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Environmental factors affecting daily water intake on cattle finished in feedlots

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ABSTRACT: Records from 7 studies conducted during 1999 to 2005 were utilized to assess the effects of environmental factors on daily water intake (DWI) of finishing cattle. Data from unshaded feedlot pens (up to 24 pens utilized per study; 6 to 9 animals·pen^{-1}) containing predominantly Angus crossbred cattle were obtained by dividing total water intake by the number of animals utilizing that waterer. Each waterer was shared by 2 pens; therefore, data were derived from a database containing 72 experimental units comprising 144 pen records. Climatic data were compiled from weather stations located at the feedlot facility. The database included daily measures of mean ambient (Ta), maximum (Tmax), and minimum (Tmin) temperature (°C), precipitation, relative humidity (%), wind speed (m·s^{-1}), solar radiation (SR, W·m^{-2}), and temperature-humidity index (THI), as well as DMI (kg·d^{-1}) and DWI (L·d^{-1}). Simple and multiple regression analyses were conducted by season and for the overall data set. Results confirmed that DWI increases during the summer ($P < 0.01$). When seasons were combined and analyzed by linear regression, the best predictors of DWI were THI ($r^2 = 0.57$), Ta ($r^2 = 0.57$), Tmin ($r^2 = 0.56$), and Tmax ($r^2 = 0.54$). In multiple regression analyses, smaller coefficients of determination ($R^2 < 0.25$) were found within summer and winter seasons. Across season, the largest R^2 (0.65) were obtained from the following prediction equations: 1) DWI = 5.92 + (1.03·DMI) + (0.04·SR) + (0.45·Tmin); and 2) DWI = −7.31 + (1.00·DMI) + (0.04·SR) + (0.30·THI). In conclusion, Ta, Tmin, and THI were found to be the primary factors that influence DWI in finishing cattle, whereas SR and DMI were found to have a smaller influence on DWI.

Key words: daily water intake, feedlot, modeling

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INTRODUCTION

Water requirements have been widely studied in cattle, with numerous relationships among temperature and daily water intake (**DWI**) being established (Winchester and Morris, 1956; Hoffman and Self, 1972; Hicks et al., 1988). Beef cattle in the United States directly consume approximately 760 billion liters of water per year (Beckett and Oltjen, 1993). However, environmental conditions could affect this amount significantly. Negative effects of excessive heat load on cattle health and performance have been reported in feedlots in the United States and Australia during the summer season (Gaughan et al., 2004; Mader et al., 2007; Koknaroglu et al., 2008). During heat waves, normal heat exchange is often impeded if adequate water is not available, thus affecting the thermal equilibrium of the animal and its performance. The interaction among climatic factors, type of diets, animal breed, and animal BW, as well as animal physiological status, makes it difficult to determine DWI requirements. On the other hand, there is limited information concerning how other environmental factors, along with temperature, can simultaneously affect DWI of cattle under commercial feedlot conditions. Our hypothesis is that DWI is influenced not only by DMI and ambient temperature (**Ta**), but also by a combination of other climatic factors. The objectives of this study were to establish which factors affect DWI and to determine the best model to predict DWI.

MATERIALS AND METHODS

All experiments reported herein were conducted with the approval of the University of Nebraska–Lincoln Institutional Animal Care and Use Committee.

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Table 1. Summary of experiments utilized for constructing daily water intake models[1,2]

Exp.	Season	Sex	No. of animals	MBW (SE)	Pens	DOF
1	Summer	Steers	96	555 (3)	16	82[3]
2	Summer	Steers	96	508 (3)	12	82
3	Winter	Heifers	270	457 (2)	30[4]	104
4	Summer	Heifers	270	450 (2)	30[4]	105
5	Winter	Steers	168	485 (3)	24	99
6	Summer	Steers	48	428[5] (5)	6	92
		Heifers	96	428[5] (4)	12	
7	Winter	Steers	234	501 (3)	24	124

[1]Exp. 1 and 2 were reported by Mader and Davis (2004). Exp. 3 and 4 were reported by Kreikemeier and Mader (2004). Exp. 5 and 6 were reported by Gaughan and Mader (2009), and Exp. 7 was reported by Mader and Colgan (2007). All cattle were provided diets containing 1.43 Mcal·kg^{-1} of NE$_g$.

[2]MBW = mean BW (kg); DOF = days on feed.

[3]Only the last 59 d of the trial were considered in the database.

[4]Only data from 24 pens were utilized.

[5]Pooled values for steers and heifers.

Model Development

The data set used for model development was derived from 7 experiments conducted at the University of Nebraska Northeast Research and Extension Center and utilized predominantly Angus or Angus crossbreed steers and heifers (Table 1). Facility design and layout has been reported by Mader et al. (1997, 1999). Facilities are located at lat 42°23′ N and long 96°57′ W, with a mean elevation of 445 m above sea level. Details of the vaccination, parasite control, and implant regimens utilized for these experiments are reported in respective referenced studies. Experiments 1 and 2 utilized 96 steers each in 82-d studies to determine the effects of different feeding regimens and pen surface sprinkling routine on feed and water intake of steers exposed to environmental heat stress (Mader and Davis, 2004). In Exp. 1, the first 23 d of this study were not utilized because this was the period in which treatments were applied after cattle were fed and managed similarly. Experiments 3 and 4 utilized 540 heifers (270 animals·experiment^{-1}) to compare the effect of different growth promotant strategies among winter and summer season (Kreikemeier and Mader, 2004). The experiments were conducted over 104- or 105-d feeding periods. Experiment 5 utilized 168 crossbred steers and was conducted over a 109-d period during the winter (Gaughan and Mader, 2009). Experiment 6 utilized 96 heifers and 48 steers that were fed over a 92-d period during the summer (Gaughan and Mader, 2009). Experiments 5 and 6 were conducted to evaluate the effects of supplemental fat and sodium chloride on DMI, DWI, body temperature, and respiration rate in beef cattle. Experiment 7 was conducted over a 124-d period in the winter and utilized 234 crossbred steers to evaluate bedding and pen density on feedlot surface conditions and cold stress in feedlot cattle (Mader and Colgan, 2007). Within season, data points derived from diet supplement treatments and feeding management strategies that resulted in differences ($P < 0.05$) in DWI from the control diet were deleted from the database. Also, within a study, only data from unshaded pens (n = 24) were utilized. All cattle in these experiments were fed high-energy finishing diets (NE$_g$ = 1.43 Mcal·kg^{-1}).

Daily water intake was obtained (model C700, ABB Water Meters Inc., Ocala, FL) by dividing total water intake by the number of animals utilizing that waterer. Water meters were checked for accuracy on an annual basis. Underground water was provided to the cattle through Ritchie Model Challenger-2 waterers (Ritchie Livestock Foundation, Concord, IA) with two 27.5-cm-diameter openings for accessing water. Waterers are set in the fence-line with 1 opening per pen and designed with a plastic float covering the hole to minimize evaporation and wastage. The climatic variables were compiled continuously by using a weather station data logger CR10X (Campbell Scientific Inc., North Logan, UT) and summarized by hour. The weather station was located at feedlot facility in the center of the fence-line dividing the 2 central pens of the alley. The climatic variables collected were daily maximum ambient temperature (**Tmax**), daily minimum ambient temperature (**Tmin**), daily mean Ta, relative humidity (**RH**), wind speed (**WS**), and precipitation (**Precip**). Solar radiation (**SR**) was obtained from the High Plains Climate Center automated weather station located 0.6 km west and 1.5 km north of the feedlot facilities. In addition, the temperature-humidity index (**THI**) values were estimated based on the climatic variables collected during experimental periods {THI = 0.8·Ta + [(RH/100)·(Ta − 14.4)] + 46.4; Thom, 1959; NOAA, 1976}. The total number of observations resulted in 4,463 data points derived from cattle fed in the 24 pens over the 7 studies. However, due to water meter malfunction or possible recording error, approximately 2.3% of the total data points were removed from the final data set. Possible errors were determined by analyzing the normality of Studentized residuals of all data points.

Statistical Analysis

For model development, simple regression analyses for linear, quadratic, cubic, and quartic polynomial degrees were determined between DWI and each environmental variable using JMP (SAS Inst. Inc., Cary, NC) for each season and sex. Data were tested for homoscedasticity and normality of the residuals (Levene and Kolmogorov-Smirnoff-Lillifors tests, respectively). A Welch's ANOVA was conducted to compare climatic variables between seasons. Trends between sexes were found to be similar; therefore, subsequent analyses were conducted among sexes. Subsequently, multiple regression analyses were conducted utilizing forward stepwise regression procedures, with DWI as the response variable. These analyses were conducted within season (summer and winter) and for both seasons using the entire database. Previously, collinearity analyses were conducted to detect any potential problems among variables. Variance inflation factors (**VIF**) were calculated to determine the level of correlation among the variables previous to the multiple regression analysis. Variables with VIF >10 were eliminated or utilized in separate models or both. Upon completion of this analysis for each season, simple regression analysis for linear, quadratic, cubic, and quartic polynomial degrees were determined between DWI and each environmental variable using JMP (SAS Inst. Inc.). Subsequent multiple regression analyses were conducted utilizing stepwise regression procedures of SAS. The number of final parameters included in each model was determined based on change in the magnitude of R^2 value. A parameter was included in the model only if its addition produced an increase greater than 0.01 units in total R^2 as outlined by Mader et al. (2006). Inflection points were determined from the second derivative from the best polynomial equations, respectively, and solved for interval −50 to 50°C for temperature, 0 to 1,000 $w \cdot m^{-2}$ for SR, and 0 to 100 for THI. The inflection points represent a threshold or shift in the rate of change in DWI.

RESULTS

Animal Behavior and Environmental Variables

A summary of climatic data recorded by season as well as DWI and DMI of finishing cattle is shown in Table 2. Cattle finished during the summer consumed 87.3% more water than those finished during the winter ($P < 0.01$). Mean DWI in the summer and winter were 32.4 and 17.3 $L \cdot d^{-1}$, respectively. Water temperature averages between 10 and 20°C, depending on season, animals per waterer, and usage rate. All environmental variables (Ta, Tmin, Tmax, RH, Precip, WS, and SR) were greater ($P < 0.01$) during the summer than during the winter; SR was 122% greater in the summer, whereas RH, WS, Precip, and THI were 4, 16, 283, and 113% greater in summer than winter, respectively.

Simple Regression Analysis

Table 3 displays the coefficients of determination for simple linear regression (r^2) analyses for each environmental variable. Smaller coefficients of determination were found within season ($r^2 < 0.20$). The within season analysis showed that SR and THI were the most important factors influencing DWI in the summer, showing a positive response to both variables (data not shown). However, smaller r^2 values were observed for both variables (0.14 and 0.12 for SR and THI, respectively). On the other hand, Tmax and THI were the best predictors of DWI during the winter. However, these variables also had small r^2 (<0.10). The combination of both seasons improved the r^2 values for most variables studied with the greatest r^2 values obtained with THI ($r^2 = 0.57$), Ta ($r^2 = 0.57$), Tmin ($r^2 = 0.56$), and Tmax ($r^2 = 0.53$). Subsequently, environmental variables with the greatest r^2 values among season were fitted to quadratic, cubic, and quartic polynomial regressions (Figure 1). Overall season analysis is summarized in Figure 1, which displays DWI for the 2 environmental variables that had the greatest r^2 values, Tmin and THI. Both variables show a cubic response of DWI, with a similar pattern between them. The model using THI as predictor was the best model ($r^2 = 0.61$), which was slightly superior to that using Tmin ($r^2 = 0.60$). Inflection points for THI and Tmin were found at 67.2 and 11.8°C, respectively.

Multiple Regression Analysis

There was multicollinearity for THI and Ta with Tmin and Tmax. Therefore, separate multiple regression analyses were conducted using either Ta or THI with the other variables, whereas another separate analysis was conducted using only Tmin and Tmax (Ta and THI not included) and other variables. The parameters included in each model, which produced the greatest R^2 after multiple regression analysis as well as their respective coefficients, are displayed in Tables 4 and 5. As in the simple regression analysis, coefficients of determination from multiple regression were small for seasonal models. In Table 4, the summer model explained only 23% of the variability and included 3 factors: SR ($R^2 = 0.14$), Tmin ($R^2 = 0.05$), and DMI ($R^2 = 0.04$). Moreover, the winter model included 6 of 7 variables evaluated with only Tmin excluded. Precipitation, RH, Tmax, and WS were the 4 most important factors that accounted for approximately 21% of the total variability. In the winter, Precip, WS, and RH displayed a negative effect on DWI. On the other hand, the overall (summer and winter) model explained 65% of the total variability of DWI for cattle finished in feedlots. The same 3 factors included in the summer model were found in the final overall model. However, based on the partial R^2, the relevance or importance of the variables was different between the summer and overall models (Table 4). In the summer, SR was the

Table 2. Mean (±SE) values of DWI, DMI, and environmental variables observed for data collection period[1]

Season	DWI, $L \cdot d^{-1}$	DDMI, $kg \cdot d^{-1}$	Tmax, °C	Tmin, °C	Ta, °C	RH, %	WS, $m \cdot s^{-1}$	SR, $W \cdot m^{-2}$	Precip, $cm \cdot d^{-1}$	THI
Summer	32.4 ± 0.1	9.57 ± 0.02	27.5 ± 0.1	15.5 ± 0.1	21.4 ± 0.1	77.7 ± 0.2	4.00 ± 0.03	221.3 ± 1.1	1.76 ± 0.10	69.0 ± 0.1
Winter	17.3 ± 0.1	11.20 ± 0.02	4.2 ± 0.1	−8.8 ± 0.1	−2.0 ± 0.1	74.7 ± 0.2	3.45 ± 0.03	99.7 ± 0.8	0.46 ± 0.03	32.4 ± 0.2
Overall	24.6 ± 0.2	10.42 ± 0.02	15.5 ± 0.2	3.0 ± 0.2	9.3 ± 0.2	76.2 ± 0.2	3.72 ± 0.03	158.6 ± 1.3	1.08 ± 0.07	50.1 ± 0.3

[1]Within a variable, all means differed between season (Welch's ANOVA; $P < 0.01$). DWI = daily water intake; DDMI = daily DMI; Tmax = daily maximum ambient temperature; Tmin = daily minimum ambient temperature; Ta = daily mean ambient temperature; RH = relative humidity; WS = wind speed; SR = solar radiation; Precip = precipitation; and THI = temperature-humidity index, THI = 0.8·Ta + [(RH/100·Ta − 14.4) + 46.4].

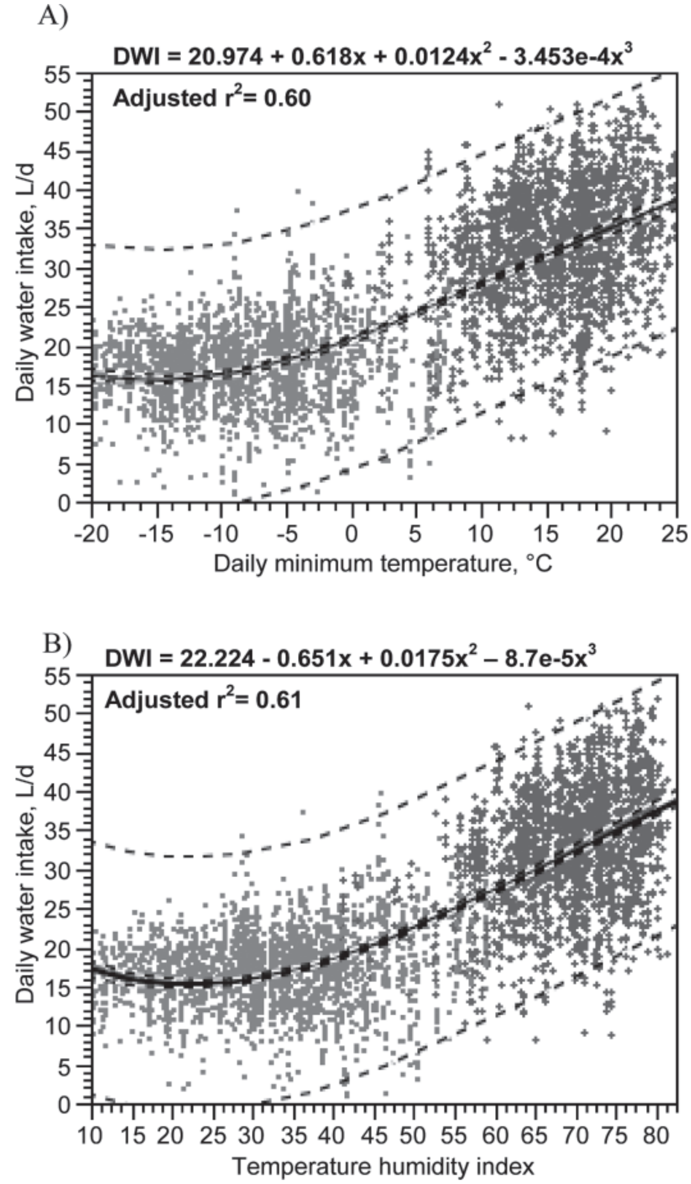

Figure 1. Observed and predicted daily water intake (DWI) of finishing cattle as a function of daily minimum temperature and temperature-humidity index among seasons. Closed squares represent winter season points, and plus signs represent summer season points. Outer dashed lines represent the 95% confidence interval for mean and individual values, respectively.

most important variable, whereas in the overall model, Tmin was the most important variable. Table 5 shows the same type of analysis but using THI instead of the temperatures variables (Ta, Tmin, and Tmax). In this case, the R^2 of the seasonal and overall models were very similar to those presented in the previous analysis. Therefore, Tmin or THI appears to have the greatest influence on DWI among seasons.

DISCUSSION

The increase of DWI during the summer would be mainly attributed to the direct effect of the animal attempting to reduce the thermal load of cattle (Beede and Collier, 1986). This is mediated by evaporative

Table 3. Coefficients of determination (r^2) of environmental variables and daily DMI on daily water intake

Variable	r^2-value		
	Summer model	Winter model	Overall model
Minimum ambient temperature, °C	0.10	0.02	0.56
Maximum ambient temperature, °C	0.06	0.07	0.54
Mean ambient temperature (Ta), °C	0.00	0.04	0.57
Solar radiation, $W \cdot m^{-2}$	0.14	0.03	0.47
Wind speed, $m \cdot s^{-1}$	0.00	0.04	0.00
DMI, $kg \cdot d^{-1}$	0.00	0.02	0.12
Relative humidity (RH), %	0.00	0.07	0.00
Precipitation, $cm \cdot d^{-1}$	0.00	0.02	0.01
Temperature-humidity index (THI[1])	0.12	0.05	0.57

[1]THI = Ta·0.8 + [(RH/100)·(Ta − 14.4)] + 46.4.

cooling, which is probably the most practical means for cooling livestock (Morrison, 1983), but demands that cattle consume extra water to maintain homeostasis. Limited studies have been conducted to assess the effects of environmental conditions, other than temperature, on DWI on cattle. The study conducted in Oklahoma by Hicks et al. (1988) during the summer season reported 35.9 $L \cdot d^{-1}$ as the average DWI in an experiment using 47 yearling steers in an open lot with 3 salt levels in the diet. Hicks et al. (1988) also reported 37.1 $L \cdot d^{-1}$ as the average DWI for 120 yearling steers housed in a confinement barn. These values are slightly greater than those reported herein. Differences could be attributed to salt levels being greater and slightly warmer environmental conditions associated with the Oklahoma studies. Parker et al. (2000) reported 35.6 $L \cdot d^{-1}$ in a study conducted in feedyards located in the Texas high plains using 50,000 head of cattle. Results of these studies confirm the importance of environmental temperature on DWI as reported by ARC (1980) and NRC (1981). However, neither the Texas nor the Oklahoma study assessed the effects of RH or SR on DWI. These 2 variables are widely recognized as potential factors affecting cattle performance and welfare (NRC, 1981; Fox and Tylutki, 1998; Sakaguchi and Gaughan, 2004). Morrison (1983) reported that RH affects the rate of evaporation from surfaces, so it would be expected to also affect evaporative heat loss. Likewise, SR has been found to influence body temperature and DWI (Mader and Davis, 2004; Amundson et al., 2006; Mader et al., 2006).

The effects of environmental factors on DWI and DMI have been reported previously (NRC, 1981), although a relationship is not always found. Generally, DMI increases under cold conditions, whereas DWI decreases, and the opposite occurs under hot conditions. However, Hicks et al. (1988) and several others (NRC, 2001) reported a positive relationship between DWI and DMI. An apparent relationship between Ta and DMI does exist (NRC, 1981); however, because DMI is influenced by cattle type and body condition, in addition to management and other environmental factors, the strength of the relationship of Ta, by itself, and DMI is questioned (Mader et al., 2010).

The THI threshold (67.2) found in this study for DWI was slightly below threshold values (THI <72) reported for the Livestock Weather Safety Index. The Livestock Weather Safety Index (LCI, 1970) has been widely used as a guide for management of livestock in general, and feedlot cattle in particular, during hot weather (Hahn and Mader, 1997; Mader et al., 2007). The THI inflection point of 67.2 may be an indicator that repre-

Table 4. Partial regression coefficients for models assessing environmental factors and DMI influences on daily water intake (mean temperature and temperature heat index excluded)[1]

Variable	Summer model			Winter model			Overall model		
	Estimate	SE	Partial R^2	Estimate	SE	Partial R^2	Estimate	SE	Partial R^2
Intercept	4.81	1.42	—	16.10	1.18	—	5.92	0.81	—
DMI, $kg \cdot d^{-1}$	1.20	0.11	0.04	0.54	0.08	0.01	1.03	0.07	0.02
Solar radiation, $W \cdot m^{-2}$	0.04	0.00	0.14	0.01	0.00	0.01	0.04	0.01	0.07
Maximum temperature, °C	—	—	—	0.16	0.01	0.05	—	—	—
Minimum temperature, °C	0.50	0.03	0.05	—	—	—	0.45	0.00	0.56
Wind speed, $m \cdot s^{-1}$	—	—	—	−0.50	0.04	0.04	—	—	—
Relative humidity, %	—	—	—	−0.06	0.01	0.07	—	—	—
Precipitation, $cm \cdot d^{-1}$	—	—	—	−0.45	0.05	0.05	—	—	—
Total R^2			0.23			0.23			0.65

[1]*P*-values for all statistics <0.01.

Table 5. Partial regression coefficients for models assessing environmental factors excluding all temperatures values and including temperature-humidity index (THI) and DMI influences on daily water intake in feedlot[1]

	Summer model			Winter model			Overall model		
Variable	Estimate	SE	Partial R^2	Estimate	SE	Partial R^2	Estimate	SE	Partial R^2
Intercept	−12.45	2.18	—	12.26	1.29	—	−7.31	0.92	—
DMI, kg·d^{-1}	1.22	0.11	0.04	0.57	0.08	0.01	1.00	0.07	0.02
Solar radiation, W·m^{-2}	0.04	0.00	0.14	0.01	0.00	0.02	0.04	0.00	0.06
THI[2]	0.37	0.02	0.06	0.13	0.01	0.04	0.30	0.01	0.57
Wind speed, m·s^{-1}	—	—	—	−0.53	0.04	0.04	—	—	—
Relatively humidity, %	—	—	—	−0.06	0.01	0.07	—	—	—
Precipitation, cm·d^{-1}	—	—	—	−0.47	0.05	0.05	—	—	—
Total R^2			0.24			0.24			0.65

[1]*P*-values for all statistics <0.01.

[2]Temperature-humidity index = Ta·0.8 + [(RH/100)·(Ta − 14.4)] + 46.4. Ta = mean daily ambient temperature; RH = relative humidity.

sents an environmental threshold when animals begin to activate physiological mechanisms to cope with the extra heat load received. In general, a THI of 70 or 72 would be considered a decreased threshold, although differences among animals do exist with high producing animals with increased metabolic heat load having decreased heat stress thresholds (Mader, 2003). Inflection points would possibly represent a threshold or shift in some physiological or biological response due to changing environmental conditions (Amundson et al., 2006). In addition, Mader (2003) and Amundson et al. (2006) established the importance of Tmin in energy balance of cattle, mainly used as a strategy to dissipate heat during the night. Amundson et al. (2006) found Tmin inflection point to range from 10.0 to 16.7°C in reproducing females. Therefore, a Tmin that is greater than the threshold (12°C) could indicate that feedlot cattle heat loss through convection and conduction during summer nights is no longer at optimum physiological capacity. Consequently, Tmin could be considered an indirect modulator of DWI. An example of water modulation on heat loss was reported by Purwanto et al. (1996). In their study, Purwanto et al. (1996) concluded that 2 indices of heat stress, respiration rate and skin temperature, were decreased after cattle consumed water.

Murphy et al. (1983) also concluded that Tmin is an important factor in predicting DWI in dairy cows. Results herein presented demonstrate that Tmin had similar effects in beef cattle. However, there are studies reporting Tmax as the primary factor influencing DWI (Hicks et al., 1988; Parker et al., 2000). These contradictions could be due to estimates by Parker et al. (2000) that included water used in the feedmill and from overflow waterers, whereas Hicks et al. (1988) utilized weekly averages of climatic data instead of daily averages.

Nevertheless, THI has always been used as an excellent indicator of potential heat stress, whereas Tmin has been shown to be an indicator that is associated with beef cattle reproduction (Amundson et al., 2006). The overall model using Tmin or THI displayed greater R^2 values and provided good estimates of DWI. The results herein presented demonstrated that DMI plus other climatic factors such as SR, when combined with Tmin or THI, exert a strong effect on DWI.

Implications

The response of cattle to adverse environmental conditions is markedly individual and highly variable, which can obstruct the accuracy of predictive models. However, more accurate estimates of water usage in the commercial livestock sector are needed due to the increased demand for water in rural and urban sectors. Estimates of DWI can assist in feedlot cattle management by predicting peak daily use over a range of environmental conditions. These estimates are essential in the design and layout of water supply systems. In addition, estimates are useful in ensuring adequate water is available for mitigating and minimizing heat stress in cattle. Minimum temperature is an excellent DWI predictor, whereas THI, although typically not used in the winter, is also a good indicator of DWI. Both variables are indicators of environmental stress that can influence DWI.

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