A PRELIMINARY ASSESSMENT OF THE NET ECONOMIC BENEFIT OF SOLID-SET SPRINKLERS USED FOR DUST CONTROL AND MICROCLIMATE MODIFICATION

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Abstract

Solid-set sprinkler systems operated on cattle feedyards in the semi-arid Southern High Plains are alleged to improve the comfort, health and feed-to-gain performance of beef cattle during the summer as a result of evaporative cooling effects and a consequent reduction in the heat stress of feeder cattle. Our investigation, which coupled an extensive literature review with field measurements of the feedyard microclimate as modified by sprinkler use, revealed that the change in microclimate associated with sprinkler use was of insufficient magnitude and duration to affect the heat status of feeder cattle in the Southern High Plains. It is therefore unlikely that any improvement in feed-to-gain performance of feeder cattle associated with the use of solid-set sprinklers can be attributed to evaporative cooling affects alone, although there may be other, non-thermodynamic effects (e. g., reduced respiratory stress via dust control) that may justify their use in a broader economic context.

Introduction

The summer climate of the Southern High Plains is characterized by long, warm days, abundant sunshine, persistent winds and generally low to moderate humidity depending on the position of the "dry line," an active boundary separating Gulf of Mexico influence (SE winds, higher humidity) from Mexican plateau influence (SW winds, lower humidity). Although Gulf influence is common, the predominant flow is SSW for the majority of the cattle-feeding region, and summer afternoon humidity is usually below 30%. As a consequence of the generally low humidity and persistent wind, evaporative cooling is well suited to this semi-arid region.

The substantial moisture deficit in the Southern High Plains contributes to the high potential for fugitive dust emissions from open-lot cattle feedyards in the region. Hoof action on dry, uncompacted manure on the surface of feedyard corrals grinds manure particles and resuspends them in the air, creating a cloud of coarse dust near the ground surface. As a result of neighbors' nuisance complaints, impaired roadway visibility or concerns about the respiratory health implications of feedyard dust for newly received cattle (MacVean et al., 1986), some feedyard owners have opted to install solid-set sprinkler systems on new or existing feedyards or feedyard expansions.

In addition to the dust-suppression benefit, it is widely thought that these sprinkler systems modify the feedyard microclimate through evaporative cooling and thereby forestall the negative influence of heat stress on the health and/or feed-to-gain performance of beef cattle (*Bos taurus*). If so, reduced veterinary costs and/or improved feed efficiency partially offset the cost of installing and operating the sprinkler systems. Our objective was to couple a thorough literature review with field data on the magnitude and duration of microclimate modification to determine whether or not the cost of solid-set sprinkler systems can be recovered in improved health or performance of beef cattle.

Experimental Methods

Literature Review

The primary research effort for this project consisted of an extensive literature review. The purpose of the literature review was to establish the physiological basis for supposing that microclimate modification in Southern High Plains feedyards will relieve heat stress or improve the overall health and performance of beef cattle during the summer months. We examined the scientific literature for both beef and dairy cattle to (a) find a generally accepted index of bovine heat stress and (b) determine the range of values of that index in which microclimate modification may be thought to mitigate the effects of heat stress on the health or productivity of the livestock.

Commercial Feeding, Sales and Hospital Records

The purpose of this component of the research was to determine whether or not the operation of a solid-set sprinkler system on a portion of a commercial feedyard had any measurable effect on the feed-to-gain performance or health status of the fed cattle. A commercial feedyard in the TCFA membership area made 6 years of data available to us for statistical analysis. After accounting for confounding factors such as breed, sex, date of arrival, date of departure and location of origin, we compared feed, sales and health records of cattle assigned to (a) pens without sprinklers and (b) pens with sprinklers, looking for significant differences in average daily gain, pulls, buller behavior and other economically significant data.

Field Data

The purpose of the field experiment was to (a) describe the climate of the Southern High Plains with respect to the typical values of the heat-stress index and (b) determine the magnitude and duration of transient changes in the heat-stress index attributable to the operation of a solid-set sprinkler system in a commercial cattle feedyard. First, we calibrated an array of nine HOBO™ dataloggers equipped with on-board temperature and humidity sensors to ensure their repeatability and accuracy. Then, we deployed the datalogger array for three days in July 2001 on a commercial feedyard in Deaf Smith County, TX, equipped with an operational solid-set sprinkler system. We deployed the dataloggers in groups of three at three different locations within the feedyard boundary, one upwind (background) and two within the feedyard where we could detect the effect of the sprinkler system on the feedyard microclimate. The upwind datalogger location was near the SW corner of the feedyard, and the two downwind locations were along the feeding alleys and working alleys to approximate the microclimate within the corral boundaries. (Our first attempt to deploy the dataloggers within the corrals themselves resulted in datalogger damage by the livestock.) We measured temperature (T) and relative humidity (RH) on a one-minute interval from September 27-28, 2001.

Results and Discussion

Principles of Heat Stress and Heat Dissipation

Beef and dairy cattle, like most large mammals (including humans), are *homeostatic*, which refers to their ability to modify behavior or internal metabolic processes to maintain a thermal equilibrium within which physiological systems operate normally. For example, when the body core temperature of a homeostatic organism begins to rise, it may initiate vasodilation, or the expansion of small capillaries near the body surface, to increase blood flow near the body surface and accelerate the dissipation of excess heat to the environment. In the case of beef cattle, one of the well-known homeostatic responses to excessive core temperature is to consume less food, which reduces the amount of heat generated by metabolic processes. However, it is possible to overwhelm the body's capacity to compensate for excessive heat inputs, and if that capacity is overwhelmed, the result is a rise of core body temperature. When the core temperature of a beef animal (or any homeostatic animal) rises beyond critical thresholds, essential physiological systems may be compromised or interrupted, resulting in stress-induced health problems, reduced feed-to-gain performance or death.

The combined effect of T and RH on the health and performance of beef cattle is not as well documented as that of dairy cattle. The most frequently cited heat-stress index for dairy cattle is the "temperature-humidity index," or THI, which was defined by Rosenburg et al. (1983) as

$$THI = T_{dbf} - (0.55 - (0.55 * (RH / 100))) * (T_{dbf} - 58) \qquad [1]$$

in which T_{dbf} is the dry-bulb air temperature (C) and RH is the relative humidity (%). In biological terms, THI represents the combined effect of temperature and humidity on the ability of an organism to dissipate heat to the environment. Humans experience that effect qualitatively when we sense, for example, that a warm, "muggy" summer environment is less pleasant than a hotter but drier environment because we cannot cool off. The related "heat index" is a standard component of local weather reporting and forecasting, and in many areas, public health agencies issue heat advisories in response to the forecast heat index instead of the air temperature alone. A slightly more sophisticated model that captures the effect of not only temperature and humidity but also direct solar radiation and wind speed is the effective ambient temperature (EAT) (Ames, 1986).

In a generalized engineering model, heat loss from an animal is proportional to the gradient of a combined thermal "potential" between the animal and its environment. Much as water flows from a region of higher elevation or pressure to a region of lower elevation or pressure, heat flows from a region of higher thermal potential to a region of lower thermal potential. In order for an animal to dissipate heat, the animal's thermal potential must be higher than the environment's. Thus, as the thermal potential of the environment rises (as indicated, for example, by a rise in EAT), the animal's thermal potential must rise proportionally to maintain a constant rate of heat dissipation. From this perspective, some homeostatic processes are internal means of increasing the animal's thermal potential in response to changes in the environment. For example, sweating and panting are means of moving moisture from the interior of the animal to the exterior of the animal where evaporative processes can strip surplus heat from the animal. Similarly, vasodilatation has the net effect of moving heat from the body core to its surface, effectively increasing the animal's surface temperature and its overall thermal potential relative to the environment.

The *thermoneutral zone*, then, might be loosely defined for individual animal types as the range of EAT within which a homeostatic animal is able to modify its own internal processes or its behaviors in response to environmental changes in order to maintain normal core temperature. Figure 1 is a conceptual rendering of that definition, which is animal-specific because of variations in frame size, specific surface area (surface area per unit body mass), body composition and other animal characteristics that influence heat gain and heat loss.

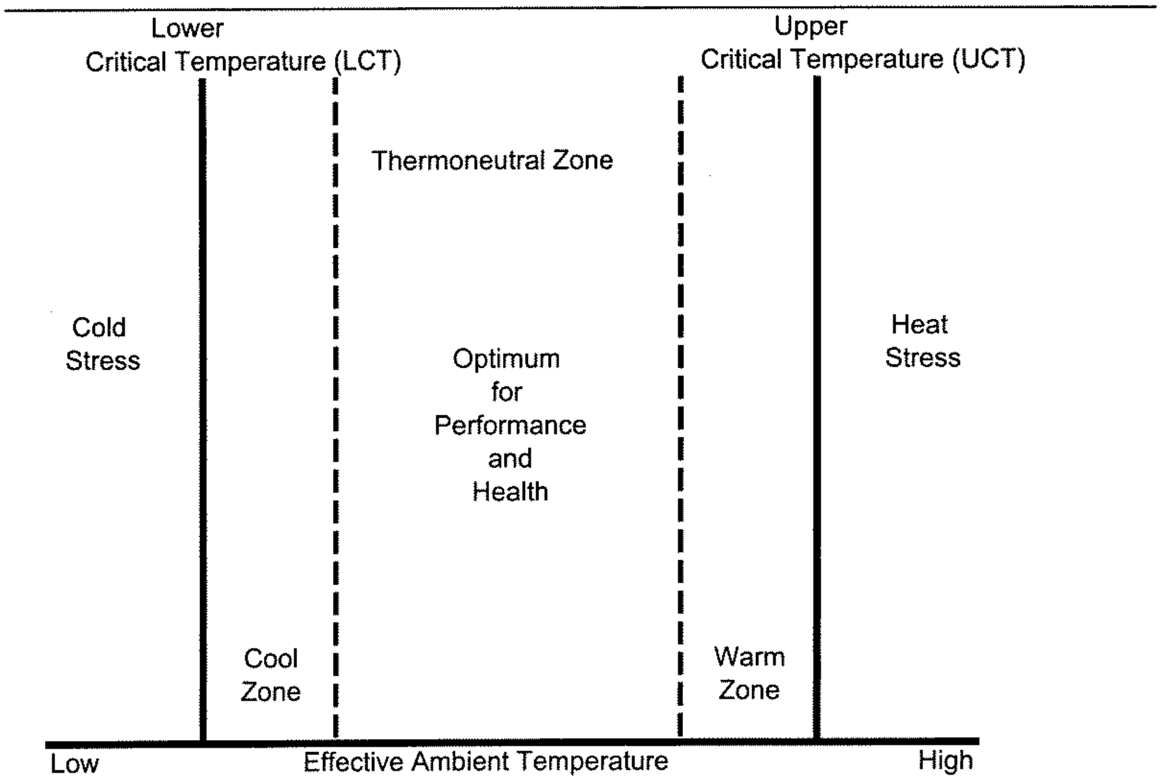


Figure 1. In the thermoneutral zone, a homeostatic organism is able to adapt to small changes in its environment (as measured by effective ambient temperature, EAT) without experiencing hypothermic or hyperthermic stress. Adapted from Ames (1986) and Mader et al. (2001).

Most of the literature relating THI to bovine health and performance pertains to dairy cattle. Ryan et al. (1992) have proposed a critical value of THI_c=75 as the upper steady-state threshold above which a dairy cow is no longer able to maintain normal core temperature through homeostatic processes. Assuming that threshold is accurate, the *health effects* of heat stress therefore accumulate during periods when THI>75. That does not necessarily imply that there are no *performance* losses when THI<75; in fact, the very homeostatic processes that allow the animal to maintain core temperature within the thermoneutral zone also represent an increase in apparent maintenance-energy requirements. In other words, the excess energy is dissipated to the environment rather than deposited in milkfat, body tissue or other marketable products. Theoretically, there is a single optimum environment that maximizes an animal's feed conversion to a given marketable product, so any perturbation of that environment must by definition reduce the animal's feed conversion whether the animal is able to maintain homeostasis or not.

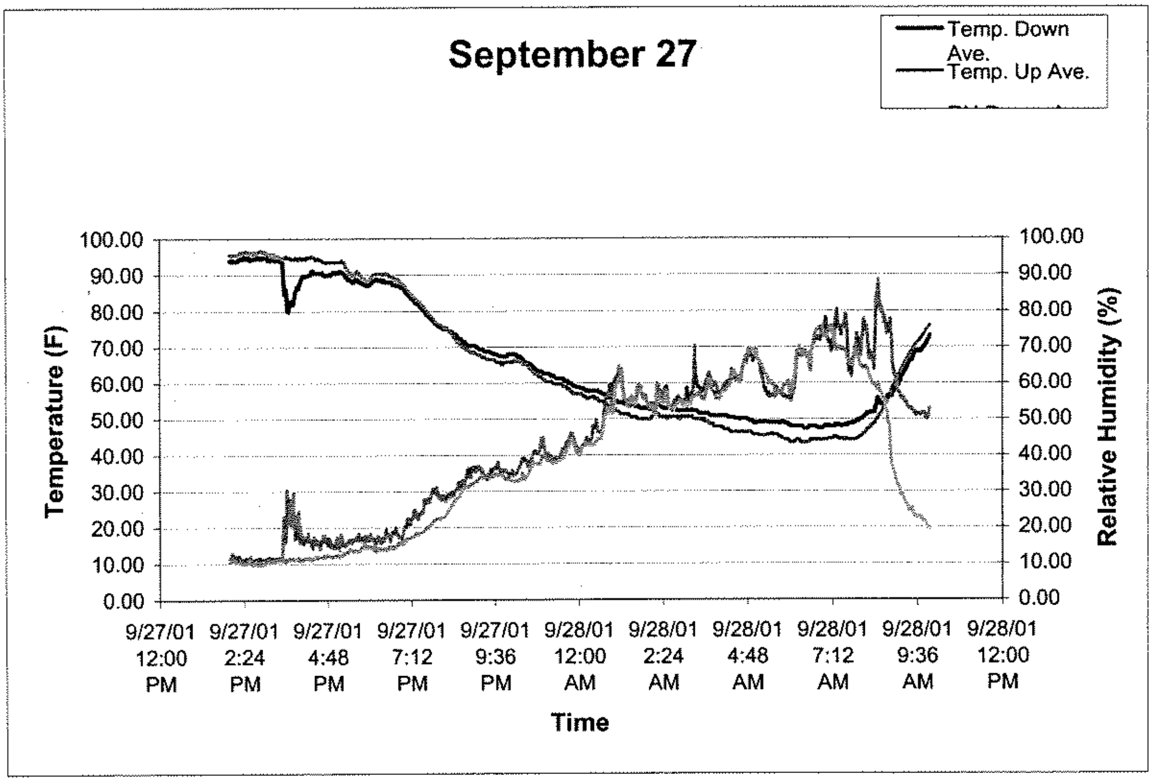
Equation [1] does not capture the other major environmental variable that contributes to the thermal status of beef cattle. Increasing the wind speed increases the rate at which excess heat dissipates from the animal's surface. (The familiar forecaster's term, "wind chill," pertains to that effect on humans.) Equation [2] is the wind-chill formula currently accepted by the National Oceanic and Atmospheric Administration (NOAA) for use in predicting hypothermia or frostbite potential in humans:

$$T_{wc} = 35.74 + (0.6215 \bullet T_{db}) - (35.75 \bullet U^{0.16}) + (0.4275 \bullet T_{db} \bullet U^{0.16}) \quad [2]$$

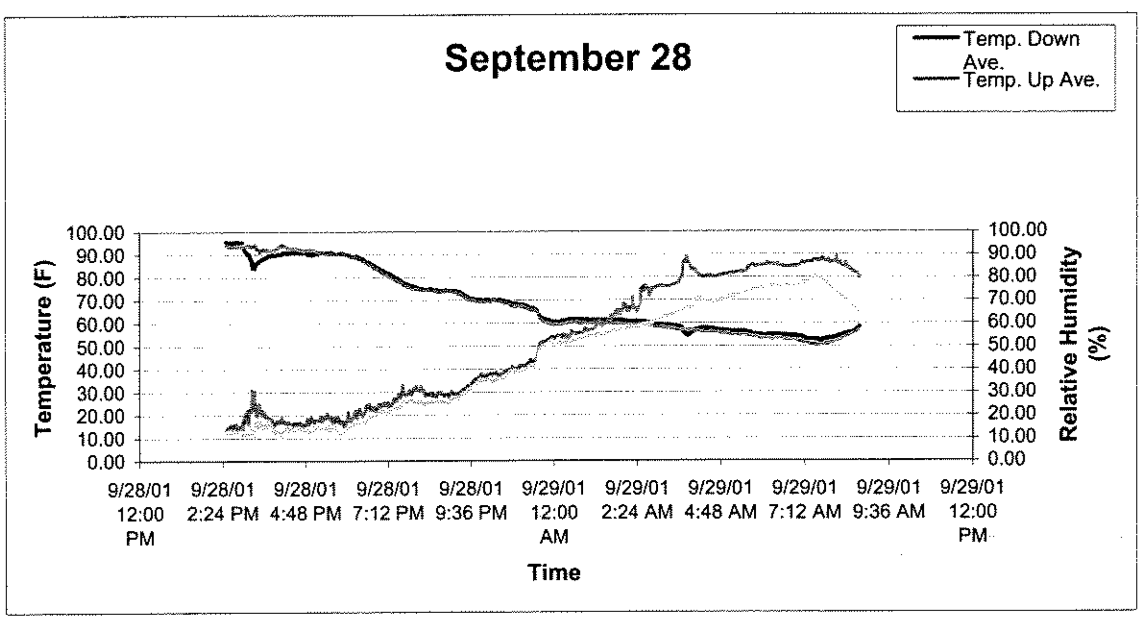
in which T_{wc} is the wind-chill equivalent temperature (C) and U is the wind speed (mph). Equation [2] is not strictly applicable to bovines because of the geometric and physiological differences that influence a species' propensity to dissipate heat, but it does serve as a useful starting point. To date, noone has published a model combining the effects of humidity and wind speed on the potential for heat dissipation by bovines. Such a model might generate an *effective ambient temperature,* T_{ae} (C), which would be defined as the steady-state, calm, dry-bulb temperature that would give rise to the same rate of heat loss as the existing temperature/humidity/wind speed conditions.

Field Data

Measurements of temperature and relative humidity in September 2001 both upwind and within a feedyard with an operating sprinkler system illustrate the short-term effect of sprinklers on THI (i. e., the combination of temperature and humidity only). The effect of sprinklers on the feedyard microclimate does not last more than about 20-30 minutes. The following graphs of upwind and downwind temperature and RH clearly show the operation of the sprinkler system at 2:30 p.m. in the region of the feedyard where the sensors were located. On September 27, the 2:30 p.m. sprinkler cycle dropped ambient temperatures by about 15F and raised RH from 10% to 30%, with those variables returning to their original diurnal trends by 3:00 p.m. The 5:30 p.m. sprinkler cycle had a much less pronounced effect on both temperature and RH; indeed, it is barely detectable in the graphical presentation.



The story was much the same on September 28, 2001, another day of hot, dry weather ideal for evaporative cooling to take place. Again, the change in temperature and RH were dramatic but short-lived after the 2:30 p.m. sprinkler cycle, and the changes (if any) were barely detectable after the 5:30 p.m. sprinkler cycle.



Conclusions

These field data appear to confirm the results of the interim analysis of commercial feeding, sales and hospital records, to wit, that the duration of the evaporative cooling effect of solid-set sprinklers, at least in the intermittent mode in which those sprinklers are currently used, is not sufficient to reduce the overall thermal load on the livestock by any appreciable amount. Our conclusion in this regard is tempered by the fact that measurements of temperature and RH alone do not allow us to compute EAT, which may be a more useful measure of the environment actually experienced by the livestock. Computations of EAT would incorporate solar radiation and wind speed, requiring more measurements that we did not undertake. It may well be that the effect of sprinkler systems on EAT is closely related to hide and hair color (i. e., in terms of absorption of solar radiation) and the wetting of the animal's surface, not just the ambient temperature and RH in the pens. In conclusion, however, we were unable to confirm that the use of sprinkler systems changes the animals' environment enough to affect their performance, especially in view of the fact that the pronounced overnight cooling of the High Plains environment allows the animals to eliminate all of the surplus heat that they accumulate during the day. We were also unable to detect any significant trends in cattle health or performance attributable to sprinkler operation from the feeding, sales and hospital data made available to us by the cooperating cattle feedyard.

Those readers interested in a fuller description of the research are referred to a graduate thesis submitted in 2002.

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