that only half of the decrease in milk yield could be accounted for by decreases in feed intake.

Water intake requirements are increased during heat stress to account for increases in water required for evaporative cooling. Water intake in the animals used from the same summary of the 4 studies used for Figures 1 and 2 is shown in Figure 4. Peak water intake to heat stress occurs 3 days following the initiation of the stress and remain essentially the same for the remainder of the stress. The mean increase in water intake in these summarized studies was 20.8%, (Figure 5).

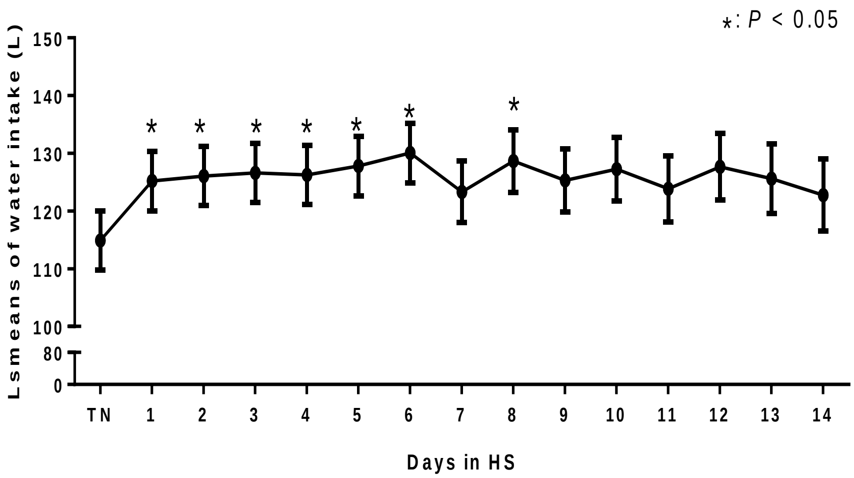


Figure 4. Water intake responses to increase in THI from 57 to 73. Data summarized from Zimbleman et al., 2010; Wheelock et al., 2010; Hall et al., 2015 and Hall et al., 201

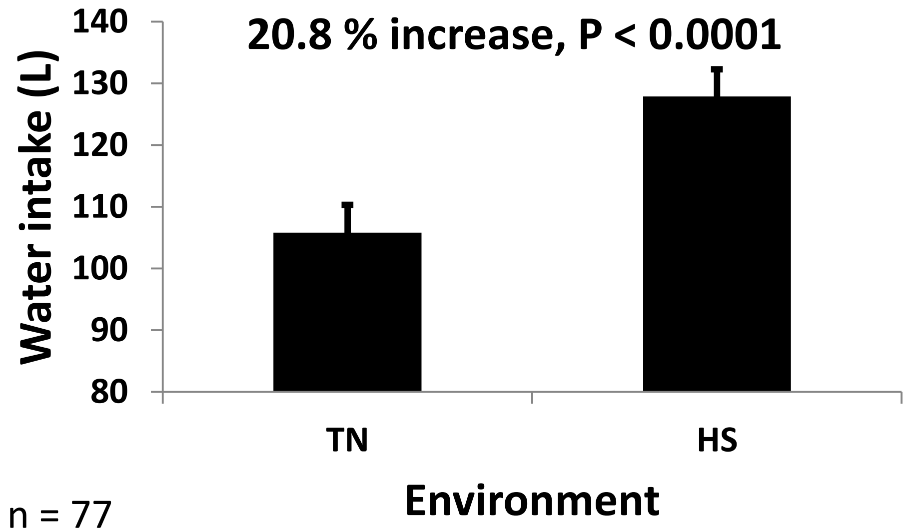
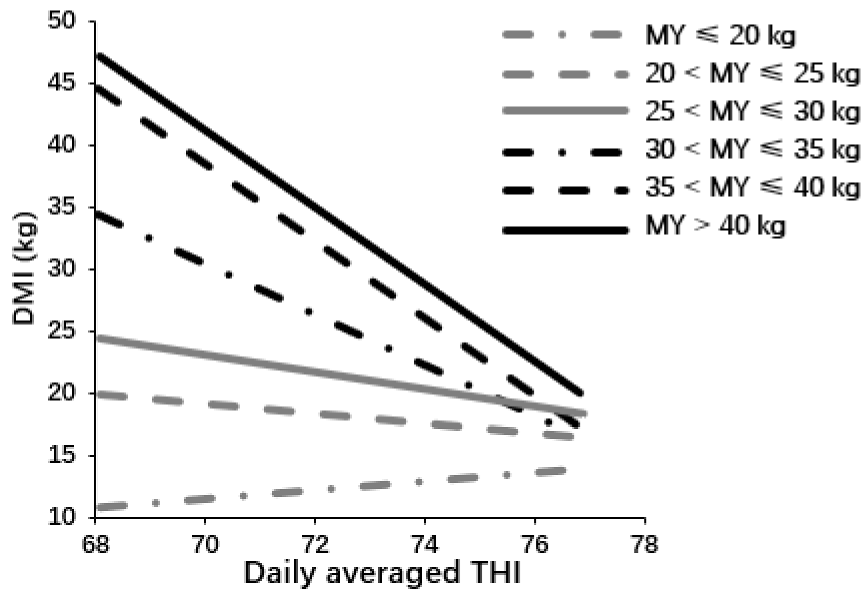


Figure 5. Mean water intake responses to increase in THI from 57 to 73. Data summarized from Zimbleman et al., 2010; Wheelock et al., 2010; Hall et al., 2015 and Hall et al., 2018

Responses in High Producing Cows

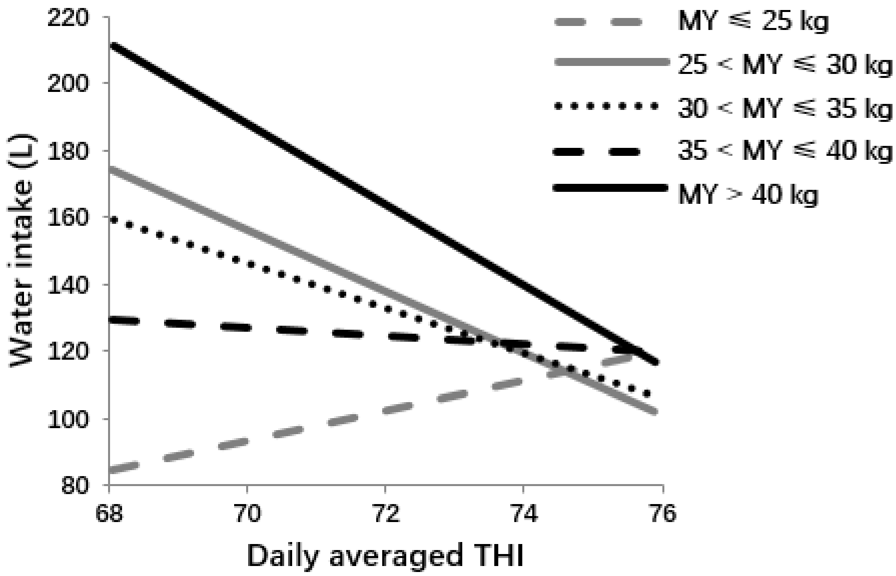
However, if you examine the relationship between production level and thermal stress you see a different pattern. As shown in Figure 6, the higher the milk yield at the onset of acute thermal stress the greater the decrease in feed intake in lactating dairy cows. At low levels of milk yield (e. g. below 25 kg of milk per day) there is little impact of heat stress on feed intake. Furthermore, the strength of the negative correlation between thermal environment and feed intake increases as daily milk yield increases as shown in Figure 3. The accelerated decline in intake of high producing animals is dictated by the need to rapidly decrease heat production to balance thermal load. This clearly demonstrates that high producing dairy cows are most susceptible to acute thermal loads.



Milk yield range (kg)	Observations	Slope	Intercept	Adjust R-square	*P* value
All	948	-1.2615	115.598	0.1171	<0.0001
≤ 20	39	0.3515	-13.1158	0.0477	0.0968
>20, ≤ 25	120	-0.4019	47.2386	0.0444	0.0119
>25, ≤ 30	250	-0.693	71.544	0.0551	0.0001
>30, ≤ 35	254	-2.0355	173.0116	0.2965	<0.0001
>35, ≤ 40	178	-3.0967	255.338	0.5452	<0.0001
>40	107	-3.0559	255.1011	0.5387	<0.0001

Figure 6. Effect of level of milk production on feed intake response to increasing environmental temperature. Data summarized from Zimbelman et al., 2010; Wheelock et al., 2010; Hall et al.,2015 and Hall et al., 2018.

A similar issue occurs with water intake of high producing dairy cows. Since water intake in high producing cows is increased well above maintenance requirements and there is an imperative need to decrease milk yield at the onset of heat stress there is actually a decline in water intake in these animals at the onset of heat stress as shown in Figure 7. Water intake is more variable than feed intake in part because animals will throw water from water cups onto their backs to cool themselves when heat stressed. However, as shown in Figure 7, at high levels of milk yield (> 30 kg milk per day) water intake decreases to acute thermal load as water requirements for milk synthesis are decreased to decrease heat production of lactation. At lower levels of milk yield the water intake does indeed increase in order to meet increased water requirements for heat loss. Thus, acute heat stress drives down milk yield by multiple mechanisms which include rapid decreases in feed and water intake in conjunction with reduced milk synthesis. The local factors regulating reduced milk synthesis have not yet been elucidated. The THI threshold for reduced milk yield in lactating dairy cows has been established at 68, (Zimbelman et al., 2010). The data on feed intake and water intake also indicate that at a THI of 68 we see dramatic changes in both feed and water intake which subsequently lead to reduced milk synthesis.



Milk yield range (kg)	Observations	Slope	Intercept	Adjust R-square	*P* value
All	768	-3.7559	401.1406	0.0129	0.001
≤ 25	100	4.43418	3.1171	0.01	0.158
>25, ≤ 30	217	-9.16	798.3476	0.008	0.096
>30, ≤ 35	217	-6.7012	615.6073	0.0436	0.0012
>35, ≤ 40	150	-1.0901	203.3506	-0.0039	0.5173
>40	84	-12.0965	1035.38	0.1314	0.0004

Figure 7. Effect of level of milk production on water intake response to increasing environmental temperature. Data summarized from Zimbleman et al., 2010; Wheelock et al., 2010; Hall et al., 2015 and Hall et al., 2018.

Conclusions

Feed and water intake responses to heat stress in lactating dairy cows precede initial changes in milk yield. Degree of decline in feed intake is related to level of milk yield and is greater in high producing cows compared to low producing cows. Due to high water intake of high producing cows the initial response in water intake is a decrease in intake in conjunction with the need to reduce milk yield. This response is not seen in lower producing cows. Collectively these data indicate that high producing cows are more adversely affected by heat stress than lower producing cows and support the need to maximize cooling in the high production cows in a dairy experiencing heat stress.

References

Collier, R.J., R.M. Eley, A.K. Sharma, R.M. Peirera and D.K. Buffington.1981. Shade management in subtropical environment for milk yield and composition in Holstein and Jersey Cows. J. Dairy Sci. 64:844—849.

Collier, R.J. and K.G. Gebremedhin. 2015. Thermal Biology of Domestic Animals. Annu. Rev. Anim. Biosci. 3:10.1–10.20.

Collier, R.J., B.J. Renquist, Y. Xiao. 2017. A 100-Year Review: Stress physiology including heat stress. J. Dairy Science 100: 10367-10380.

Hall, L.W., F.R. Dunshea, J.D. Allen, S. Rungruang, J.L. Collier, N.M. Long and R.J. Collier 2015. Evaluation of dietary betaine (BET) in lactating Holstein cows subjected to heat stress (HS). J. Dairy Sci. 99: 9745–9753.

Hall. L.W., F. Vilar. J.D. Chapman, D.J. McLean, N.M. Long, Y. Xiao, J. L. Collier and R.J. Collier. 2018. An evaluation of an immunomodulatory feed ingredient in heat-stressed Holstein cows: Effects on hormonal, physiological and production responses. J. Dairy Sci. 101:7095-7105.

IPCC (Intergovermental Panel on Climate Change), 2014. Climate Change 2014: impacts, adaptation, and vulnerability. part A: global and sectoral aspects. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1132.

Klinedinst, P., D. A. Wilhite, G. Leroy Hahn and K.G. Hubbard. 1993. The potential effects of climate change on summer season dairy cattle milk production and reproduction. Climatic Change 23:21-36.

Rhoads, M.L., R.P. Rhoads, M.J. VanBaale, R.J. Collier, S.R. Sanders, W.J. Weber, B.A. Crooker, and L.H. Baumgard. 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. production, metabolism and aspects of circulating somatotropin. J. Dairy Sci. 92:1986-1997.

Rhoads, M.L., J. W. Kim, R.J. Collier, B.A. Crooker, Y.R. Boisclair, L.H. Baumgard, and R.P. Rhoads. 2010. Effects of heat stress and nutrition on lactating Holstein cows: II. Aspects of hepatic growth hormone responsiveness. J. Dairy Sci. 93:170-179.

Thornton P. K., J. van de Steeg, A. Notenbaert, M. Herrero. 2009. The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric. Syst. 101, 113–127.

West, J.W., B.G. Mullinix, and J.K. Bernard. 2003. Effects of hot, humid weather on milk temperature, dry Matter Intake, and Milk Yield of Lactating Dairy Cows. J. Dairy Sci. 86:232-242.

West, J. W., 2003. Effects of heat-stress on production in dairy cattle. J. Dairy Sci. 86, 2131–2144.

Wheelock, J., R. Rhoads, M. VanBaale, S. Sanders, and L. Baumgard. 2010. Effects of heat stress on energetic metabolism in lactating Holstein cows. J. Dairy Sci. 93(2):644-655.

Zimbelman, R.B., L.H. Baumgard, and R.J. Collier.2010. Effects of Encapsulated Niacin on Evaporative Heat Loss and Body Temperature in Moderately Heat-Stressed Lactating Holstein Cows. J. Dairy Science. J. Dairy Sci. 93:2387-2394.