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Analysis of Meteorological Parameters of Different Extreme Heat Waves

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Abstract. *Heat waves have caused severe losses in beef cattle feedlots and dairies in different areas of the cattle producing areas of the world. A comparison of climatic conditions that have resulted in cattle deaths was completed. Analyses of lethal heat waves in northeast Nebraska in 1999 and north-central South Dakota in 2007 were analyzed. Factors of temperature, humidity, wind speed, and solar radiation dominate the impact that local climatic conditions have on livestock. Based on the analysis of these two heat waves, it appears that the following factors contribute to making an extreme event: a preceding cooling period of a few days, antecedent rainfall, two or more consecutive days in the Danger or Emergency categories as calculated by the THI or* RR_{est}*, and limited nighttime cooling (THI>72).*

Keywords. *Cattle, Feedlot Cattle, Heat stress, Livestock, THI, Weather*

Introduction

Heat waves are a reoccurring phenomenon in the cattle producing regions of the United States (Figure 1). A heat wave can be defined as "a period of abnormally hot and unusually humid weather of at least 1 day in duration, but conventionally lasting several days to several weeks …" (AMS, 1989). Hahn and Mader (1997) reported an operational definition of heat waves as "3-5 successive days with maximum temperatures above a threshold, such as 32 °C". During a heat wave, the environmental conditions have negative impacts on the animal's growth, performance and ultimate well-being (Brown-Brandl, 2008).

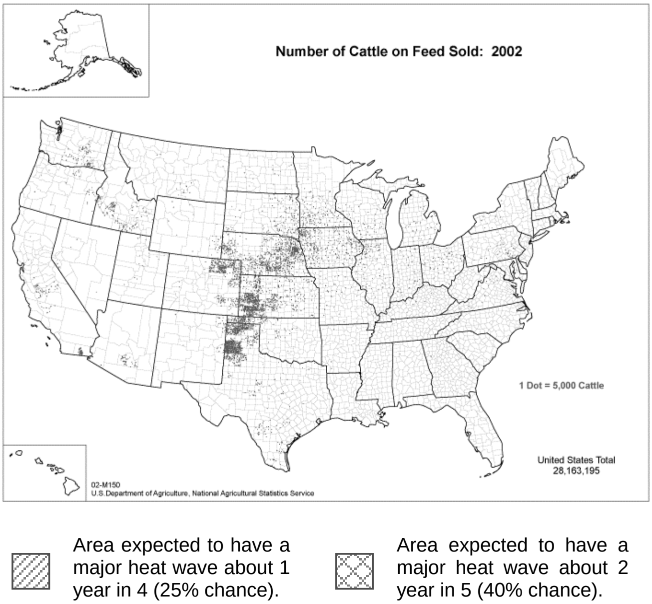

Figure 1. The probable areas expected to have a major heat wave on a regular basis (Nienaber et al., 2007) superimposed on the cattle-on-feed distribution in the USA from 2002 (NASS, 2008).

Several severe heat waves have occurred in the Midwestern USA in the last 10 years that have caused the death of thousands of feedlot cattle and loss of millions of dollars in revenues to the cattle industry, both in direct animal losses and indirect performance losses (Busby and Loy, 1996; Hahn et al., 1999; Hubbard et al., 1999)

Objective

The objective of this study was to investigate the weather parameters before, during, and after two extreme heat wave events for several Midwestern sites in the United States. Description of the events leading up to an extreme event should make that extreme event more easily recognized, so precautionary and remedial measures may be taken in a more timely manner.

Background

While, temperature is the primary parameter used to describe the environment, other weather parameters can also impact the total heat load. Solar radiation, humidity, and wind speed are three other parameters that are considered important (MLA, 2002). Several mathematical models have been developed to help summarize these components into a single usable number (Brown-Brandl et al., 2005; Eigenberg et al., 2005; Gaughan et al., 2008; Mader et al., 2006; Thom, 1959). The Temperature Humidity Index (THI) combines the effects of temperature and humidity (Thom, 1959). The other more recently developed equations combine temperature, humidity, wind speed, and solar radiation. For the purposes of this manuscript and in the interest of conciseness, THI and only one estimated respiration rate (Eigenberg et al., 2005) will be used in this heat wave analysis. The THI equation is shown in equation 1; where t_{db} is dry-bulb temperature in C and RH is relative humidity in decimal form.

$$THI = 0.8t_{db} + RH(t_{db} - 14.4) + 46.4 \quad (1)$$

Advisories were issued by the U.S. Weather Bureau based on the Livestock Weather Safety Index consisting of four THI categories: Normal THI < 74; Alert, 74 < THI ≤ 79; Danger, 79 < THI ≤ 84; and emergency, THI ≥84. These categories were originally established by the Livestock Conservation, Inc. and were based on transportation losses (LCI, 1970).

The estimated respiration rate (RR_{est}) equation is shown in equation 2; where t_{db} is dry-bulb temperature, RH is relative humidity in percentage, v_w is wind speed in m/s, and r_s is solar radiation in W/m^2. Four categories of RR_{est} were established based on the original THI categories, assuming a solar radiation of 800 W/m^2 and a wind speed of 0 m/s. The categories for RR_{est} have the following thresholds: Normal, 90; Alert 90 – 110; Danger, 110 – 130; and Emergency, ≥ 130.

$$RR_{est} = 5.1t_{db} + 0.58RH - 1.7v_w + 0.039r_s - 52.8 \quad (2)$$

Materials and Methods

Two recent heat waves were selected. The first heat wave, caused the loss of an estimated 5000 head of feedlot cattle (July 20 and 21, 1999), was located in an area near West Point, NE. The second heat wave was located in the area surrounding Britton, SD in July, 2007, which caused the loss of an estimated 2000 head of feedlot cattle (July 24, 2007). As part of this assessment, 4 other US locations were investigated (Figure 2). Clay Center, NE was chosen because this is the site of our research program and several research projects have been conducted here. McCook, NE was chosen because of the different climate in this area (drier and warmer climate). Rockport, MO was chosen because of an extreme event that occurred in that area in 1995 and because this is an area that is more likely to have extreme weather (Figure 1, Bowles et al., 2008). Garden City, KS was selected because of the large number of feedlots in the area (Figure 1).

Hourly weather data for the month of July for these cities was downloaded through the High Plains Regional Climate Center (Lincoln, NE). A period of 10 days surrounding days cattle were lost were analyzed (including 5 days prior to the extreme days). Index values of THI and RR_{est} were calculated for each time period. Total number of hours spent in each THI category (Normal, THI<74; Alert, 74≤THI<79; Danger, 79≤THI<84; Emergency, THI≥84) was calculated for both the entire month of July and the 10 day analysis. In addition, the total number of hours below a THI of 72, or recovery time per day during the extreme event was also calculated.

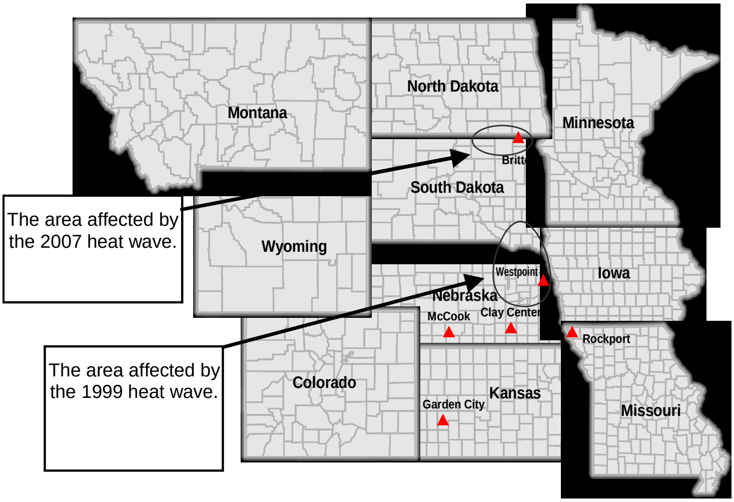

Figure 2. Map of the central United States showing the location of the six selected cities and the areas impacted by the 1999 and 2007 heat waves.

Results and Discussion

1999 Heat Wave

July 21, 1999, an extreme heat wave hit North Central Nebraska and killed approximately 5000 head of finishing cattle. The question that must be asked is: Can the set of conditions be found to describe the weather which caused the extreme event and the loss of the cattle? If the set of conditions could be described, it would be useful in predicting or forecasting events.

The analysis of the weather data reveals a relatively intense summer (all locations had hours in the emergency category, Table 1). Rockport had an excessively hot summer, 85 hours in the emergency category. WestPoint had 15 hours in the emergency category, while Garden City and Clay Center reported 14 and 11 hours, respectively. McCook, NE and Britton, SD both reported 5 hours in the emergency categories. During the 10 days surrounding the event, West Point, McCook, and Britton all reported 0 hours in the emergency category (Figure 3.), while Rockport, Garden City and Clay Center reported 42, 8, and 1 hour(s) of emergency conditions (THI), respectively. The feedlot deaths occurred in the area near West Point, NE not Rockport, MO. It is interesting to note that the animals at West Point had been exposed to warmer weather before the day of the losses. This indicates THI alone can not predict animal losses.

Table 1. Number of hours in each of the four THI categories for the month of July, 1999, for each of the locations listed.

	Normal	Alert	Danger	Emergency
Clay Center, NE	416	164	153	11
McCook, NE	446	140	153	5
West Point, NE	391	195	143	15
Rockport, MO	222	281	156	85
Britton, SD	548	132	59	5
Garden City, KS	425	150	155	14

When solar radiation and wind are added to the analysis as used in the RR_{est}, the numbers change slightly (Table 2). Rockport's weather condition resulted in 44 hours of emergency conditions, considerably higher than any other station. West Point had 10 hours of emergency conditions. Garden City and Clay Center reported 2 and 1 hours of emergency conditions, respectively. When the 10 days surrounding the heat wave are examined, only Rockport and Garden City report any time in the emergency category (23 hour Rockport and 1 hour Garden City). While, adding the effects of solar radiation and wind speed helped identify West Point as a site with potential extreme weather, it did not identify the problem dates.

Table 2. Number of hours in each of the four Estimated RR categories for the month of July, 1999, for each of the locations listed.

	Normal	Alert	Danger	Emergency
Clay Center, NE	553	109	81	1
McCook, NE	561	98	85	0
West Point, NE	556	101	77	10
Rockport, MO	477	123	100	44
Britton, SD	647	70	27	0
Garden City, KS	546	118	78	2

Nighttime recovery has been shown as an important element in the overall stress on the animals (Hahn and Mader, 1997). Figure 3 indicates July 20 (day before the losses) was in the Danger category for both THI and RR_{est}, followed by a night with little or no recovery, followed by a day time high conditions again in the Danger category. This might explain the losses in West Point. However, a similar situation occurred in Rockport over a 4 night – 5 day period instead of a 1 night – 2 day period in West Point.

Recent rain fall that saturates the feedlot soil has been hypothesized to increase the stress level of feedlot cattle by increasing the microclimate humidity (Nienaber et al., 2007). While, Figure 3 shows a rain event occurring on July 19 (JD 199) and again on July 21 (Puma et al., 1999), the effected feedlots reported rain on four days (JD 199, 200, 201, and 202). Reports from the local producers in the affected area indicated a 50 mm event July 20 and 21. This rain event would have contributed to the humidity in the feedlot microclimate and to the total heat load on the animals.

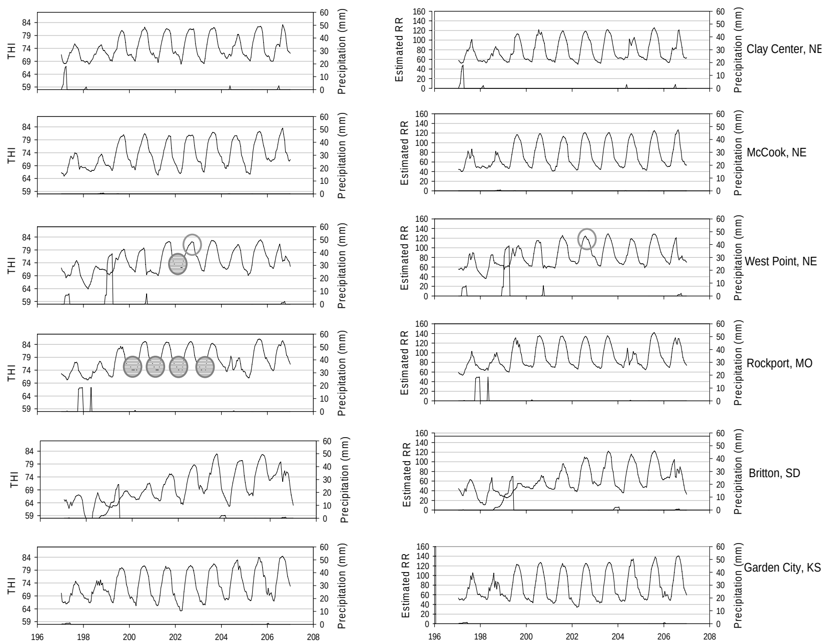

Figure 3. Environmental conditions for 6 selected cities for the days of July 16, 1999 (JD=197) to July 26, 1999 (JD=207). Gray circles indicate nights with THI greater than 72, a threshold for night time recovery. White circles indicate days with reported cattle losses.

The question remains: Why didn't the feedlot operators in Rockport, MO suffer cattle losses July, 1999? All the indicators have suggested the weather conditions were more severe at Rockport than in West Point. According to Figure 1, there are not many feedlots in the Rockport area. Also, it appears the Rockport area is in a high probability area for extreme events (Figure 1). So, it would stand to reason the producers in that area may have developed management strategies for extreme heat events. Those strategies may include, marketing cattle before summer and leaving the lots empty during the summer, or adding shade to their lots. In the hypothetical situation of a producer in the Rockport area having shades made of 40% and 80% shade cloth, RR_{est} can be estimated and shows a reduction in the solar radiation value by 40% and 80%, respectively. If a producer supplies ample shaded area with 80% shade cloth, the hours for the month of July 1999 in the emergency category drop from 44 (without shade) to 0 hours (with 80% Shade cloth), and instead of 100 hours in the danger category there would be only 27 hours (566 hours in the Normal Category; 151—Alert Category). If the producer chose to use a 40% shade cloth, the numbers would change slightly (7 hour in the Emergency Category, 85 hours – Danger; 131 hours – Alert; and 521 hours – Normal). In this situation, it would appear adding shade (either 40% or 80% Shade cloth) could have reduced the risks to the animals significantly.

In summary, the extreme conditions in West Point, NE which contributed to the animal losses were a combination of two consecutive days with high day time THIs or RR_{est} (Danger category), saturated feedlot soils from recent rains, and lack of nighttime recovery (THI> 72). Other contributing factors may have been the relatively cool few days that preceded this event which stimulated feed consumption, thus adding to the total heat load on the animals.

July 2007 Heat Wave

July 23, 2007, an extreme heat wave affected North Central South Dakota killing an estimated 2000 head of cattle. This is an area that rarely experiences heat stress. There were no losses reported at any other of the selected locations during this year. The 2007 summer had been relatively mild compared to the 1999 season for all the selected locations. Eighty seven percent of the hours analyzed in the month of July were either in the normal or alert categories (Table 3.) Britton, SD had the most hours in the emergency categories for THI with a total of six hours in the month of July, only 2 of those hours were on July 23, 2007. The other four hours were on July 7, 2007; there were no cattle losses reported on this day. The two hours on July 23 in the emergency zone would not be particularly dangerous in itself (Figure 4.). So, like in the July 1999 heat wave these losses were associated with more than maximum temperature and humidity on any given day.

Table 3. Number of hours in each of the four THI categories for the month of July, 2007 for each of the locations listed.

	Normal	Alert	Danger	Emergency
Clay Center, NE	501	167	76	0
McCook, NE	471	175	98	3
West Point, NE	451	208	85	0
Rockport, MO	381	242	121	0
Britton, SD	525	165	54	6
Garden City, KS	432	174	138	0

When solar radiation and wind are added to the analysis in the form of the RR_{est}, the number of emergency hours in the month of July, 2007 falls to zero (Table 4.) The conditions at Britton, SD were the coolest of any selected station (only 23 hours in the Danger category and 82 hours in the Alert category). These cool conditions might have contributed to the losses experienced.

Table 4. Number of hours in each of the four Estimated RR categories for the month of July, 2007 for each of the locations listed.

	Normal	Alert	Danger	Emergency
Clay Center, NE	608	113	23	0
McCook, NE	585	103	56	0
West Point, NE	583	121	40	0
Rockport, MO	545	158	41	0
Britton, SD	639	82	23	0
Garden City, KS	545	145	54	0

It appears that precipitation may have played a role in the losses at Britton, SD (Figure 4). Although the rain event was not as large or as prolonged as the one in West Point, NE, in July, 1999, there was a 12 mm rain event reported at the weather station, in the early morning hours of July 22 (JD 203). This rain event was also reported by the affected feedlots. The affected feedlots received approximately the same amount and no other rain events were reported.

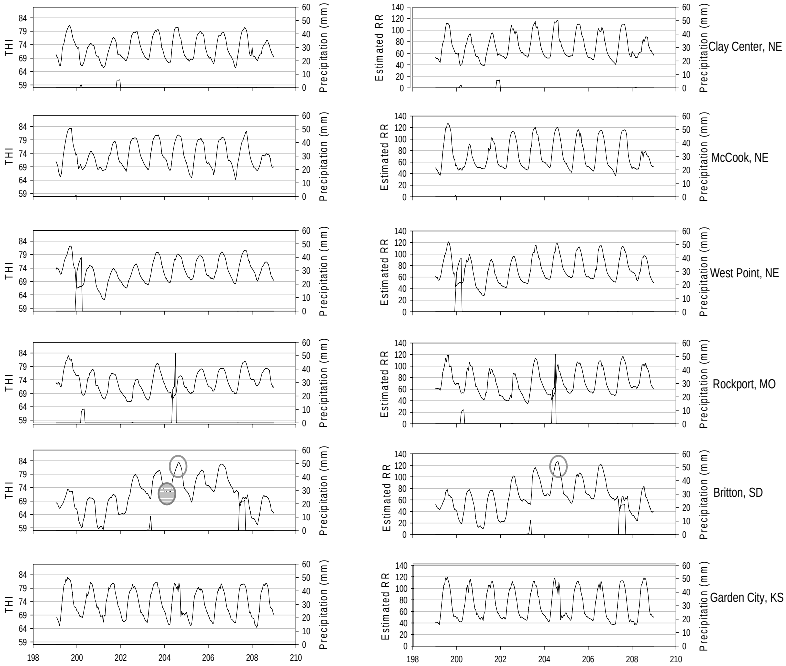

Figure 4. Environmental conditions for 6 selected locations for the days of July 17, 1999 (JD=199) to July 29, 1999 (JD=208). Gray circles indicate nights with THI greater than 72, a threshold for night time recovery. White circles indicate days with reported cattle losses.

In summary, the extreme conditions in Britton, SD which contributed to the animal losses were very similar to the extreme event near West Point, NE in July 1999. There were two consecutive days with high day time THIs or RR_{est} (Danger category) with a single warm night without any cool hours for recovery (THI> 72). Also, there was a rain event two days before the losses that might have saturated feedlot soils. Additionally the event was preceded by relatively cool days, which may have encouraged the animals to eat.

Conclusion

Weather patterns surrounding two extreme heat wave events which caused the loss of thousands of animals in a localized area were examined. West Point, NE in July 1999 reported losses of 5000 head of cattle, and Britton, SD in July 2007 reported losses exceeding 2000 head of cattle. Based on the analysis of these two heat waves, it appears the following factors contribute to making an extreme event:

- A preceding cooling period of a few days
- Recent rain events
- Two or more consecutive days in the Danger or Emergency categories as calculated by the THI or RR_{est}
- Little or no nighttime cooling (THI>72)

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