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Remote characterization of locomotion, grazing and drinking behavior in beef cattle using GPS and ruminant temperature dynamics

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Remote characterization of locomotion, grazing and drinking behavior in beef cattle using GPS and ruminant temperature dynamics

by

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CHAPTER 1. GENERAL INTRODUCTION

Introduction

The ability to remotely and continuously monitor animal behavior and physiological variables related to health of animals has tremendous potential impact, both on animal well being and economics of animal production. Characterizing locomotion of livestock will provide fundamental knowledge in animal behavior and land utilization. Real-time monitoring of cattle locomotion could provide a producer with information on forage quantity and quality, and the ability to continuously adjust grazing systems. In addition to monitoring locomotion, monitoring variables such as water consumption will provide insight into feeding behavior and the interaction between grazing system management and this behavior. Quantifying drinking activity within a grazing system could provide information on its impacts to water quality, animal health, and land utilization.

Traditionally, animal location within a field has been monitored by visual observation relying on natural hide color or artificial features such as colored collars or tags (Turner et al., 2000). Turner et al. (2000) stated that not only is visual observation labor intensive, problems can occur due to observer fatigue, study area accuracy, and physical limitations, alteration of cattle movement due to observer presence and visibility factors due to night and weather conditions.

Advances in GPS technology have provided remote means of monitoring livestock location at < 3 m accuracies over selectable sampling intervals. These new capabilities offer objective measurements for studying how spatial and temporal distribution of livestock arise due to factors such as forage type, grazing system, landscape, hide color, health status, ambient conditions, and feature location (water tank, shade, stream). Researchers have utilized global positioning system (GPS) along with geographic information systems (GIS) to assess cattle behavior and pasture utilization (Turner et al., 2000) and to determine beef cattle water intake rates as affected by stream access (Bicudo et al., 2003).

GPS collars that are large enough for beef cattle cost approximately $3000/unit plus peripherals and software. Hence, monitoring multiple animals over multiple plots becomes extremely cost prohibitive. To this end, researchers are only able to monitor a small number of animals as a subset of the herd for given activities or treatments (Udal, 1998; Turner et al., 2000; and Agouridis et al., 2005). These data are then extrapolated across the total number of animals in each treatment to determine herd behavior and to develop system requirements. This method relies on the assumption that all animals in the herd traversed the study area in a well-defined grouping. This begs the question of whether one can infer patterns in behavior and movement from 1 or 2 animals and then extrapolate these patterns to a population if the financial constraints do not allow the purchase of many collars (Moen et al., 1996).

Most conventional GPS collars are limited in the minimum sampling interval and maximum data storage capacity. In consideration of GPS sample interval, Moen et al. (1996) stated that the concern of the investigator is whether to take fewer precise locations or more less-precise locations. The driving force determining the length of sampling interval and quality of readings (2D fix vs. 3D) in a portable GPS tracking unit is power management. Small sampling intervals and higher quality readings require larger quantities of energy over a given period. This determines the minimum physical size of the unit housing the batteries and length of time a researcher can monitor an animal before the GPS logger has to be removed and batteries changed or charged. Most researchers have used the smallest interval (5-min) commercially available in their studies (Udal, 1998; Turner et al., 2000; Agouridis et al., 2005; and Ungar et al. 2005). However, a 5-min sampling interval may be insufficient to distinguish between specific behaviors based on spatial distance alone. In addition to locomotion behavior, simultaneous measurement of physiological parameters may provide a more complete analysis of animal health and well-being.

It has been a common husbandry practice in the United States that livestock graze on large pastures and are allowed to drink, walk and lounge in any creek, river or lake available. Conservation of stream and ground water quality and more efficient use of livestock watering sources have become an issue of increasing concern to researchers, producers and environmentalists alike. Producers need low-cost clean water sources to protect streams while optimizing herd health and production. Researchers have been concerned with developing better grazing systems, improving stream water quality, and stabilizing stream banks from erosion. To help address these issues, knowledge of water consumption patterns and intake rates of the animals would be highly valuable.

Individual water intake has been continuously monitored by researchers in laboratory settings for poultry (Puma et al., 2001), swine (Phillips et al., 1990) and cattle (Dado and Allen, 1993). These studies work well for individually penned animals with separate drinking systems. However, these systems do not allow the study of individual drinking behavior in group settings or grazing systems containing multiple watering sources. GrowSafe Systems Ltd (2007) developed a radio frequency identification (RFID) system (GrowSafe Beef, Airdrie, Alberta, Canada) to monitor animal growth and health determined by trips to the water tank. The GrowSafe Beef system can determine individual drinking activity within a group setting but must be installed at every watering source and the system does not quantify volume consumed. Winchester and Morris (1956) stated that the prediction of water intake of a single or of a few animals was not possible due to large variations in water intake among individuals or of the same animal for consecutive days. In spite of the variations, can each study animal be "calibrated" before being introduced into remote monitoring research projects?

Objectives

The objectives of these studies were to:

1. Develop a low-cost GPS herd activity and well-being kit (GPS HAWK) to collect GPS location data at a user-specified frequency. Demonstrate the use of the GPS HAWK by monitoring the locomotive behavior of multiple cows on pasture at a high frequency.
2. Characterize GPS-based cattle grazing behaviors and the effect of animal sample size and sample interval on the measurements.
3. Characterize rumen temperature response to water consumption in cattle. Assess the use of rumen temperature change to detect when water consumption occurs and estimate the volume of water ingested.

Dissertation Organization

This dissertation is organized in paper format and comprises three papers. Each manuscript concentrates on one of the major objectives listed above. The first manuscript describes the design and construction of a low-cost GPS herd activity and well-being kit (GPS HAWK). The GPS HAWK was employed at a high frequency to illustrate short-term dynamic behaviors in cattle. The second manuscript focuses on the delineation of grazing behavior using data gathered visually and using the GPS HAWK. The effects of animal sample size and GPS sampling rate were evaluated. The third manuscript describes the development of a drinking detection algorithm that detects drinking events and predicts the volume consumed. An overall summary of major conclusions of this research endeavor and a bibliography listing of references cited in the general introduction are included at the end of this dissertation.

References

Agouridis, C.T., D.R. Edwards, S.R. Workman, J.R. Bicudo, B.K. Koostra, E.S. Vanzant, J.L. Taraba. 2005. Streambank erosion associated with grazing practices in the humid region. Trans. ASABE 48(1): 181-190.

Bicudo, J.R., C.T. Agouridis, S.R. Workman, R.S. Gates, and E.S. Vanzant. 2003. Effects of air and water temperature, and stream access on grazing cattle water intake rates. Paper for the 2003 ASAE International Meeting, Paper #034034, July 27-30. Las Vegas, NV.

Dado, R.G., M.S. Allen. 1993. Continuous computer acquisition of feed and water intakes, chewing, reticular motility, and ruminal pH of cattle. J. Dairy Sci. 76:1589-1600.

GrowSafe Systems Ltd., 2006. GrowSafe Beef. Airdrie, Alberta, Canada. Available at: www.growsafe.com/assets/growsafe%20Beef%20Brochure.pdf. Accessed 27 June 2007.

Moen, R., J. Pastor, Y. Cohen, C.C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. J. Wildl. Manage. 60:659-668.

Phillips, P.A., D. Fraser, J.M. Leclerc, B.K. Thompson. 1990. Measurement of individual water intake by group-housed piglets. Trans. of the ASAE 33(3): 912-916

Puma, M.C., H. Xin, R.S. Gates, D.J. Burnham. 2001. An instrumentation system for studying feeding and drinking behavior of individual poultry. Applied Engineering in Agriculture 17(3): 365-374.

Turner, L.W., M.C. Udal, B.T. Larson, and S.A. Shearer. 2000. Monitoring cattle behavior and pasture use with GPS and GIS. Can. J. Anim. Sci. 80(3) 405-413.

Udal, M.C. 1998. GPS tracking of cattle on pasture. M.S. Thesis, University of Kentucky, Lexington, Kentucky. December.

Ungar, E.D., Z. Henkin, M. Gutman, A. Dolev, A. Genizi, D. Ganskopp. 2005. Inference of animal activity from GPS collar data on free-ranging cattle. J. Rangeland Ecol. Manage. 58: 256-266.

Winchester, C.F. and M.J. Morris. 1956. Water intake rates of cattle. J. Anim. Sci. 15: 722-740.

CHAPTER 2. DEVELOPMENT AND USE OF A GPS HERD ACTIVITY AND WELL-BEING KIT (GPS HAWK) TO MONITOR CATTLE BEHAVIOR ON PASTURE

J.D. Davis, M.J. Darr, H. Xin, J.D. Harmon

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ABSTRACT

A low-cost GPS herd activity and well-being kit (GPS HAWK) was newly developed as an alternative to commercial GPS tracking collars. The operational goal of the GPS HAWK was to collect GPS location data at a user-specified frequency and store the data in a secure format. The GPS HAWK utilizes a Garmin 12-channel low-power GPS receiver powered by a 6V, 7.2 Ah sealed-lead acid battery housed in a shoulder-mounted aluminum enclosure. Operation of the GPS HAWK was commanded by a micro-controller based system equipped with six external sensor ports. Data were stored to compact flash media for retrieval. The locomotion behavior of multiple cows was monitored at 20-s intervals. The high-frequency sampling data were used to delineate grazing behavior of the cows on pasture including cumulative travel distance, travel velocity and acceleration. Behavior data of this nature could be useful to efficient pasture management and assessment of herd health/well-being.

Keywords: animal behavior, animal well-being, data logger

INTRODUCTION

Global positioning systems (GPS) have been used together with geographical information systems (GIS) to monitor both wildlife and domestic animal movement and behavioral activities (Moen et al., 1996; Rutter et al., 1997; Udal, 1998; Turner et al., 2000; Schlecht et al., 2004; Agouridis et al., 2005; Ungar et al., 2005). Within livestock production, GPS loggers have been utilized to monitor grazing, lying, or standing behavior of domestic sheep (Rutter et al., 1997); to track beef cattle in intensively managed grazing systems (Udal, 1998; Turner et al., 2000), and to study the effectiveness of using locomotion distance to distinguish among grazing, traveling and resting activities of beef cattle (Ungar et al., 2005). Agouridis et al. (2005) monitored beef cattle locomotion under several grazing systems to determine the treatment effects on streambank erosion in the humid region of the United States.

Moen et al. (1996) stated that the concern of the investigator regarding the data collection was whether to take fewer locations with high precision or more locations with low precision. The driving force for determining the length of sampling interval and quality of readings in a portable GPS tracking unit is power management. The smaller the sampling interval and a higher quality (differentially corrected) reading required longer satellite monitoring and calculation intervals, leading to greater energy consumption over a given period. This power requirement in turn determines the minimum physical enclosure size and the length of time a researcher can monitor an animal before the GPS logger has to be removed and batteries changed or charged.

Some researchers have used the smallest sampling interval (5-min) commercially available in their studies (Udal, 1998; Turner et al., 2000; Agouridis et al., 2005; and Ungar et al. 2005). However, even the smallest 5-min interval may not be sufficient to capture and delineate the dynamic behavior of beef cattle, under certain circumstances, such as under a rotational grazing system.

Several companies market GPS collars (Advanced Telemetry Systems, Lotek, and Telemetry Solutions, for example) for tracking animal movement patterns. GPS collars that are large enough for beef cattle cost approximately $3000/unit plus the cost of software and any peripherals. Hence, monitoring multiple animals over multiple plots becomes very cost prohibitive.

Objectives of This Study

1. Develop a low-cost GPS Herd Activity and Well-being Kit (GPS HAWK) to collect GPS and analog sensor data at a user-specified frequency.
2. Demonstrate use of the GPS HAWK by monitoring locomotion behavior of multiple cows on pasture at a high frequency.

MATERIALS AND METHODS

GPS HAWK Design and Refinement

In response to the relatively high costs and limited capabilities of commercial GPS collars, this study was initiated to develop a GPS Herd Activity and Well-being Kit (GPS HAWK). The operational goal for the GPS HAWK was to collect animal location and optional sensor data at a user-specified sampling frequency, store the data in a secure format, and optimize power consumption to extend logger life.

<u>GPS Receiver</u>

The quality of location data gathered is dependent upon the GPS receiver utilized. When choosing the GPS receiver, several characteristics including accuracy, weight, power use, complexity and cost were considered. Many of the GPS receivers (OmniStar, Trimble, Starfire, etc.) currently used in precision agriculture, though highly accurate (sub meter accuracy), were eliminated due to their bulky size, excessive weight, and high power consumption. Furthermore, most of these systems are quite expensive, making it cost prohibitive to monitor multiple animals simultaneously. The relatively inexpensive, weatherproof 12-channel receiver selected for this application (GPS 18 LVC, Garmin International, Inc., Olathe, KS) is disk-shaped and measures 61.0 mm diameter x 19.5 mm height, and weighs only 115.6 grams (fig. 1). The low-power receiver had a published Wide Area Augmentation System (WAAS) accuracy of less than 3 m and acquisition times of 15 seconds (Garmin International, Inc., 2004).

The GPS 18LVC used NMEA (National Marine Electronics Association) 0183 v. 2.0 protocol to transmit data over serial communication. The receiver could be programmed to transmit only the needed NMEA sentences. The following parameters were collected and stored as space delimited text file with the following information: latitude, longitude, number of satellites in view, and differential correction status. The World Geodetic System 1984 earth datum was used to calculate location. In addition, the receiver output the date and time in Coordinated Universal Time (UTC). The receiver was tested to determine the minimum time required to initialize and acquire a differentially corrected signal. Data sampled at intervals greater than this minimum time would allow the GPS receiver to be powered down between samples, thus ensuring more efficient power management and increasing duration between battery adjustments.

Microprocessor

A microcontroller-based system (PIC18LF258, Microchip, Chandler, AZ) was chosen to serve as the main computing unit for the GPS HAWK. The selection was based on power management qualities and input and output I/O capabilities of the microcontroller. The microcontroller was equipped with six analog to digital (A/D) conversion channels (0-5V single-ended, 10-bit resolution) as well as 16 general purpose I/O pins that could be configured for digital operations or serial communication. The unused I/O lines provided substantial future expandability as they could interface with various other digital sensors or peripheral devices. Future control routines could also be implemented through available digital output lines. A printed circuit board was designed to house the PIC microcontroller and all necessary peripheral components. The circuit board also allowed for external connection to the GPS receiver, power supply and test ports.

The microcontroller code was compiled using the PIC Basic Pro compiler and transferred to the microcontroller via an EPIC flash programmer both from Micro Engineering Labs, Inc. (Colorado Springs, CO). The program code was developed to enable the microcontroller to record GPS information as well as data from analog sensors at predetermined intervals (fig. 2). Once the user connects the power, the microcontroller powers up the GPS receiver to acquire satellite almanac information and calculate a differentially corrected GPS signal. The microcontroller synchronizes the sampling interval to the UTC obtained from the satellites. Upon capturing a DGPS reading, the value was stored to a serially electrically erasable programmable read-only memory (EEPROM) device. Then depending on the needed sample interval, the microcontroller might power down the GPS receiver for the difference in time between the sample interval and the minimum time to initialize the GPS receiver (2.5 min). The microcontroller initialized the GPS receiver 2.5 min before the next reading. The sample interval was again synchronized with the satellite UTC and data stored to the EEPROM. After a predetermined number of readings based on sample interval and EEPROM storage size, the microcontroller would download the data from the EEPROM to the compact flash card. Finally, the microcontroller powered the GPS receiver down and repeated the algorithm (fig. 2). A schematic representation of wiring circuitry for the GPS HAWK is presented in Figure 3.

Data Collection and Storage

Compact Flash cards were chosen as the data storage media. Upon acquisition of GPS fix and sensor data, the information was transferred directly to a space delimited text file. Initial testing of this method was successful, but power consumption became problematic as the Compact Flash storage technique required 750 mW of power. This was nearly twice the power needed for the GPS receiver (390mW). A secondary solution was implemented in which the individual sampling information was stored to an EEPROM device and downloaded at intervals determined by storage size and sampling frequency.

Power Management

As with all portable GPS systems, power consumption was the limiting factor when determining sampling frequency and length of operation. Based on the power consumption by the microcontroller (40mW) and GPS receiver (390mW) and sampling frequency, the required battery size could be calculated (Table 1). Any sample interval shorter than 2.5-min would require the receiver to continuously operate at 9.4 Wh/day. As the sample interval is increased, the amount of time the receiver is operational decreases thus decreasing the energy requirement. A 6-hr or longer sample interval would stabilize the power consumption at a minimum of 1Wh/day.

Many battery types (alkaline, lithium ion, sealed lead acid, etc.), shapes, and power ratings were examined. Sealed lead-acid (SLA) batteries have the highest power density of sealed rechargeable batteries. The battery chosen to power the GPS HAWK was an SLA0926 Interstate Battery (6V, 7.2Ah). The battery had dimensions of 151 x 34 x 98 mm and weighs 0.82 kg. With the receiver continuously powered, the battery would last approximately 4.5 days sampling at 20-s intervals.

In an attempt to decrease the size and weight of the battery, a seven-day trial was conducted to determine the power output of thin film solar panels (PowerFilm WeatherPro P7.2-75, PowerFilm, Inc., Boone, IA). The thin film solar panel had a dimension of 270mm x 100mm and operating current and voltage of 100mA and 7.2V, respectively. Three solar panels were placed in full sun and voltage monitored across a 10Ω resistor with a 4-channel datalogger (Hobo H8, Onset Computer Corp., Pocasset, MA) at 1-min intervals. The total solar radiation (W/m^2) and average total energy output (Wh) for the solar panels are shown for each day in Table 2. The largest power output (1.01 Wh) occurred on 11-Feb under clear skies. On 13-Feb and 15-Feb, cloudy skies resulted in nearly zero power output. Under clear skies, the thin film panels have the potential to fully recharge the GPS HAWK taking samples equal to or greater than 6 hours. However, our goal was to monitor the animals at higher frequencies and the thin film panels could only recharge the batteries by 10% under clear skies. Though these daily power outputs may increase due to longer days in summer, this 7-d study showed the potential variability in the power output. This study did not consider the reduced output due to the thin film getting covered in dust or mud. The panels were not included in the final design due to these limitations.

Housing and Harness

Several methods of securing the unit on the animal were considered: halter, collar, and shoulder mounted. The GPS HAWK was arranged into a shoulder mounted harness largely due to the battery weight. The battery and circuitry were housed in a 16 x 16 x 7 cm weather-proof aluminum enclosure (HMD604-ND, Digikey Corp., Thief River Falls, MN). The enclosure was fastened to a 0.64 x 12.7 x 43.2 cm leather blank. Two 0.64 x 3.8 cm slots were cut at both ends to securely attach straps. A custom foam pad was constructed of two 6 mm layers of black neoprene glued on top and bottom of a 1.27cm polyethylene foam blank. An adjustable 5.1 x 143.3 cm nylon webbing strap attached to an 11 x 91 cm felt cinch encircled the animal's girth while 3.8 cm elastic webbing was placed down both sides of the neck and attached to the cinch strap between the legs to provide stability to the GPS HAWK. The unit was positioned on the back of the animal just behind the shoulders (fig. 4). Each shoulder-webbing was attached between the front leg and the brisket using two D-rings centered 12.7 cm off center of the cinch strap. The GPS HAWK weighed 3.37 kg including all straps and padding.

Experimental Pasture for the Study

A 12.1 ha Bromegrass pasture was located along Willow Creek at the Iowa State University Rhodes Research Farm (fig. 5). The pasture ran North and South with approximately 133 m of stream access. Drinking water was provided to the animals through open access to the Willow Creek and supplemental water tanks.

Environmental Parameters Monitored

Environmental parameters, including dry-bulb temperature, dew point temperature, solar radiation and wind speed, were measured at 5-min intervals with a commercially available weather station (Onset Corporation, Bourne, MA). Black globe temperature was measured using a temperature probe (PT916, Pace Scientific, Mooresville, NC) centered in a 15-cm copper globe painted flat black and recorded at 5-min intervals with a data logger (XR440, Pace Scientific, Mooresville, NC). Black globe humidity index (BGHI) values were calculated using the equation by Buffington et al. (1981), of the form:

$$BGHI = T_{bg} + 0.36 \times T_{dp} + 41.5$$

Where T_{bg} = black globe temperature (˚C)

T_{dp} = dew point temperature (˚C)

Experimental Cattle Monitored

Fifteen fall-calving Angus cows were fitted with a GPS HAWK unit. The GPS HAWK units were set to intensively monitor the animal locations at 20-s intervals for three 4-day periods during June and July of 2006. The animals were returned to the pasture and allowed to settle on day 1.

Concurrent visual observations of the animals were conducted at 1-min intervals for 11 consecutive (daytime) hours on days 2 and 3 of each period. The observer followed the herd of animals maintaining a distance of no less than 20 m; the observer had minimal effects on observable animal behavior. Large identification numbers (01 through 15) painted on each GPS HAWK unit were used to track each cow. Animal activities monitored included grazing (G), standing (S) and standing in shade (SSH), lying (L) and lying in shade (LSH), and traveling (T). Definitions of the animal activities are as follows.

Grazing (G): Animal actively gathers forage with head near the ground and occasional short walking breaks of distance (D) < 15 m;

Standing (S) and standing in shade (SSH): Animal stands with raised head, may have short movements within a bunch/cluster, either in open pasture or shade;

Lying (L) and lying in shade (LSH): Animal physically lies on ground, either in open pasture or shade; and

Traveling (T): Animal moves (raised head) in a linear fashion over a distance (D) of greater than 15m.

For the purposes of this paper, the lying and standing behaviors were consolidated into resting behavior. GPS HAWKs were removed to retrieve data cards and replace batteries on day 4.

Data Analysis

The GPS data were viewed and processed using a geographical information system (GIS) software package (ArcMap, ESRI, Redlands, CA). The location data were converted from latitude and longitude coordinates (WGS 1984) to the Universal Transverse Mercator (UTM) coordinate system (NAD 1983 UTM zone 15N). Aerial photos with 1-meter resolution were downloaded from the USDA National Agriculture Imagery Program through the Iowa State University Geographic Information Systems Support Facility. The animal location data, fencing, and other attributes were overlaid upon the aerial photos for further analysis.

The daily cumulative travel distance (CTD) from 0:00h to 23:59h for three available animals on 26-Jun, 24-Jul and 25-Jul were calculated using the Euclidean distance between consecutive GPS locations, namely,

$$\text{CTD} = \sum_{i=1}^{n} \sqrt{(Y_{i+1} - Y_i)^2 + (X_{i+1} - X_i)^2}$$

Where: CTD = cumulative travel distance (m)

X_i = x coordinate (UTM) of location i (m)

Y_i = y coordinate (UTM) of location i (m)

The rate of animal locomotion may provide insight into distinguishing behavior. Hence, the rate of animal travel or velocity was computed as the following:

$$V_i = \frac{\sqrt{(Y_{i+1} - Y_i)^2 + (X_{i+1} - X_i)^2}}{(t_{i+1} - t_i)} * 3.6 \text{ (s/m)}$$

Where V_i = Velocity of travel at time I (km/h)

t_i = time (s) of i^{th} monitoring moment

Furthermore, the rate at which the animal changed its velocity, or acceleration of travel, was computed as the following:

$$A_i = \frac{(V_{i+1} - V_i)}{(t_{i+1} - t_i)}$$

Where A_i = Acceleration of travel at time i (km/hr/s)

The PROC GLM procedure (SAS, SAS Institute Inc., Cary, NC) was used to determine differences in CTD between the three cows.

RESULTS AND DISCUSSION

The programmable GPS HAWK was designed and constructed to monitor cattle location at intervals as short as 20 s for less than $500 in materials and approximately 5 hours in labor. Table 4 compares the GPS HAWK to five commercially available GPS collars large enough to fit cattle. The Televilt GPS-Budget collar was the least expensive of the five commercial units but the data could not be differentially corrected to decrease location errors. The four remaining collars cost at least six times that of the GPS HAWK. The high sampling frequency required a larger battery for the GPS HAWK making the unit heavier than the commercial collars.

The 24-hr diurnal locomotion paths of three cows (2375, 8374 and 2280) on 26 June 2006 are illustrated in Figure 6. The animals began the day lying at the south end of the pasture, started grazing and traveled to the north end of pasture before returning south. Looking closer at the three locomotion paths in figure 7, the cows started the morning lying just south-east of the water tank (illustrated with three large red circles). The animals began grazing south of the maintenance road before grazing north, eventually traveled to the stream. The 20-s sampling rate allowed for recording of the meandering paths as the animals grazed. These paths might not have been as apparent in larger sampling intervals (i.e. 10-min sample interval).

Most grazing studies using GPS technologies give estimates of time spent at certain activities (i.e. resting, grazing or traveling) or distance from specified aspects within defined areas over a period. However, you get little sense of the distances covered during the period of a day. Figure 8 depicts the daily CTD for the three cows on 26-Jun, 24-Jul and 25-Jul 2006, respectively. The concomitant BGHI profiles are included to demonstrate the variations in the environmental conditions each day. The CTD ranged from a minimum of 3.4 km (cow 2375) on 24-Jul to a maximum of 4.4 km (cow 2280) on 26-Jun. There was no difference in CTD among the three cows over the three days (Table 4).

The locomotion behavior, starting from the south and moving north, of cow 8374 over a 6-hr period is illustrated in Figure 9. Figure 10 shows the cow's velocity (km/h), CTD (km), and visual observations of the activities for the same 6 hr period. Figure 11 illustrates the acceleration (km/h/s) of cow 8374 and the corresponding visual observation of activity during the period. The resting behavior is clearly distinguishable with velocity and aceleration being near zero. The magnitude of velocity was higher for traveling than for grazing.

Though not the focus of this paper or study, locomotion behavior data of this nature could prove useful to efficient pasture management (e.g., time of rotation as deemed necessary from increased CTD) or timely assessment/identification of herd health (e.g., unusually small CTD).

SUMMARY AND CONCLUSIONS

- A low-cost GPS HAWK was developed to monitor locomotion behavior of cattle at high frequency (20-s sample interval).
- The 20-s sampling data by the GPS HAWK were used to delineate grazing behavior of cattle on pasture, including daily cumulative travel distance, travel velocity and travel acceleration.

- Behavior data of this nature could be useful to efficient pasture management and timely assessment of herd health/well-being.

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REFERENCES

Agouridis, C.T., D.R. Edwards, S.R. Workman, J.R. Bicudo, B.K. Koostra, E.S. Vanzant, J.L. Taraba. 2005. Streambank erosion associated with grazing practices in the humid region. Trans. ASABE 48(1): 181-190.

Buffington, D.E., A. Collazo-Arocho, G.H. Canton, D. Pitt. 1981. Black globe humidity index (BGHI) as comfort equation for dairy cows. Trans. ASABE 24(3): 711-714.

Garmin International, Inc. 2004. GPS 18 Technical Specifications. Olathe, KS. Garmin International, Inc. Available at: www.garmin.com/manuals/GPS18_TechnicalSpecification.pdf. Accessed 15 November 2004.

Moen, R., J. Pastor, Y. Cohen, C.C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. J. Wildl. Manage. 60:659-668.

Rutter, S.M., N.A. Beresford, and G. Roberts. 1997. Use of GPS to identify the grazing areas of hill sheep. Computers and Electronics in Ag. 17:177-188.

Schlecht, E., C. Hulsebusch, F. Mahler and K. Becker. 2004. The use of differentially corrected global positioning system to monitor activities of cattle at pasture. J. Applied Animal Behaviour Sci. 85:185-202.

Turner, L.W., M.C. Udal, B.T. Larson, and S.A. Shearer. 2000. Monitoring cattle behavior and pasture use with GPS and GIS. Can. J. Anim. Sci. 80(3) 405-413.

Udal, M.C. 1998. GPS tracking of cattle on pasture. M.S. Thesis, University of Kentucky, Lexington, Kentucky. December.

Ungar, E.D., Z. Henkin, M. Gutman, A. Dolev, A. Genizi, D. Ganskopp. 2005. Inference of animal activity from GPS collar data on free-ranging cattle. J. Rangeland Ecol. Manage. 58: 256-266.

Table 1: Calculated power consumption for a given sample interval.

Sample Interval (Min)	Receiver Operation Time (%)	Power Consumption (Wh/day)
≤ 2.5	100	9.4
5	50	5.2
10	25	3.1
30	8.3	1.7
60	4.2	1.3
360	0.7	1.0
720	0.3	1.0
1440	0.2	1.0

Table 2: PowerFilm solar panel power output for 7-d period.

Day	Total Solar Radiation W/m^2	Total Panel Output Wh	SE Wh
11-Feb-05	3674	1.01	0.04
12-Feb-05	2312	0.28	0.01
13-Feb-05	305	1.81E-03	5.36E-05
14-Feb-05	3241	0.67	0.03
15-Feb-05	954	1.10E-02	3.78E-04
16-Feb-05	3809	0.76	0.03
17-Feb-05	3592	0.61	0.02
	Total	3.34	

Table 3: Comparison of GPS HAWK with commercially available GPS systems.

Company/Institution	Product Name	Weight (g)	DGPS	Unit Price (US$)	Software
Iowa State University *(USA)*	GPS HAWK	3371	WAAS	$ 500	--
Advanced Telemetry Systems *(USA)*	ATS GPS	1250	Post-Process	$3,000	included
BlueSky Telemetry *(Scotland)*	AgTraX-L6	470	Post-Process	$3,000	included
Lotek Wireless, Inc. *(Canada)*	GPS 3300	870	Post-Process	$3,600	$2,500
Telonics *(USA)*	TGW-3570	850	Post-Process	$3,000	$ 350
Televilt *(Sweden)*	GPS-Budget	650	GPS	$1,100	$ 60

Table 4: Cumulative travel distance for three cows over four days.

Cow No.	26-Jun km	24-Jul km	25-Jul km	Average km	SE km
8374	4.361	3.430	3.827	3.873	0.234
2375	4.397	3.676	3.933	4.002	0.183
2280	4.388	3.419	4.220	4.009	0.259
Average	4.382	3.508	3.993		

SE = Standard error

Figure 1: The GPS Herd Activity and Well-being Kit (HAWK) unit developed and used for the study.

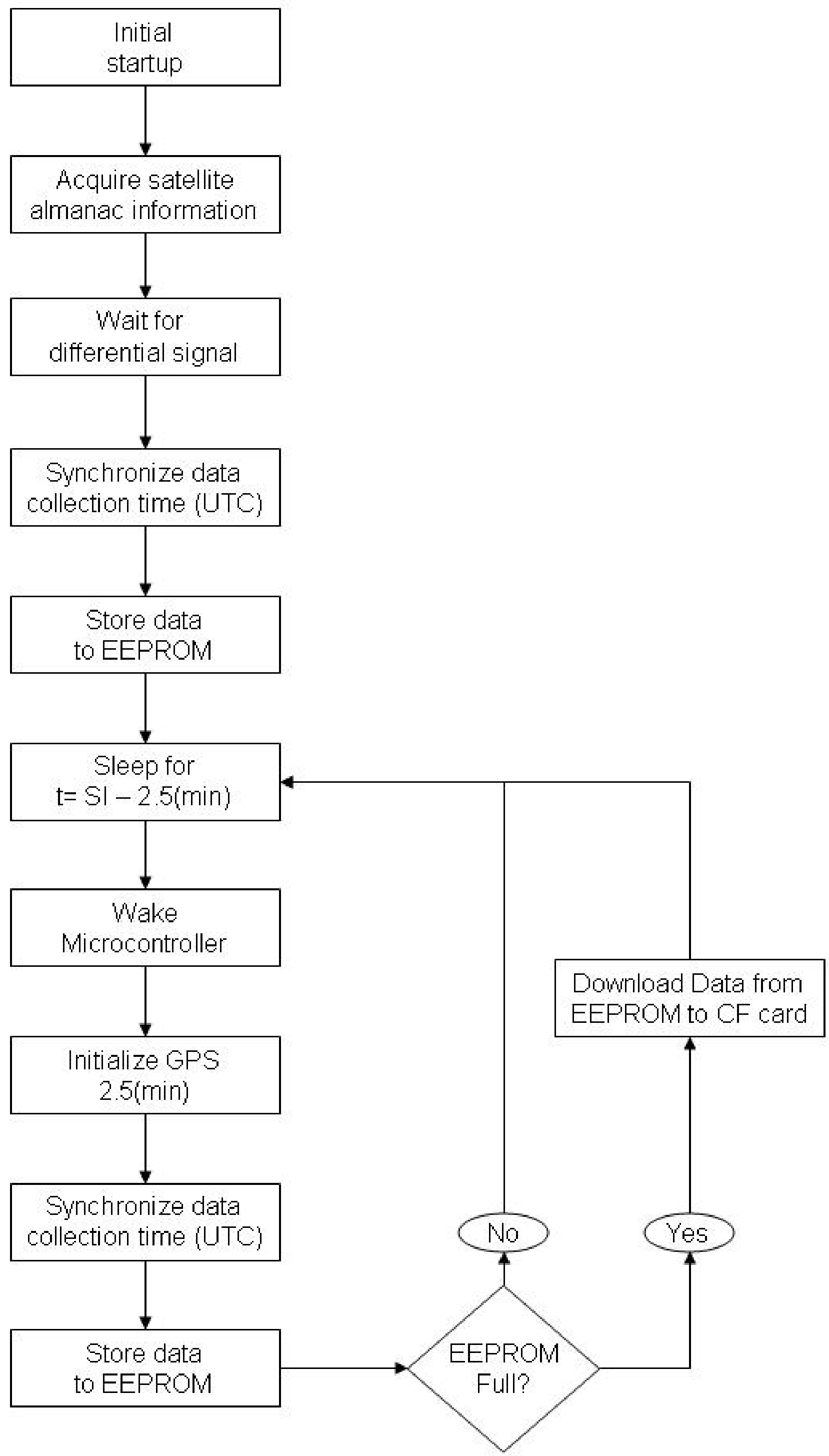

Figure 2: Flowchart of the GPS HAWK operation.

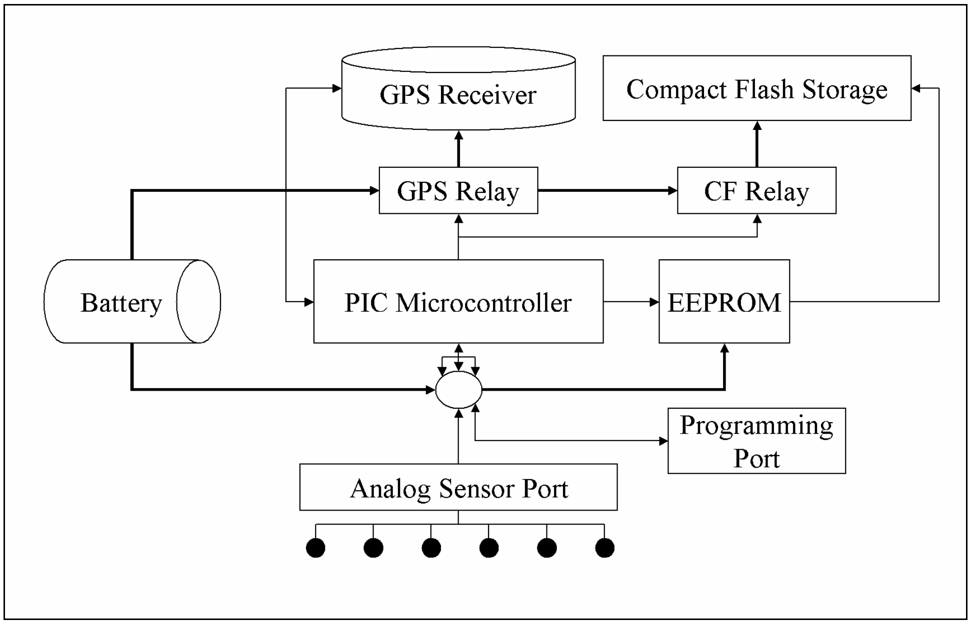

Figure 3: GPS HAWK hardware schematic.

Figure 4: An Angus cow grazing in Bromegrass pasture fitted with a GPS HAWK unit.

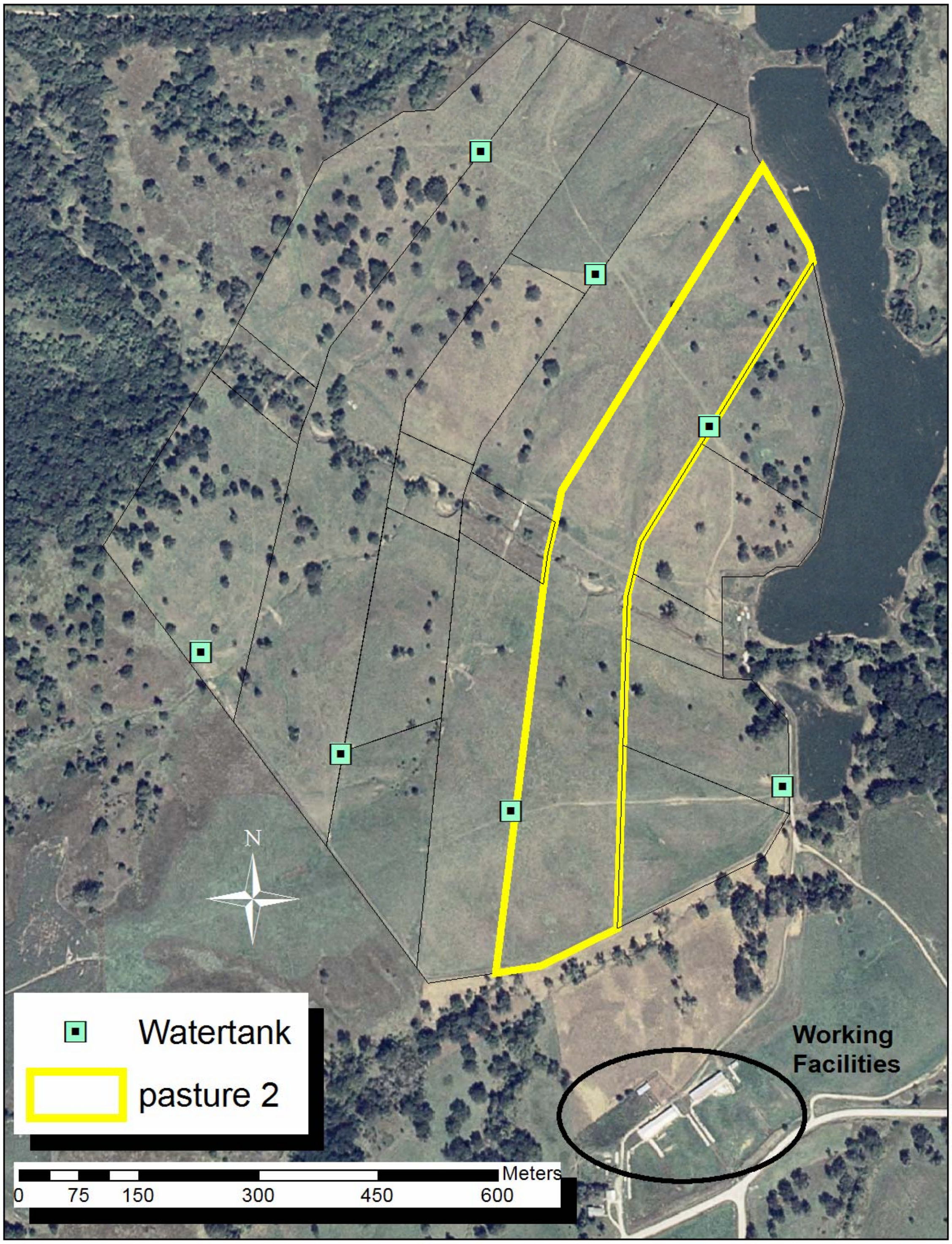

Figure 5: The cow herd was held in the highlighted pasture (12.1 ha) of the ISU Rhodes Research Farm, Rhodes, Iowa.

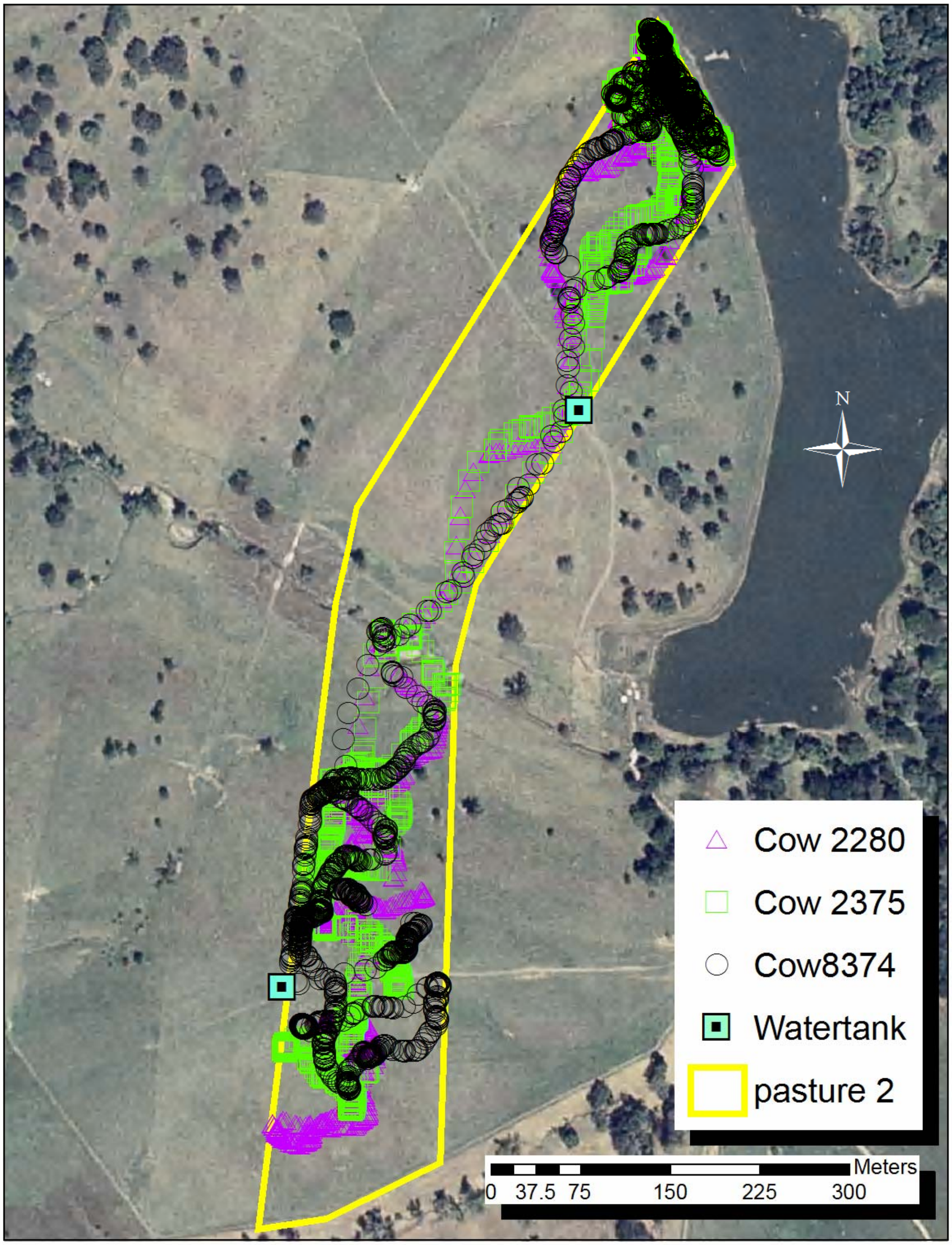

Figure 6: Location profiles of three cows over a 24-hr period on 26-Jun 2006 as measured with the GPS HAWK unit.

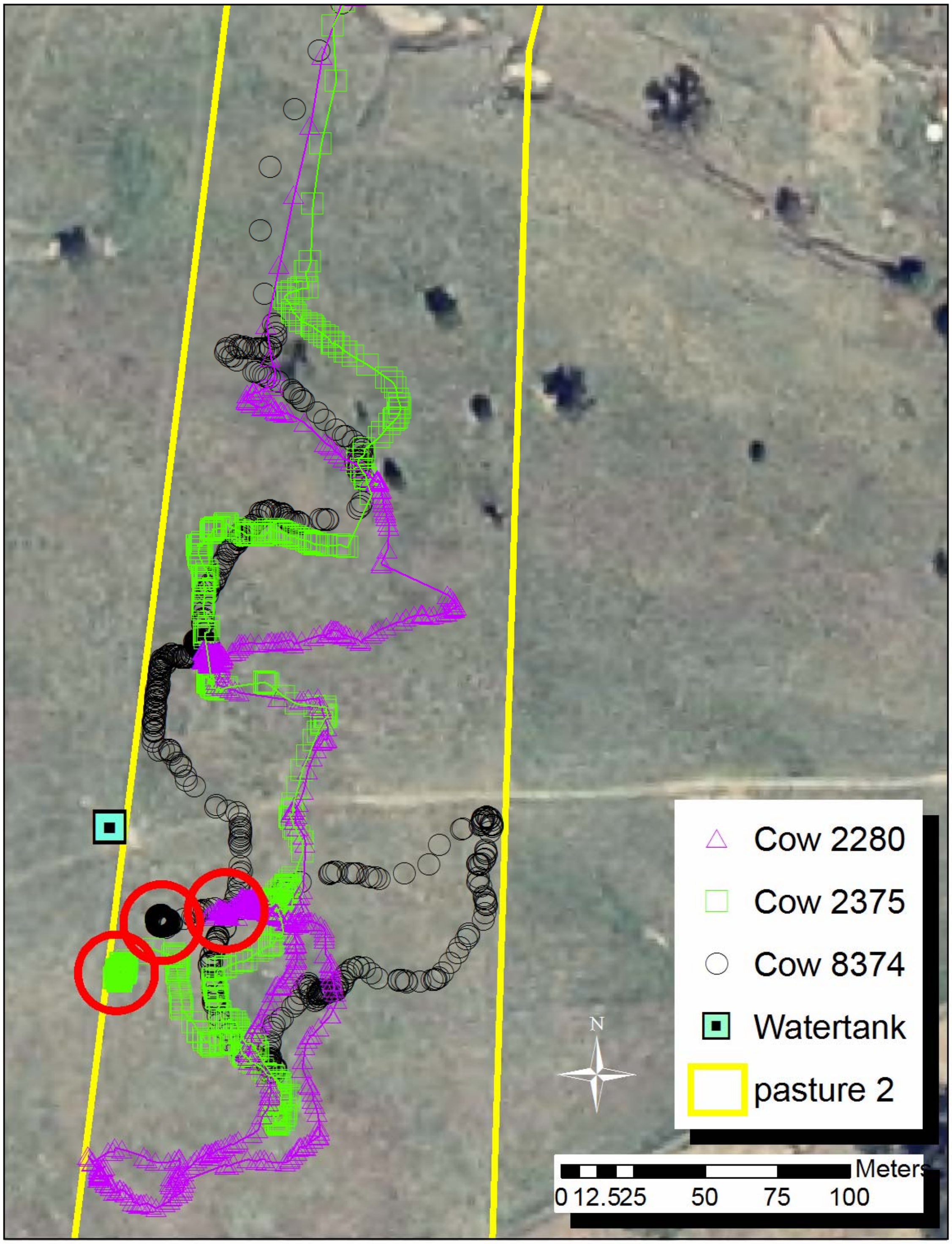

Figure 7: Location profiles during the morning of 26-Jun. The large red circles indicate where the three cows were lying at the beginning of the day.

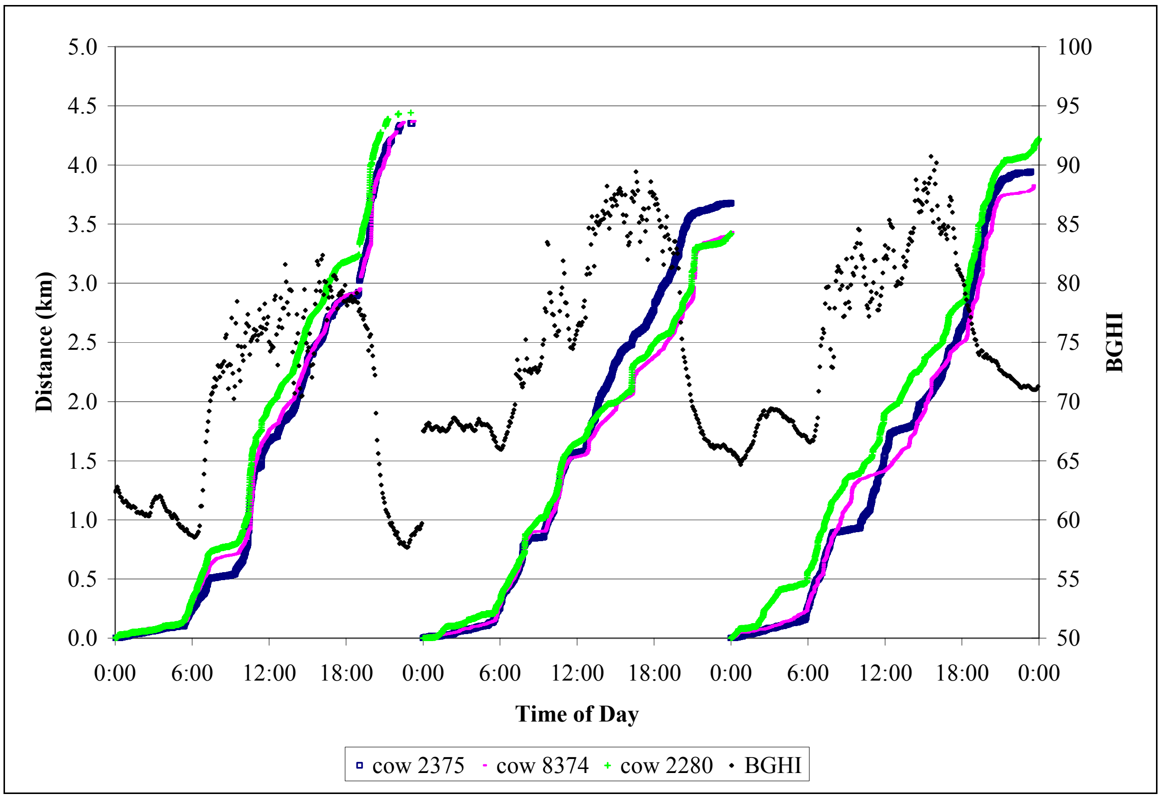

Figure 8: Cumulative travel distance (m) of three cows on 26 June 2006, 24 July 2006 and 25 July 2006, respectively. BGHI was calculated from environmental parameters at 5-min intervals.

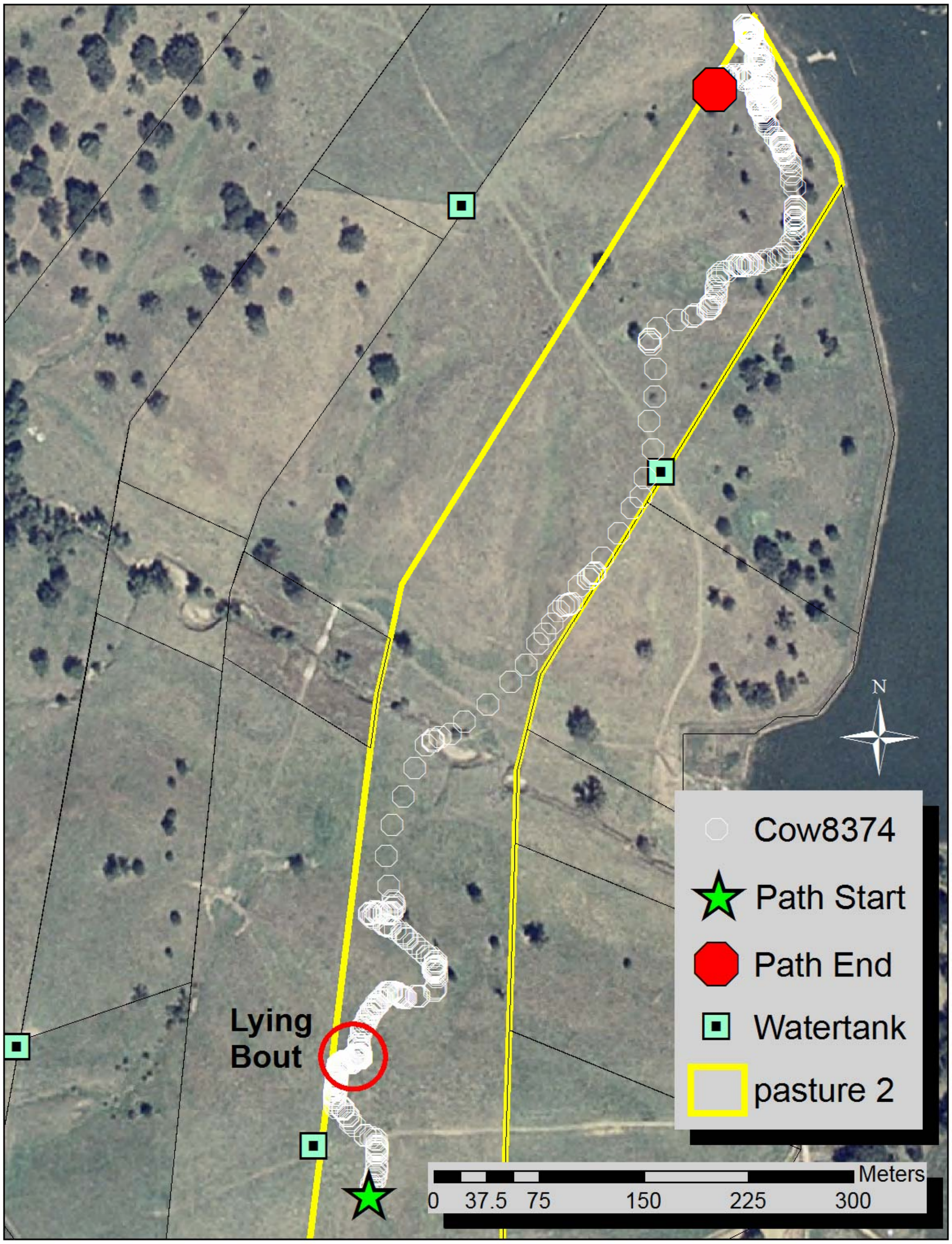

Figure 9: Aerial view of Cow 8374 on 26-Jun traveling from the south (path start) at 07:00h to the north until 13:00h (path end).

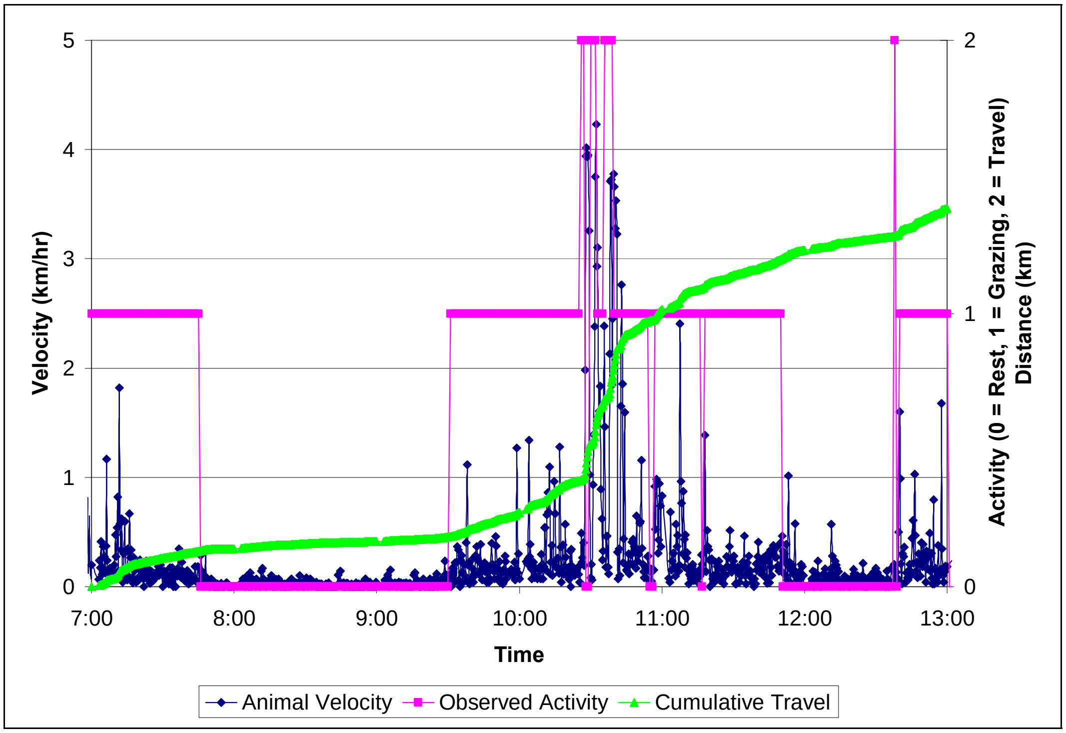

Figure 10: Cow 8374 velocity profile over 6-hr on 26-Jun-06 with associated visual observations.

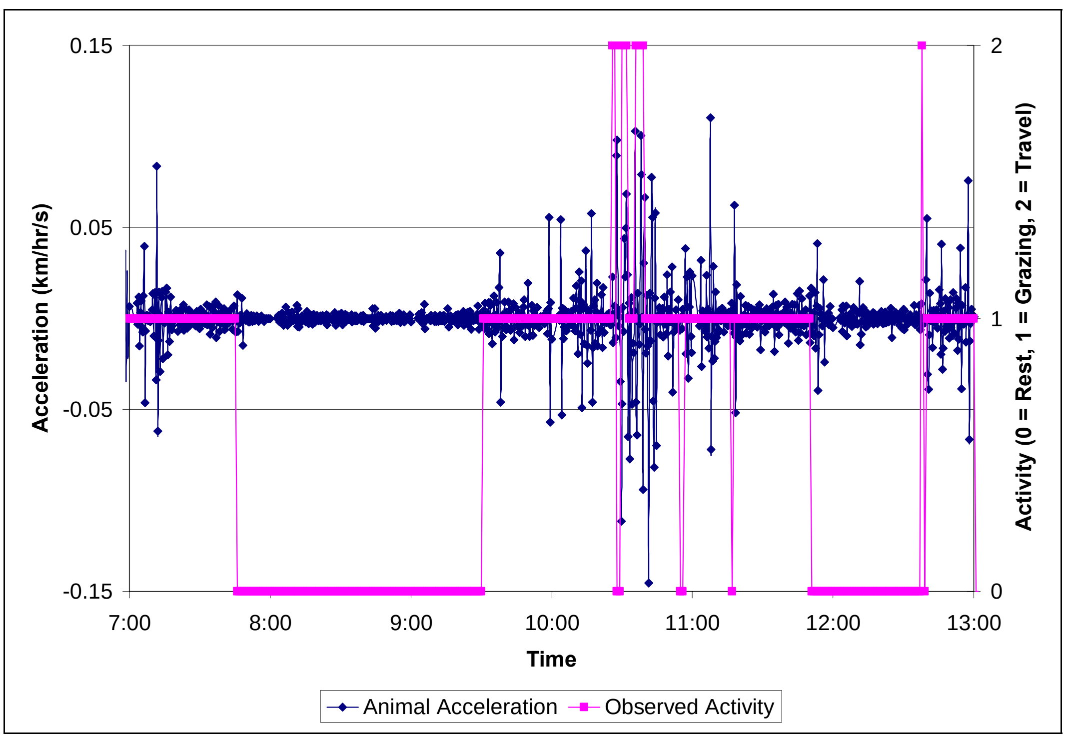

Figure 11: Cow 8374 acceleration profile over 6-hr on 26-Jun-06 with associated visual observations.

CHAPTER 3. GPS-BASED CHARACTERIZATION OF CATTLE GRAZING BEHAVIORS AND EFFECTS OF ANIMAL SAMPLE SIZE AND SAMPLE INTERVAL ON THE MEASUREMENT

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ABSTRACT

Locomotion behavior of cattle on pasture was characterized with the aid of a newly developed GPS monitoring unit. Use of one animal to represent herd behavior and the effect of GPS sampling rate on the characterization of the animal locomotion behavior were assessed. Though the percentage of time spent at each activity varied over days, cows spent 33.2%, 25.5%, 40.4% and 0.9% of four 8-hr observation periods on lying (L), standing (S), grazing (G) and traveling (T), respectively. Cows within the herd in this study spent 56.7% of the time performing the same activity simultaneously; however, mean daily duration for each activity was similar for cows. Use of a cow location vector (CLV) provided a simplistic method to illustrate the dynamic locomotive behavior of cows over time. The CLV provided a visual means to discern grouping of cows based on locomotion. Though differences in location occurred due to sub-grouping of cows throughout each day, the cumulative distances traveled were similar across cows. Therefore, monitoring a single cow will suffice in the quantification of average time spent at activities of L, S, G and T and cumulative travel distance (CTD). However, a single animal would not be not sufficient to illustrate dynamics in herd location. The GPS location sample interval (SI) had an effect on CTD. By changing the SI from 20 s to 20 min, the mean CTD decreased by 1.68 km or 44% of the reference value.

Keywords: animal behavior, tracking, monitoring

INTRODUCTION

Researchers began remotely tracking wildlife over 30 years ago using radio telemetry and triangulation. Initially, the large distance errors (>30m) associated with the telemetry systems were acceptable because animals such as moose or wolves travel large distances over an expansive territory. The advent of tracking via global positioning systems (GPS) and the recent use of differential GPS (DGPS) enabled more precise tracking through much improved accuracy (less than 3 meters with some devices) and reliability. These new capabilities offer objective measurements for studying how spatial and temporal distribution of livestock arise due to factors such as forage type, grazing system, landscape, hide color, health status, ambient conditions, and aspect location (water tank, shade, stream).

Many researchers have used GPS to monitor wildlife and livestock movement and behavioral activities (Moen et al., 1996; Rutter et al., 1997; Udal, 1998; Turner et al., 2000; Schlecht et al., 2004; Agouridis et al., 2005; Ungar et al., 2005). Within livestock production, GPS loggers have been utilized to monitor the grazing and lying/standing behavior of domestic sheep (Rutter et al., 1997), to track beef cattle in intensively managed grazing systems (Udal, 1998; Turner et al., 2000) and to study the effectiveness of using distance to distinguish between grazing, traveling and resting activities of beef cattle (Ungar et al., 2005). Agouridis et al. (2005) monitored beef cattle location within several grazing systems to determine their effects on streambank erosion in the humid region of the U.S.

Many of the commercial GPS collars carry a relatively large price tag. To this end, researchers are only able to monitor a small number of animals as a subset of the herd for given activities or treatments (Udal, 1998; Turner et al., 2000; and Agouridis et al., 2005). These data are then extrapolated across the total number of animals in each treatment to determine herd behavior and to develop system requirements. This method relies on the assumption that all animals in the herd traversed the study area in a well-defined grouping. This begs the question of whether one can infer patterns in behavior and movement from 1 or 2 animals and then extrapolate these patterns to a population if the financial constraints do not allow the purchase of many collars (Moen et al., 1996).

Most conventional GPS collars are limited in the minimum sampling interval and maximum data storage capacity and require expensive proprietary software packages to retrieve and process data. In consideration of GPS sample interval, Moen et al. (1996) stated that the concern to the investigator is whether to take fewer precise locations or more less-precise locations. The driving force determining the length of sampling interval and quality of readings (2D fix vs. 3D) in a portable GPS tracking unit is power management. Small sampling intervals and higher quality readings require larger quantities of energy over a given period. This determines the minimum physical size of the unit housing the batteries and length of time a researcher can monitor an animal before the GPS logger has to be removed and batteries changed or charged. Most researchers have used the smallest interval (5-min) commercially available in their studies (Udal, 1998; Turner et al., 2000; Agouridis et al., 2005; and Ungar et al. 2005). However, a 5-min sampling interval may be insufficient to distinguish between specific behaviors based on spatial distance alone.

Objectives of This Study

1. Characterize grazing behaviors of cows on pasture using a newly developed GPS-based Herd Activity and Well-being Kit (HAWK) monitoring system;
2. Evaluate the use of single animal to represent herd behavior; and
3. Evaluate the effect of GPS location sampling rate on quantification of locomotion behavior in cattle.

MATERIALS AND METHODS

This study was conducted as a part of a larger project titled "Quantifying the Role of Riparian Management to Control Non-Point Source Pollution of Pasture and Cropland Streams (E24-2004)". The study site was a 12.1 ha Bromegrass pasture located along the Willow Creek at the Iowa State University Rhodes Research Farm (fig. 1). The pasture was oriented North and South with approximately 133 m of stream access. Drinking water was provided to the animals through open access to the Willow Creek and supplemental water tanks. The water tanks were constructed along ridges north and south of the stream.

Environmental Parameters Monitored

Environmental parameters, including dry-bulb temperature, dew point temperature, solar radiation, and wind speed, were measured at 5-min intervals with a commercially available weather station (Onset Corporation, Bourne, MA[1]) located in the center of the study area. Black globe temperature was measured using a thermistor temperature probe (PT916, Pace Scientific, Mooresville, NC) centered in a 15-cm copper

[1] Mention of product or vendor names is for presentation clarity and does not imply endorsement by the authors or Iowa State University, nor exclusion of other suitable products.

globe painted flat black and recorded at 5-min intervals with a data logger (XR440, Pace Scientific, Mooresville, NC). Black globe humidity index (BGHI) values were calculated using the equation by Buffington et al. (1981), of the form:

$$BGHI = T_{bg} + 0.36 \times T_{dp} + 41.5$$

Where T_{bg} = black globe temperature (˚C)

T_{dp} = dew point temperature (˚C)

Experimental Cattle Monitored

Fifteen fall-calving Angus cows were fitted with a shoulder mounted Global Positioning System Herd Activity and Well-being Kit (GPS HAWK) unit developed as described by Davis et al. (2007) (fig. 2). The GPS HAWKs were set to intensively monitor the animal locations at 20-s intervals for two 72-h periods during June and July of 2006. The GPS HAWK recorded date, time, latitude, longitude, number of satellites used, and quality of reading (i.e. 2D fix or 3D fix). The animals were returned to the pasture and allowed to settle on day 1. Concurrent visual observations of the animals were conducted on days 2 and 3 of each period. On day 4, the GPS HAWKs were removed to retrieve data cards and replace batteries.

Visual Observation

Visual observations were recorded at 1-min intervals for 8 consecutive (daytime) hours (9:00 hr to 16:50 hr) while the observer maintained a distance no less than 20 m from the animal travel path; the observer had minimal effects on observable animal behavior. Large identification numbers (01 through 15) painted on each GPS HAWK unit were used to track each cow. Animal activities monitored included grazing (G), standing (S) and standing in shade (SS), lying (L) and lying in shade (LS), and traveling (T). Definitions of the animal activities are as follows.

Grazing (G): Animal actively gathers forage with head near the ground and occasional short walking breaks of distance (D) < 15 m;

Standing (S) and standing in shade (SS): Animal stands with raised head, may have short movements within a bunch/cluster, either in open pasture or shade;

Lying (L) and lying in shade (LS): Animal physically lies on ground, either in open pasture or shade; and

Traveling (T): Animal moves (raised head) in a linear fashion over a distance (D) of greater than 15m.

GPS Location Calculations

GPS HAWK data were viewed and processed using a geographical information system (GIS) software package (ArcMap, ESRI, Redlands, CA). In order to analysis the data in meter format, the location data were converted from latitude and longitude coordinates (WGS 1984) to the Universal Transverse Mercator (UTM) coordinate system (NAD 1983 UTM zone 15N). Aerial photos with 1-meter resolution were downloaded from the USDA National Agriculture Imagery Program through the Iowa State University Geographic Information Systems Support Facility. The animal location data, fencing, and other attributes were overlaid upon the aerial photos for further analysis.

Cow Location Vector

It is difficult to simplistically illustrate dynamic data such as the changing spatial distribution of a cow herd over time in a two-dimensional plot. Therefore, a cow location vector (CLV) was created to compare the herd centroid and each animal's location to a known fixed point (fig. 3). The herd centroid is defined by:

$$Centroid(X_C, Y_C) = \left(\frac{\sum_1^n X_i}{n}, \frac{\sum_1^n Y_i}{n} \right)$$

Where n = number of animals in herd at time i

X_i = x coordinate (UTM) of the nth cow at time i

Y_i = y coordinate (UTM) of the nth cow at time i

The CLV magnitude (D) is calculated using the Euclidean distance between the herd centroid or animal location and a fixed origin:

$$D = \sqrt{(Y_i - Y_O)^2 + (X_i - X_O)^2}$$

Where D = CLV magnitude (m)

X_O = x-coordinate (UTM) of the origin

Y_O = y-coordinate (UTM) of the origin

The origin was fixed at the southwest corner (482045m Easting, 4637952m Northing) of pasture 2. This origin placement yielded CLV magnitudes between 0 and 1060 m and vector angles (Θ) between 0˚ and 90˚ calculated as:

$$\Theta = \tan^{-1}\left(\frac{Y_i - Y_O}{X_i - X_O} \right)$$

The daily cumulative travel distance (CTD, m) from 0:00h to 23:59h was calculated using the Euclidean distance between consecutive GPS locations, namely,

$$\text{CTD} = \sum_{i=1}^{n-1} \sqrt{(Y_{i+1} - Y_i)^2 + (X_{i+1} - X_i)^2}$$

Subsets of Location Data at Different Sample Intervals

The main dataset collected at 20-s intervals set for each available cow was parsed to create five subsets at sampling intervals of 20, 60, 120, 300, 600 or 1200 s. These subsets were formed to evaluate the effects of SI on delineation of the animal locomotion behaviors.

Data Analysis

One-way analysis of variance (ANOVA) were performed with the PROC GLM procedure (SAS, SAS Institute Inc., Cary, NC) to determine if statistical differences exist in 1) mean time cows spent at each visual observed activity 2) mean CTD for the cows, 3) mean CTD for sample interval.

RESULTS AND DISCUSSION

Visual Observation Analysis

Visual observation data were divided into four categories (i.e. lying, standing, grazing, and traveling). Figure 4 shows the percentage of cows (n = 6) engaged in each activity over the 8-hr observation period on July 24, 2006. Five cows were lying while cow 63 was grazing separately at the beginning of the observation period. From 11:30 to 13:00h all six cows were resting (L or S) as a group, followed by the cows separating into two groups of three cows, with group 1 resting (L and S) and group 2 grazing (G). The percentage of observation time when all the cows were performing the same activity (resting, grazing or traveling) on June 25, June 26, July 24, and July 25 was 61.1%, 68.2%, 50.3% and 47.3%, respectively.

Mean duration (min) of each activity and fraction of the period is summarized for the available animals each day (Table 1). Illustrated in Figure 5, the mean time spent at each activity was variable across days with the least amount of time spent traveling. There were significant differences in least square mean of time spent at each activity, however there were no significant difference among the cows (table 1). The percentage of time during the four observation periods spent resting (L and S), G and T were 58.7%, 40.4% and 0.9%, respectively. In a study by Schlecht et al. (2004), 14 zebu cattle were visually observed at 5-min intervals for 8 hr a day while being tracked with GPS collars on communal pastures in western Niger. During the months of March and June, the percentage of daily time spent resting, grazing and walking on pasture was 27%, 54% and 20%, respectively (Schlecht et al., 2004). In one experiment, Ungar et al. (2005) visually monitored grazing activity at 3-min intervals and GPS location at 20-min intervals for six cows (two each on three 825-859 ha pastures) for a month beginning June 15. The percentage of time spent at resting (S and L), grazing and traveling were 47%, 45% and 6%, respectively (Unger et al., 2005).

Though the grazing times in these two previously reported projects were similar to that in the current study, travel times were significantly greater, presumably due to the larger areas and quality of forage in their grazing systems.

Differences in activity occurred among cows throughout a single day. However, the total time spent on each activity averaged among animals each day was similar.

GPS Location Analysis

Due to equipment failures and units slipping off animals, only eight animals were available for further GPS analysis with a maximum of six animals on July 24. Figure 6 illustrates the 24-hr locomotion of the six cows on July 24. The cows began the day near the southeast corner, then moved about the pasture south of the stream, and ended the day near the southeast corner. Though hard to distinguish individual patterns, most activity occurred along the flat area on top of the south ridge parallel to the water tank. The CLV was applied to each animal's location to delineate the dynamic herd behavior over the day. Figure 7 illustrates the CLV with standard deviation of magnitude and angle for the herd centriod (n = 6) on July 24. From 0:00 to 6:00 h the cows were presumably lying at a distance from each other, as the CLV remained relatively constant. At 6:00 hr, the herd centroid began to oscillate until approximately 11:30 h. In viewing the grazing activities in Figure 4 from 11:30 to 13:00 h, five cows were lying and one cow was standing. The CLV remained unchanged during that period and the standard deviation of CLV illustrated that the animals were close together. From 13:00 to 21:00 h, the activities varied and were reflected by the large standard deviations in the CLV.

Figure 8 comprises six charts illustrating individual CLV magnitude and angle for each cow on July 24. In viewing the animals between 14:00 and 18:00 h, two distinct profiles emerge. Group 1, comprising cows 1330, 2280 and 8374, spent that time standing in the shade or standing in the stream (fig. 8a-c). The CLVs of these animals remained constant during this period. Group 2 comprised of the remaining cows 63, 118 and 2375 grazed the south ridge (fig. 8d-f). While the CLV magnitude of Group 2 remained relatively constant at 100m, the CLV angle of each cow oscillated between 60˚ and 80˚ illustrating that the grazing activity was performed back and forth parallel to the slope. Calculating the CLV to the centroid of Group 1 and Group 2 yields Figures 9 and

10, respectively. During the 17:00 h, the standard deviation of the herd CLV magnitude was reduced from 230m to 4m for both Groups 1 and 2.

To verify the use of CLV, each cow's location is illustrated at six different points in time on July 24. At 0:00 h, the cows were in the southeast corner of the pasture (fig. 11a). At 10:00 h, the group had moved to the top of the south ridge and cow 63 broke from the group to go to the stream (fig. 11b). This cow created the large standard deviations in CLV magnitude (fig. 10) during this time. At 12:00 h, all six cows were lying on top of the south ridge in a tight cluster (fig. 11c). Figure 11d shows Groups 1 and 2 standing under trees and grazing at 14:00 hr, respectively. Group 1 moved to the stream to stand under a tree while Group 2 continued to graze at 17:00 hr (fig. 11e). Finally, at 23:00 h the cows were in one group and had settled at the south end of the pasture in a loose cluster (fig. 11f).

Five animals had data available on July 25. Again, the cows spent the day south of the stream. During an 8-hr period starting at 8:00 h, the five animals split into two groups. Group 1 (cows 63, 2375, and 2280) grazed near the stream while Group 2 (cows 118 and 8374) spent their time grazing and lying near the south water tank.

The CTD for cows with 24-hr GPS location data were compiled into Table 2. Of these, three cows (2280, 2375 and 8374) had four days of data. There was no significant difference in CTD among the three cows (table 3). The daily CTD for the six steers on July 24 is demonstrated in Figure 12. The concomitant BGHI profile is included to demonstrate the variation in environmental conditions over the day. The six cow CTDs ranged from 3.23 to 3.69 km (table 3). Though Group 2 grazed for a much longer duration, the difference in mean CTD for Group 1 (3.36 ± 0.11 km) and Group 2 (3.59 ±

0.16 km) was only 230m. The changes in activity (fig. 4) and location are visible in the slope of each cow's CTD. When the cows were lying at 12:00 h the slope was near zero. The profile of cow 63 was different from the herd at 10:00 h when the cow broke from the group to go to the stream. After splitting into two groups the CTD profiles within group had similar shape.

Though the use of one animal does not always illustrate the dynamic locomotion of the herd during each day, a single randomly selected healthy cow would be expected to provide an estimate of total distance traveled (CTD) representative of all cows in the herd.

Effects of Sample Interval (SI)

Using the main CTD data of available animals in Table 2, five subsets were created by parsing the 20-s data at SI of 60, 120, 300, 600 or 1200 s. Figure 13 illustrates differences in CTD due to SI for cow 8374 on June 25, 2006. As the SI increased, the CTD decreased. In viewing the visually observed activity, the periods of traveling and grazing were most affected by SI. The mean CTD for each SI and percent difference of each SI to the reference 20-s SI were compiled in Figure 14. The mean CTD for each SI is presented in Table 4. Changing the SI from 20 s to 20 min led to a reduction of CTD by 1.68 km or 44% of the reference value. Significant differences in CTD were detected for all SIs ($p < 0.05$) except for between SI of 60 and 120 s.

SUMMARY AND CONCLUSIONS

Locomotion behavior of cattle on pasture was delineated with the aid of a newly developed GPS monitoring unit. Use of one animal to represent herd behavior and the effect of GPS sampling rate on the characterization of the animal locomotion behavior were assessed. The following conclusions were drawn:

- Though the percentage of time spent at each activity varied over days, cows spent 33.2%, 25.5%, 40.4% and 0.9% of four 8-hr observation periods on lying (L), standing (S), grazing (G) and traveling (T), respectively.
- Cows within the herd in this study spent 56.7% of the time performing the same activity simultaneously; however, mean daily duration for each activity was similar for cows.
- Use of a cow location vector (CLV) provided a simplistic method to illustrate the dynamic locomotive behavior of cows over time. The CLV provided a visual means to discern grouping of cows based on locomotion.
- Though differences in location occurred due to sub-grouping of cows throughout each day, the cumulative distances traveled were similar across cows. Therefore, monitoring a single cow will suffice in the quantification of average time spent at activities of L, S, G and T and cumulative travel distance (CTD). However, a single animal would not be not sufficient to illustrate dynamics in herd location.
- Sample rate has an effect on CTD. By changing the GPS location sampling rate from 20 s to 20 min, the mean CTD decreased by 1.68 km or 44% of the reference value.

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REFERENCES

Agouridis, C.T., D.R. Edwards, S.R. Workman, J.R. Bicudo, B.K. Koostra, E.S. Vanzant, J.L. Taraba. 2005. Streambank erosion associated with grazing practices in the humid region. Trans. ASABE 48(1): 181-190.

Buffington, D.E., A. Collazo-Arocho, G.H. Canton, D. Pitt. 1981. Black globe humidity index (BGHI) as comfort equation for dairy cows. Trans. ASABE 24(3): 711-714.

Davis, J.D., M.J. Darr, H. Xin, J.D. Harmon. 2007. Development and use of GPS herd activity and well-being kit (GPS HAWK) to monitor cattle behavior on pasture. Transactions of ASAE (submitted).

Moen, R., J. Pastor, Y. Cohen, C.C. Schwartz. 1996. Effects of moose movement and habitat use on GPS collar performance. J. Wildl. Manage. 60:659-668.

Rutter, S.M., N.A. Beresford, and G. Roberts. 1997. Use of GPS to identify the grazing areas of hill sheep. Computers and Electronics in Ag. 17:177-188.

Schlecht, E., C. Hulsebusch, F. Mahler and K. Becker. 2004. The use of differentially corrected global positioning system to monitor activities of cattle at pasture. J. Applied Animal Behaviour Sci. 85:185-202.

Turner, L.W., M.C. Udal, B.T. Larson, and S.A. Shearer. 2000. Monitoring cattle behavior and pasture use with GPS and GIS. Can. J. Anim. Sci. 80(3) 405-413.

Udal, M.C. 1998. GPS tracking of cattle on pasture. M.S. Thesis, University of Kentucky, Lexington, Kentucky. December.

Ungar, E.D., Z. Henkin, M. Gutman, A. Dolev, A. Genizi, D. Ganskopp. 2005. Inference of animal activity from GPS collar data on free-ranging cattle. J. Rangeland Ecol. Manage. 58: 256-266.

Table 4: Time spent at grazing activity for available cows over four days as determined by visual observation.

Day	Cows (n)	Activity	Duration Mean (min)	Duration SE	Fraction of Period (%)	BGHI Mean	BGHI SE
25-Jun*	6	Lying	234.7	11.9	56.7	67	0.6
		Standing	49.1	7.2	11.9		
		Grazing	123.7	13.2	29.9		
		Traveling	6.5	1.1	1.6		
		Total	414				
26-Jun	4	Lying	44.3	10.0	9.4	68	0.7
		Standing	162.2	11.6	34.4		
		Grazing	255.2	15.0	54.2		
		Traveling	9.3	0.5	2.0		
		Total	471				
24-Jul	6	Lying	195.8	26.0	41.6	73	0.5
		Standing	82.3	16.0	17.5		
		Grazing	192.1	26.3	40.8		
		Traveling	0.8	0.5	0.2		
		Total	471				
25-Jul	5	Lying	82.4	16.4	17.5	74	0.5
		Standing	198.8	26.8	42.3		
		Grazing	189.2	16.0	40.3		
		Traveling	0.6	0.4	0.1		
		Total	471				
Total	21	Lying	147.0[ab]	19.2	33.2	71	0.3
		Standing	121.7[b]	15.6	25.5		
		Grazing	184.0[a]	13.5	40.4		
		Traveling	4.0[c]	1.6	0.9		

*Rain delay from 13:45 to 14:43.
[a,b,c]Denote significant difference ($p < 0.05$).
BGHI = black globe humidity index

Table 2: Mean cumulative travel distance (CTD) for animals with full 24-hr data. Missing data resulted from faulty units are units falling off animals.

Cow No.	25-Jun km	26-Jun km	24-Jul km	25-Jul km
63	-	-	3.69	4.00
118	-	-	3.41	3.60
1136	4.18	4.24	-	-
1330	-	-	3.23	-
2280	5.15	4.39	3.42	4.22
2375	5.34	4.40	3.68	3.93
8374	4.16	4.36	3.43	3.83

Table 3: Comparison of mean cumulative travel distance (CTD) for three cows.

Cow No.	Mean CTD km	SEM km
2280	3.352	0.156
2375	3.326	0.156
8374	2.919	0.156

Table 4: Mean CTD for SI.

Sample Interval sec	Mean CTD km	SEM Km
20	3.82[a]	0.09
60	3.35[b]	0.09
120	3.11[b]	0.09
300	2.78[c]	0.09
600	2.47[d]	0.09
1200	2.14[e]	0.09

[a,b,c] Denotes significant difference ($P < 0.05$).

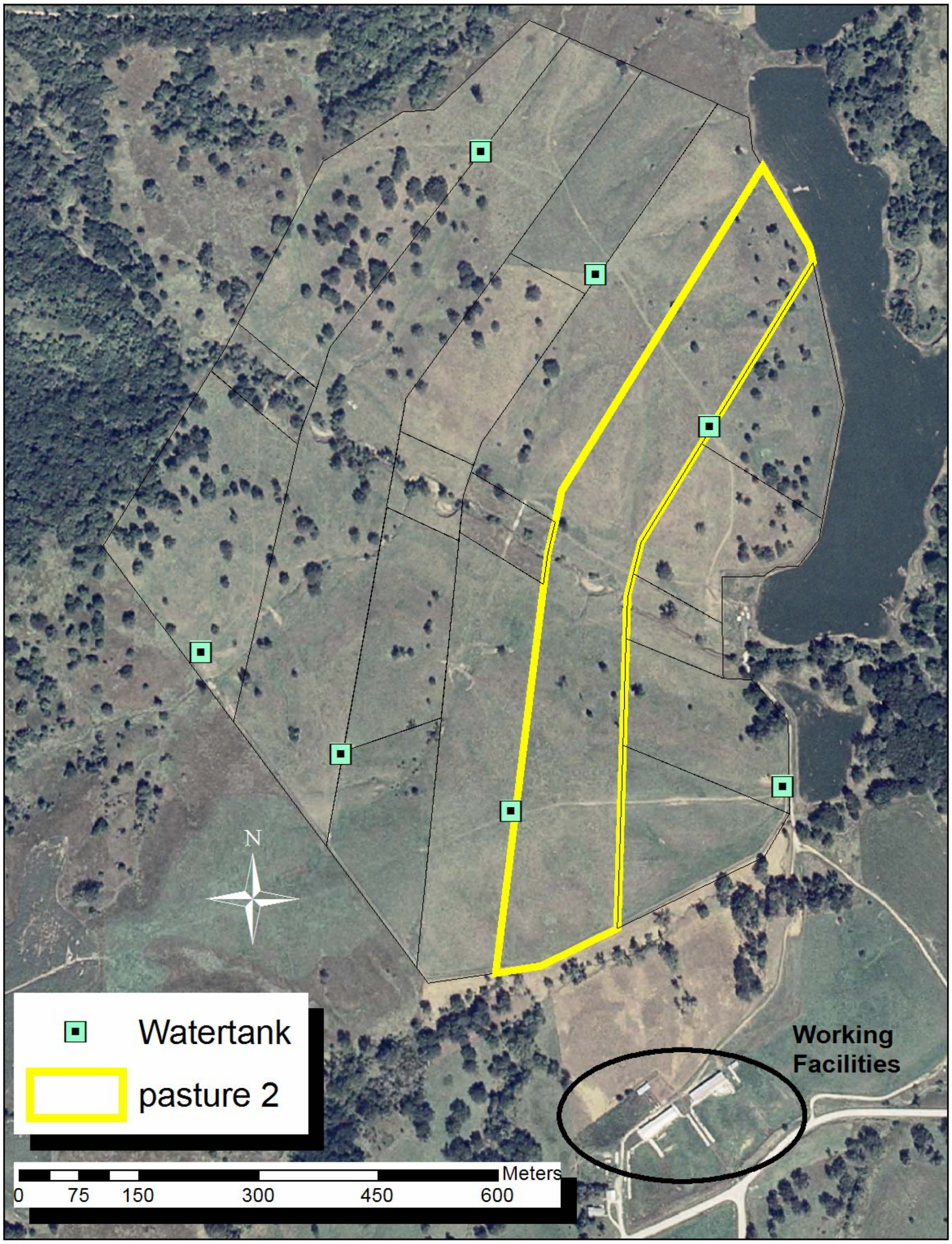


Figure 1: Experimental layout of the ISU Rhodes Research Farm, Rhodes, Iowa, showing a 12.1 ha pasture oriented North and South perpendicular to the Willow Creek.

Figure 2: Fifteen Angus cows grazing in a Bromegrass pasture fitted with GPS HAWKs.

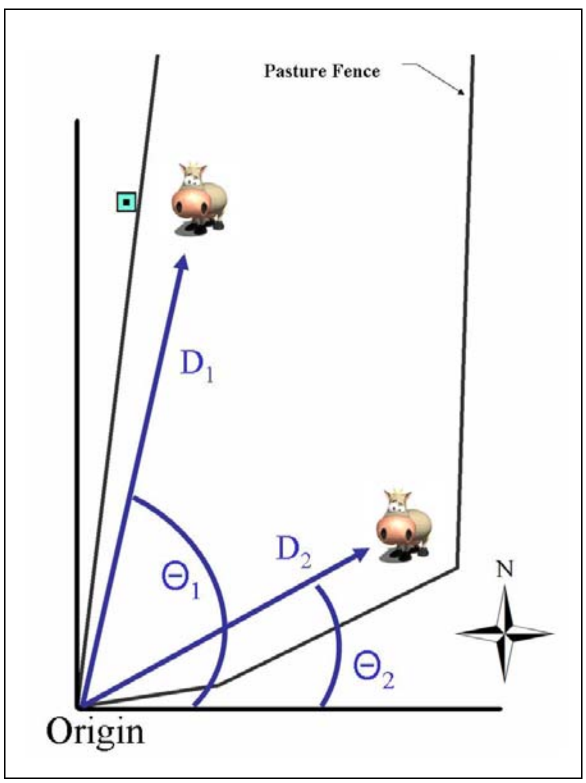


Figure 3: Schematic illustration of two cow location vectors (CLV) with variables of magnitude (D_i) and angle (Θ_i) for each cow.

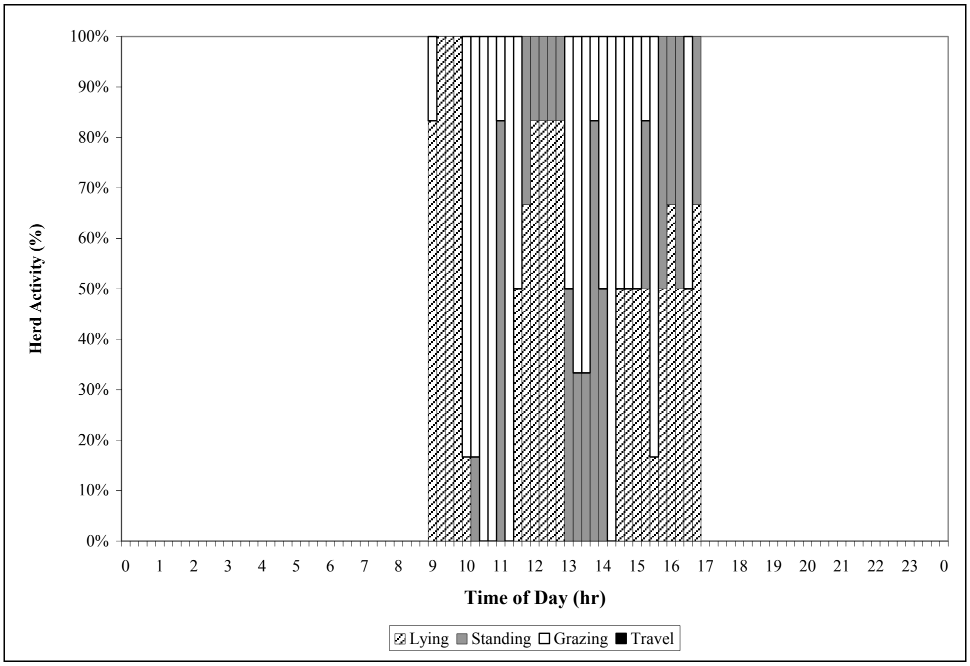


Figure 4: Percentage of animals (n=6) at each activity over 8-hr observation period beginning at 7:30 h on July 24, 2006.

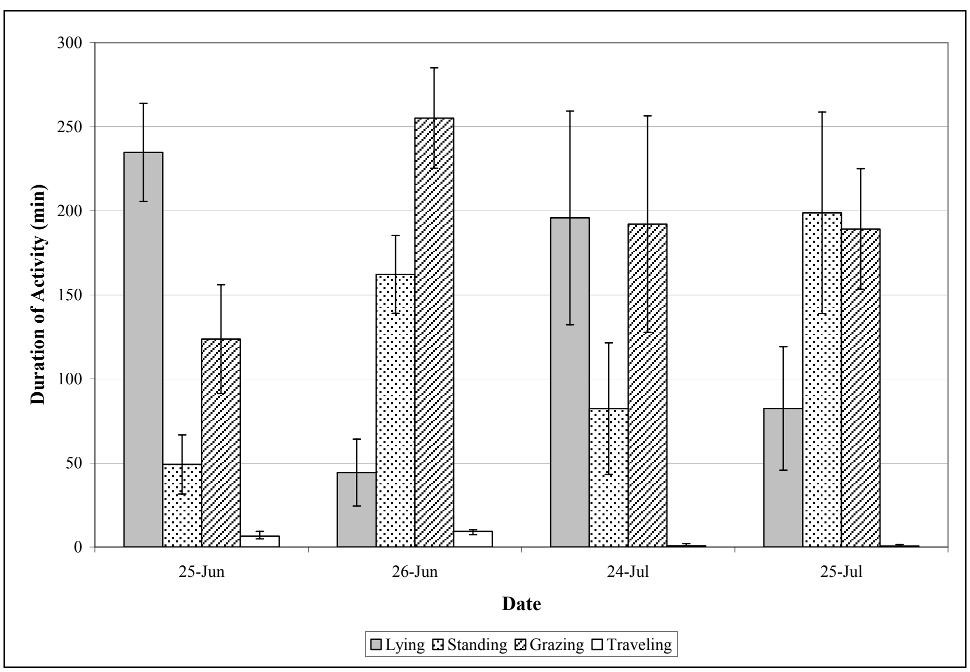


Figure 5: Mean duration that six cows spent at each activity on pasture over four days.

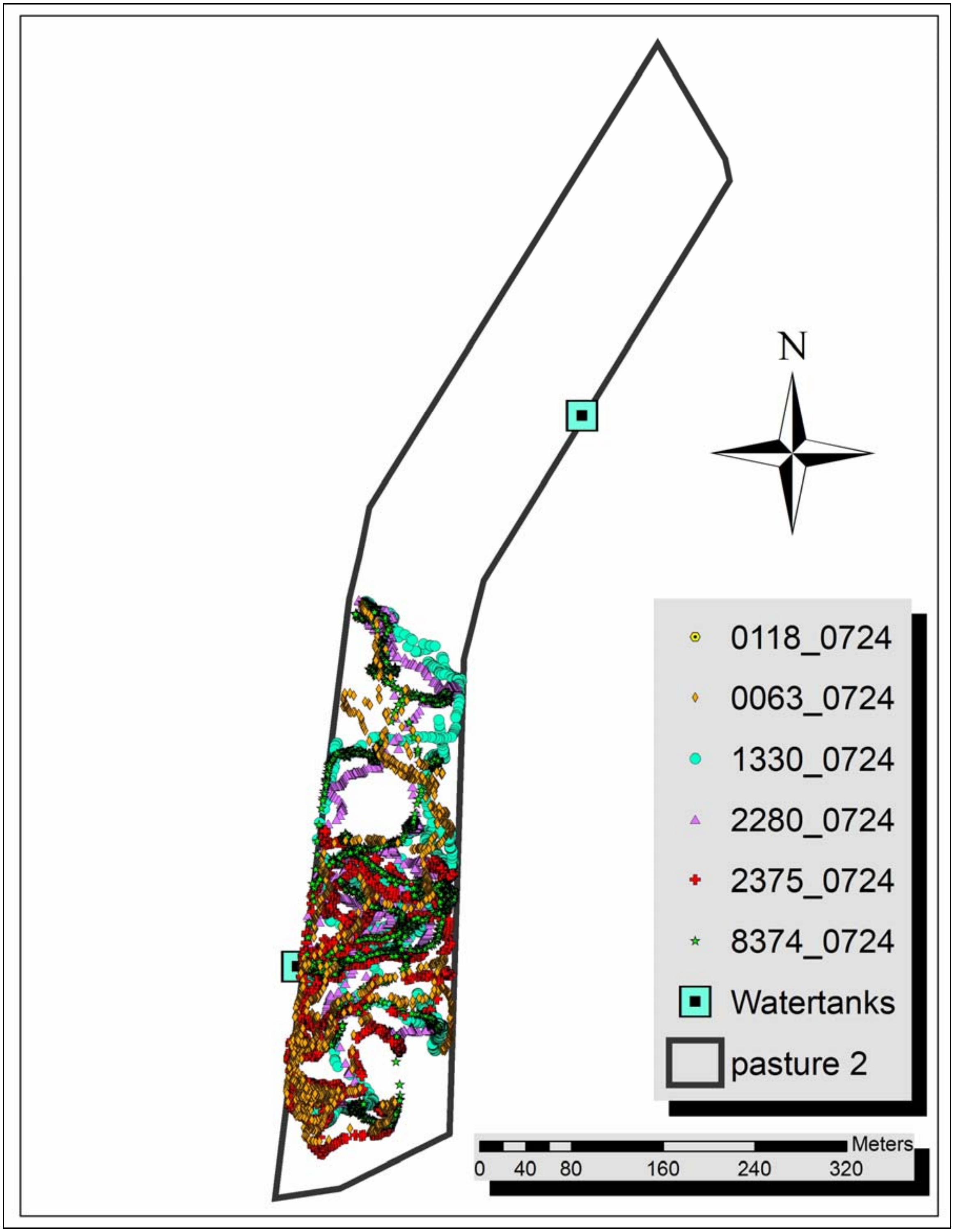


Figure 6: Illustration of 24-hr locomotion profiles for six cows on July 24, 2006.

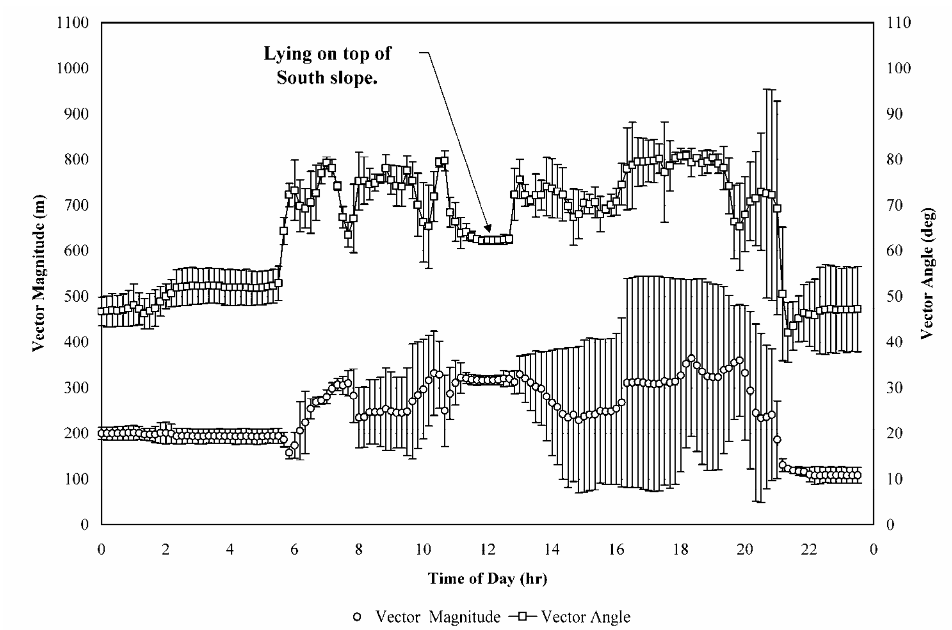
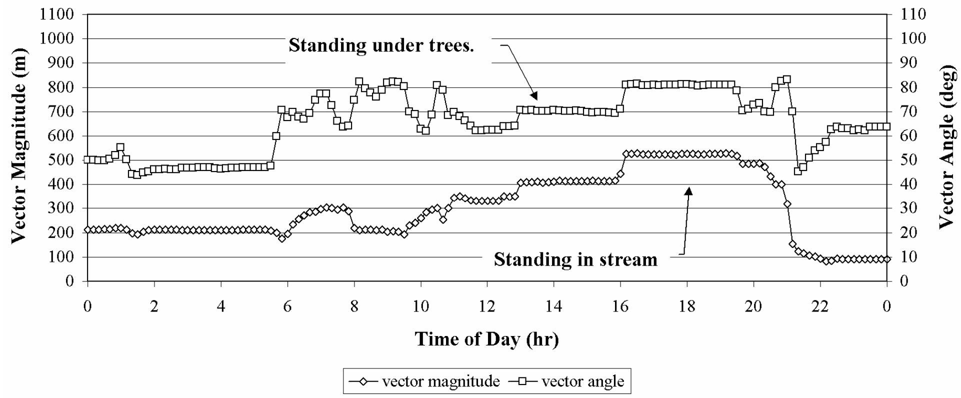
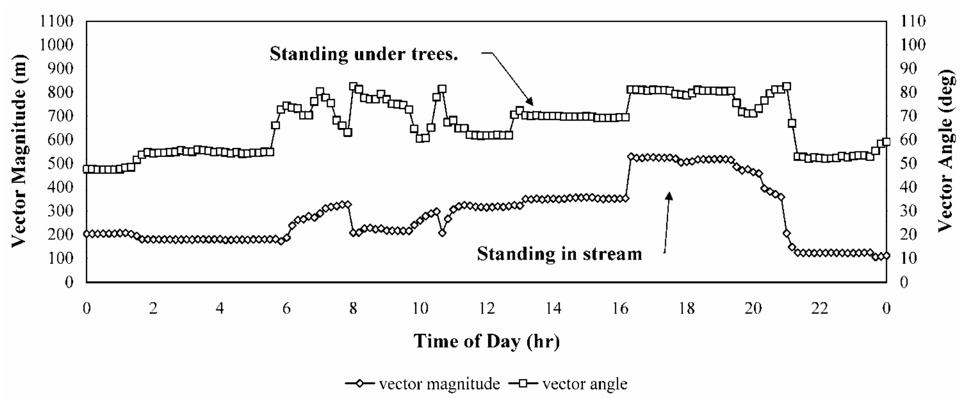


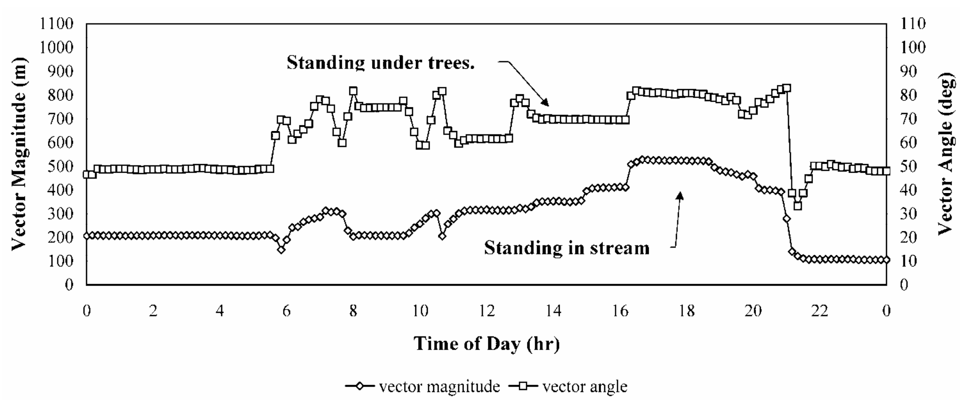
Figure 7: Magnitude and angle of cow location vector (CLV) for the six-animal herd on July 24, 2006 (vertical bars are standard deviations).


Standing under trees.
Standing in stream
Vector Magnitude (m)
Vector Angle (deg)
Time of Day (hr)
vector magnitude
vector angle

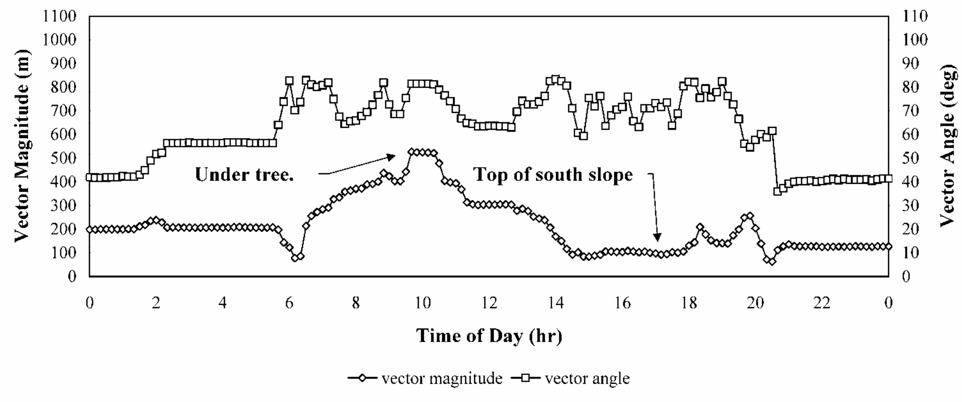
(a)


Standing under trees.
Standing in stream
Vector Magnitude (m)
Vector Angle (deg)
Time of Day (hr)
vector magnitude
vector angle

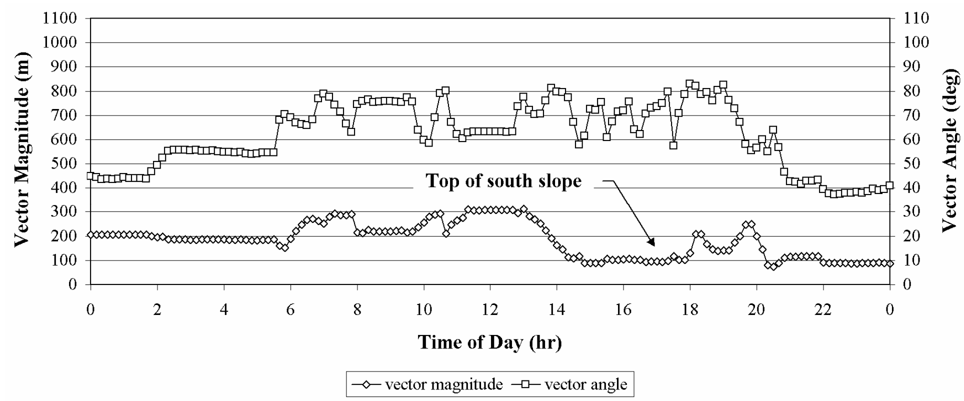
(b)


Standing under trees.
Standing in stream
Vector Magnitude (m)
Vector Angle (deg)
Time of Day (hr)
vector magnitude
vector angle

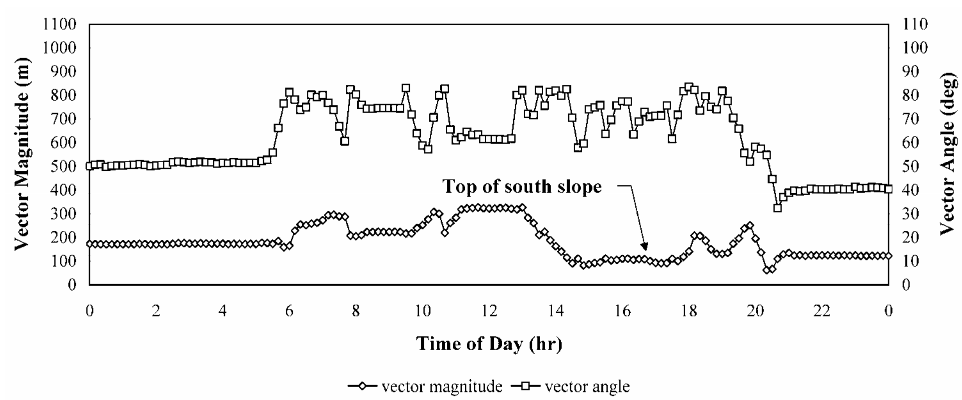
(c)



(d)



(e)



(f)

Figure 8: Magnitude and angle of individual cow location vector (CLV) on July 24, 2006 for cows 1330 (a), 2280 (b), 8374 (c), 63 (d), 118 (e), and 2375 (f).

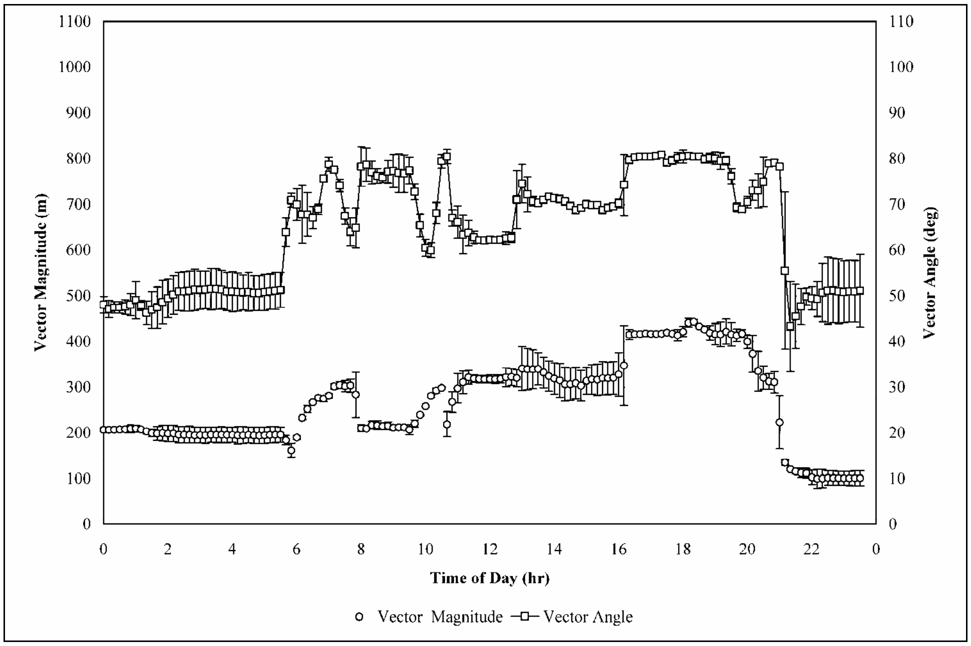


Figure 9: Cow location vector for Group 1 (3 animals) on July 24 (vertical bars are standard deviations).

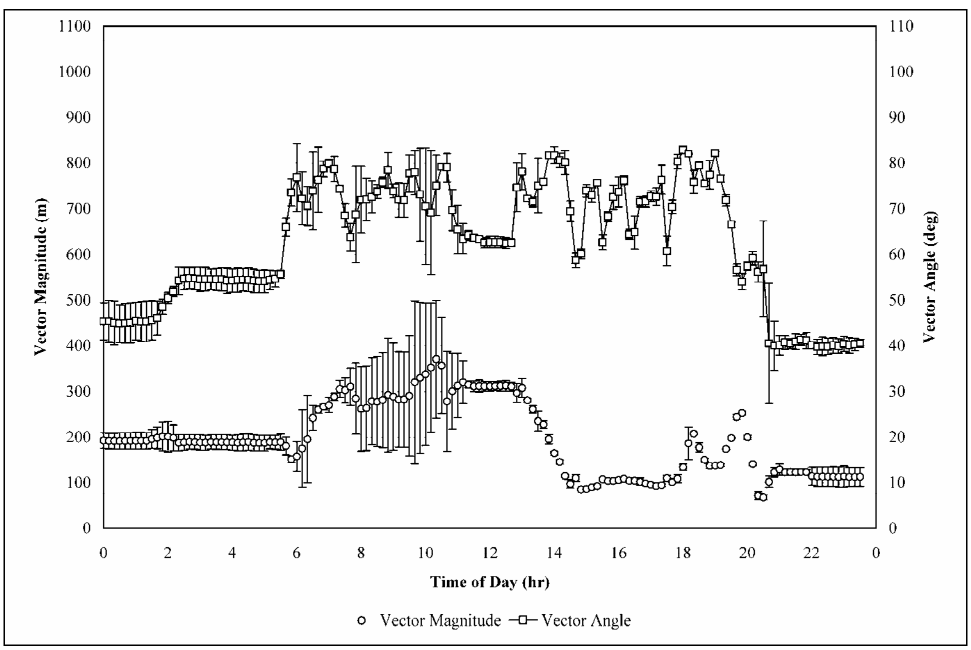
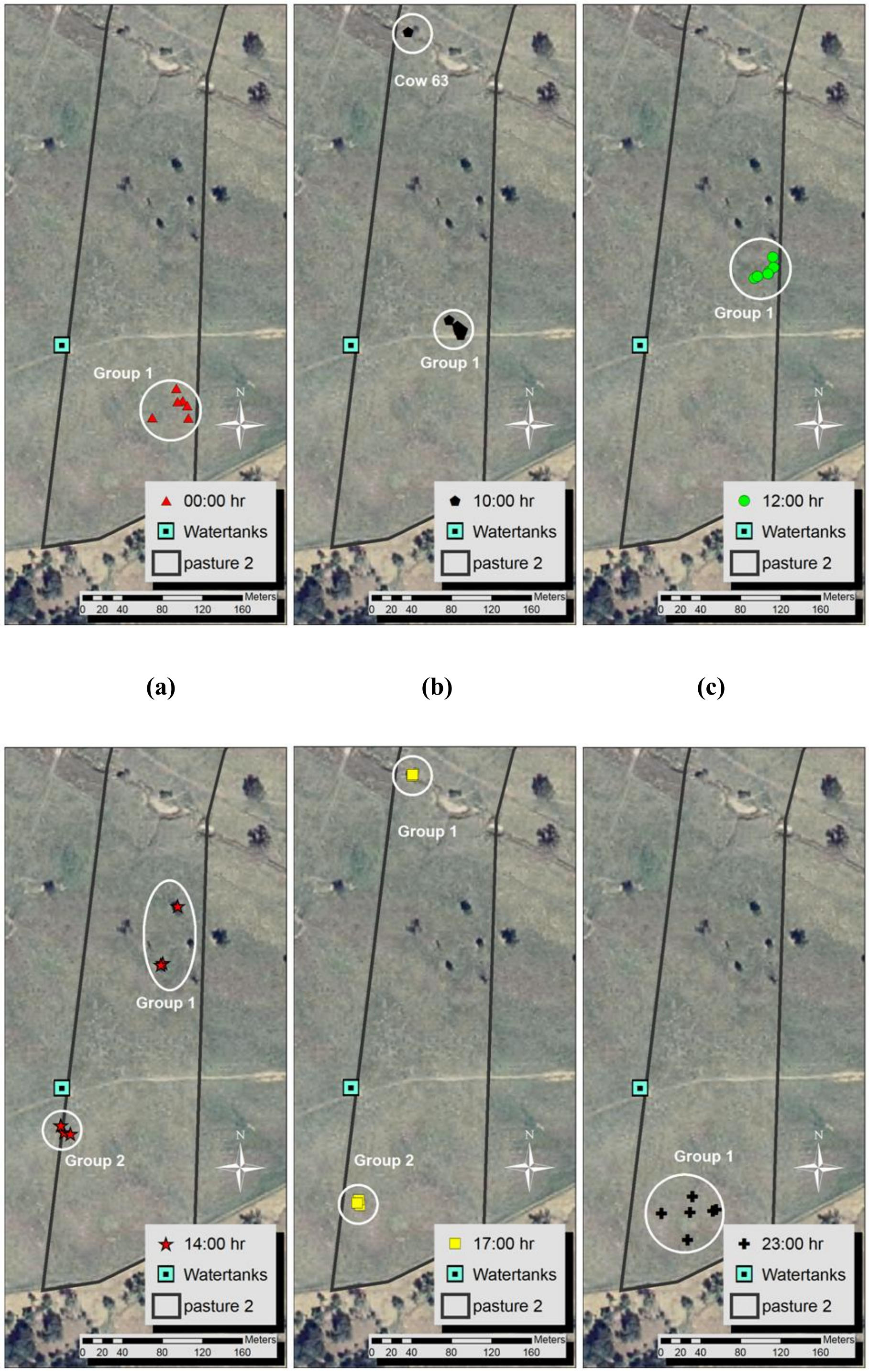


Figure 10: Cow location vector for Group 2 (3 animals) on July 24, 2006 (vertical bars are standard deviations).



(a) (b) (c)

(d) (e) (f)

Figure 11: Cow herd grouping (n = 6 on July 24 at a) 0:00 h, b) 10:00 h, c) 12:00 h, d) 14:00 h, e) 17:00 h and f) 23:00 h.

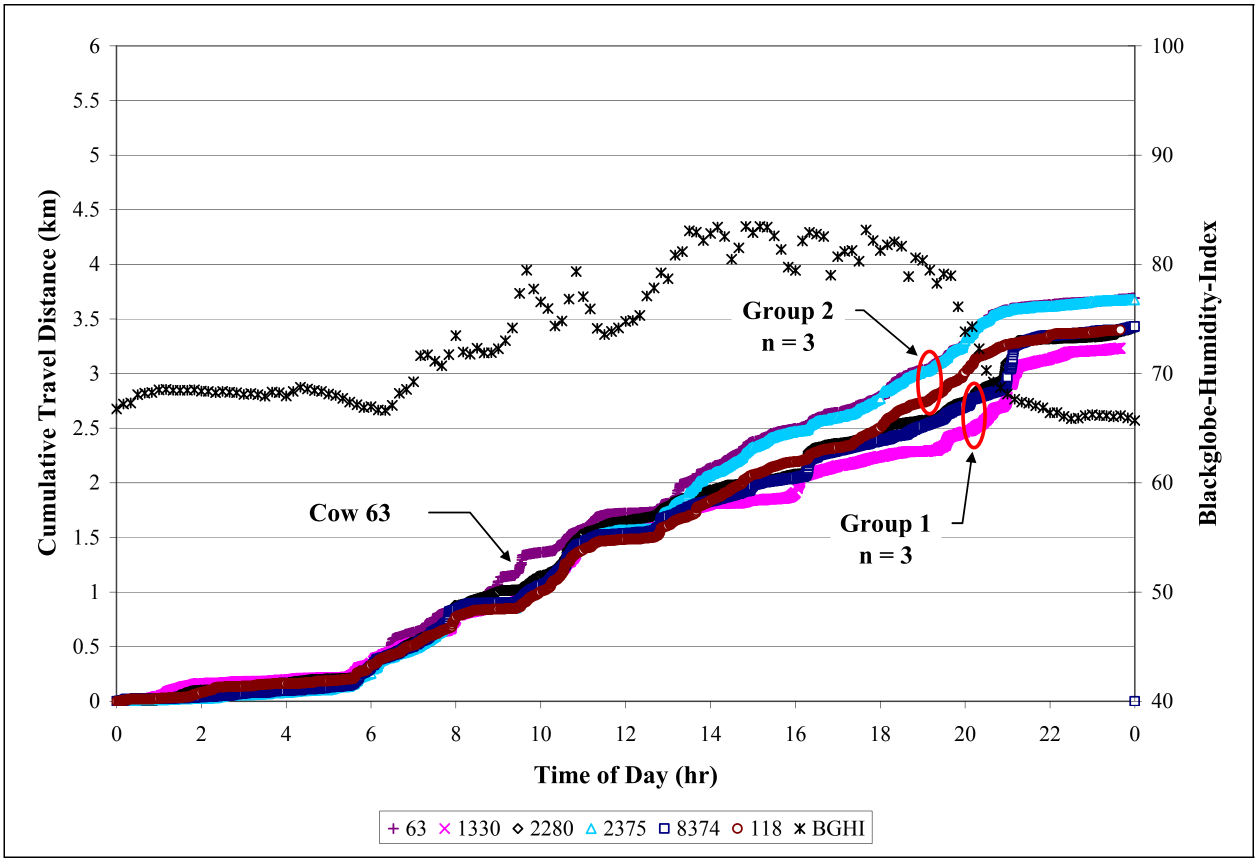


Figure 12: Cumulative travel distance profiles for six cows on July 24, 2006.

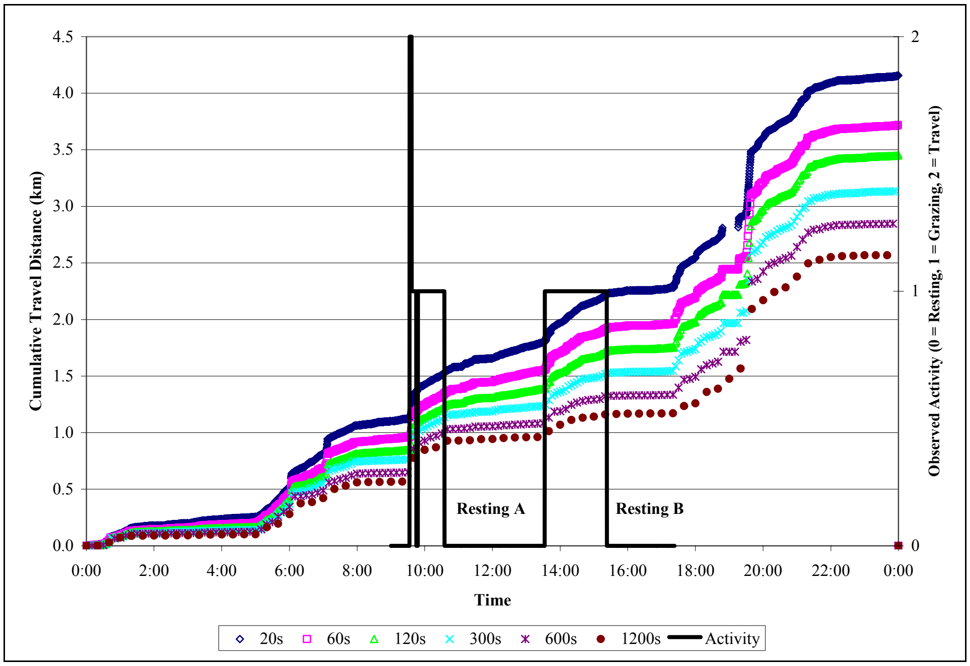


Figure 13: Cumulative travel distance for cow 8374 on June 25, 2006 as affected by sample interval. Grazing activity is shown on secondary axis.

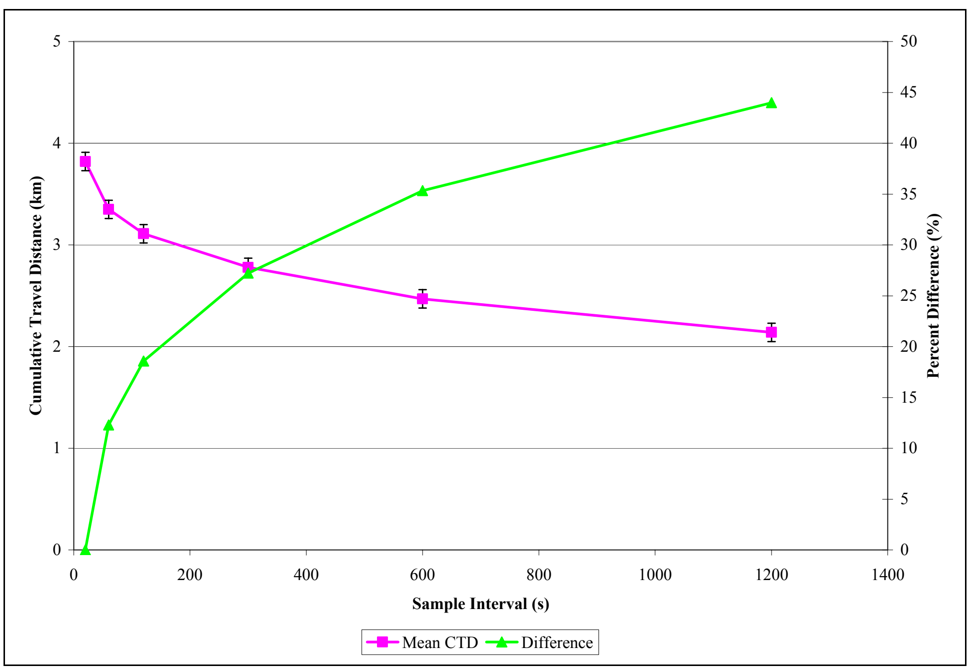


Figure 14: Cumulative travel distance of cows on pasture as affected by sample intervals of GPS location recording. (vertical bars are standard errors).

CHAPTER 4. USE OF RUMEN TEMPERATURE TO CHARACTERIZE DRINKING ACTIVITY IN RUMINANT LIVESTOCK

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Abstract

The rumen temperature and temperature responses to drinking activity were characterized for six Angus steers. The use of rumen temperature response as a measure of drinking activity was assessed. Mean temperature responses (ΔT) were different ($p < 0.001$) among the steers. Mean temperature response to ingested water volume (VOL) was -1.7˚C (±0.125), -1.0˚C (±0.125) and -0.8˚C (±0.125) for sensors on the reticulum floor (RET), the rumen floor (RUM) and tethered to a rumen cannula (TET), respectively. RET was different ($p < 0.001$) than RUM and TET. Multiple regression of ΔT against VOL and water temperature (WTEMP) explained 84% of total variation. The total predicted volume consumed by the six steers over 2 days, using the drinking event algorithm, was 10.5% greater than the actual volume. If the predicted water consumption from the best three cows were used in a field study with similar conditions, water consumption could be predicted within 1.4% of the actual consumption. The use of reticulum temperature response to a drinking event may provide a means to remotely quantify drinking activities for individual animals in remote or group settings over a period of time.

Keywords: water consumption, drinking behavior

INTRODUCTION

It has been a common husbandry practice in the United States that livestock graze on large pastures and are allowed to drink, walk and lounge in any creek, river or lake available. Conservation of stream and ground water quality and more efficient use of livestock watering sources have become an issue of increasing concern to researchers, producers and environmentalists alike. Producers need low-cost clean water sources to protect streams while optimizing herd health and production. The relationship between feed and water intake is of great importance in arid pasture areas of the tropics and subtropics, where the availability of drinking water is the limiting factor for productivity in cattle (Hafez and Bouissou, 1975). Researchers have been concerned with developing better grazing systems, improving stream water quality, and stabilizing stream banks from erosion. To help address these issues, knowledge of water consumption patterns and intake rates by the animals would be valuable in developing water sy.

Livestock water consumption is affected by physiological and environmental factors, such as type and size of species, physiological state (growing, lactating or gestation), level of activity, level of dry matter intake, thermal environment, water temperature and palability. Water intake is a function of dry matter intake such that a constant ratio of water intake to dry matter intake is maintained, all other factors being constant (Hafez & Bouissou, 1975). Several researchers have developed equations to predict water intake of beef cattle utilizing many of these variables, discussed further by Bicudo et al. (2004) and (Jeter 2001).

Free ranging cattle drink once per day and under the same conditions lactating cows will drink no more frequently but larger amounts (Houpt, 2005). Phillips (2002) stated that cattle visiting watering places infrequently, as in rangeland grazing, would usually spend a few hours drinking three to four times. Cattle drink more frequently, usually two to five times per day, when water is freely available. Cattle fed silage and limited concentrates drink four times per day (Houpt, 2005). For cattle, water intake increases with hot weather and decreases with cold, but will increase with increased food intake necessary to maintain body temperatures below 0°C ambient temperatures Houpt, 2005).

Bicudo et al. (2004) continuously monitored water intake rates of grazing cattle drinking from portable tanks to determine peak flow rates to optimize watering system designs.   In another study, Bicudo et al. (2003) concluded that water intake was significantly affected by water temperature, temperature humidity index (THI) and stream accessibility during warm weather. Water intake was only measured at water tanks. Data suggested that cattle with free access to stream consumed water mostly from the stream, especially when water tank temperatures were above 25˚C. The study could not conclude how much was consumed from the stream or the location of the drinking event.

Individual Water Consumption

Individual water intake has been continuously monitored by researchers in laboratory settings for poultry (Puma et al., 2001), swine (Phillips et al., 1990) and cattle (Dado and Allen, 1993). Dado and Allen (1993) provided each cow with an individual drink cup equipped with an inline flowmeter. Cumulative water consumption was determined through summation of flowmeter pulse counts. These systems work well for individually penned animals with separate drinking systems. However, these systems do not allow the study of individual drinking behavior in group settings or grazing systems containing multiple watering sources. GrowSafe Systems Ltd (2007) developed a radio frequency identification (RFID) system (GrowSafe Beef, Airdrie, Alberta, Canada) to monitor animal growth and health determined by trips to the water tank. The GrowSafe Beef system can determine individual drinking activity within a group setting but must be installed at every watering source and the system does not quantify volume consumed.

Dale et al. (1954) measured rumen temperature of a 3-yr old, non-pregnant, non-lactating Jersey cow in three locations (0, 15.2 and 30.5 cm from rumen floor) using a custom probe inserted through a surgical opening in the left paralumbar fossa (indentation below lumbar vertebrae between the ribs and hip). A difference of 2.2˚C was observed in mean temperature across these locations. The effect of adding water (~6.6 L @ 18.3˚C) through a stomach tube into the rumen was also investigated. Dale et al. (1954) illustrated a rapid decrease in rumen temperature for each location following the addition of water. The largest response was observed at the 30.5 cm level with smallest temperature response occurring at the rumen floor (Dale et al., 1954).

Ruminant Stomach

The ruminant stomach is comprised of four compartments (reticulum, rumen, omasum and abomasum) through which food passes successively (Dyce and Wensing, 1971) (fig. 1). The first three (forestomach) serve as a fermentation vat for microbial fermentation of ingested material (Swenson and Reece, 1993). The abomasum serves functions similar to non-ruminant animals. Dyce and Wensing (1971) estimated the ruminant stomach capacity to be approximately 60L, with each compartment apportioned as: 80% in rumen, 5% in reticulum, 8% in omasum, and 7% in abomasum. The size or body weight of animals used to determine these estimates were not given. The reticulum (A) is only partially separated from the rumen (C) by the ruminoreticular fold (F) (fig. 1). For this and other reasons, the two compartments operate as a combined functional unit; the ruminoreticulum. The ruminoreticulum occupies the entire left side of the abdomen (Swenson and Reece, 1993).

Ingesta enter the forestomach (fig. 1) from the esophagus (D) through the esophageal groove (E) into the reticulum (Swenson and Reece, 1993). The reticulum serves as a liquid pump for the rumen, regulates ingesta passage from rumen to omasum and aides in regurgitation (Reece, 1997). Heavy foreign bodies (metallic) fall to the bottom of the reticulum and remain there. The fiberous ingesta contain trapped air, have a low density and tend to float high in the ruminoreticulum creating a fibrous raft. At approximately 1-min intervals, the ruminoreticulum sequences through powerful contractions churning the soupy fluid with the surfaces of the raft. Gases produced during fermentation reside above the raft until the eructation process (Swenson and Reece, 1993).

Several researchers have remotely monitored rumen temperature. Mathew (2000) measured changes in rumen and vaginal temperatures to determine estrous cycling in dairy cattle. However, the temperature radio-transmitters were placed in plastic bottles with gravel for weight. These bottles were placed in cotton rumen digesta bags tethered to the rumen-cannula (Mathew, 2000). Since the temperature radio-transmitters were not in direct contact with the rumen fluid, thermal inertia would create a time lag in temperature measurements and clip any large short-term temperature changes, such as those associated with specific drinking events. Mayer et al. (2004) developed a wireless sensor network to remotely monitor cattle health. Their first goal was to monitor intra-rumenal temperature of a single steer over a long period and describe any emerging patterns. Rumen temperature was recorded every 10 min or when the temperature changed by 0.2°C. A significant decrease in rumen temperature was witnessed when the steer drank water (Mayer et al., 2004). This research illustrated the usefulness of remotely monitoring a physiological parameter but demonstrated little of the correlation between the volume of water consumed and the corresponding decrease in rumen temperature.

Winchester and Morris (1956) stated that the prediction of water intake of a single or of a few animals was not possible due to large variations in water intake among individuals or of the same animal for consecutive days. In spite of the variations, can each study animal be "calibrated" before being introduced into remote monitoring research projects? This project aims to increase our understanding of individual beef cattle water consumption and provide an additional quantitative measure to remote livestock monitoring.

Objectives of This Study

- Characterize rumen temperature and rumen temperature responses to drinking events.
- Assess the use of rumen temperature response as a measure of drinking activity.

MATERIALS AND METHODS

Experimental Animals and Housing

Six rumen-cannulated Angus *Bos taurus* steers (850 ± 57 kg body mass) were housed in alternating individual (3.7 m x 12.6 m) concrete pens on the Beef Nutrition Research Center at Iowa State University (table 1, fig. 2) and fed 27.2-kg rations of Fescue grass hay and 30 g of mineral mixture twice daily (08:30 hr and 17:00hr). Hay moisture content was approximately 15%. Refused hay was weighed and dry matter (DM) determined. Water was available *ad libitum* via 60.6-L water tanks (Ritchie Omni Fount 500, Ritchie Water Fountains, Conrad, IA, fig. 3). The tank float was set to a height of 10.8 cm (42.5 L volume) to reduce spillage. An initial test determined that a 0.95-L drinking event was required to initially activate the tank float.

Water and Environment Instrumentation

Individual water consumption was monitored using a positive displacement water meter equipped with an SF pulse generator that produces 26 pulses/liter (AMCO C700, Daniel L. Jerman Co., Hackensack, NJ). Each pulse generator was connected to an 8-channel switch closure input module (SDM-SW8A, Campbell Scientific Inc., Logan, UT) interfaced with a datalogger (CR10, Campbell Scientific Inc., Logan, UT) to capture the water volume (VOL) of the drinking event (DE). Water temperature (WTEMP) was measured with type-T thermocouples connected to a multiplexer (AM416, Campbell Scientific Inc., Logan, UT) interfaced with the CR10. Dry-bulb temperature and relative humidity were measured with a temperature/RH probe (HMP35C-L, Campbell Scientific Inc., Logan, UT) connected to the CR10. Each water meter came pre-calibrated. All temperature sensors were calibrated in a water bath against a precision temperature probe (DigiSense, Cole Parmer, Niles, IL). All environmental and water flow measurements were taken at 1-min intervals for the duration of the monitoring.

To determine the volume of each drinking event, the pulse counts for each consecutive sample of continuous data over the drinking period were summed and converted to liters. Water temperature changed rapidly during the drinking event due to mixing of the tank water and water held in the waterline. To provide a representative water temperature during each drinking event, 3 samples before and after the start of the drinking event were averaged.

Rumen Temperature Instrumentation

Previous pitfalls and losses of data using temperature radio-transmitters within a cow led to the use of a self-contained stainless steel logger (HOBO U12, Onset Computer Corp., Bourne, MA) was used to measure rumen temperature in the corrosive rumen environment. The logger had a resolution of better than 0.05˚C and a data storage capacity of 43,000 samples (Onset Corp, 2003. The HOBO U12s were calibrated in a water bath against a temperature probe (DigiSense, Cole Parmer, Niles, IL). The HOBO U12 measured (17.5 x 101.6 mm) and weighed 72 g.

<u>Experiment 1</u>

Two steers (EID 432 and 743) were each fitted with three HOBO U12 loggers placed in the following locations: 1) the reticulum floor (RET), 2) the rumen floor (RUM), and 3) tethered to the rumen-cannula by an 18-inch nylon string (TET) (fig. 1). The sensors, placed through the rumen-cannula, were synchronized to log data at 30-s intervals. The nylon tether was used for ease of sensor retrieval and the tether length was estimated to allow the sensor to be emerged in the rumen liquid, but short enough to prevent extensive tangling in the motile rumen. After a 3-day sample period beginning 29-Sep-2005, the temperature sensors were retrieved through the rumen-cannula.

Experiment 2

Six steers were fitted with a single HOBO U12 probe placed on the reticulum floor through the rumen-cannula logging (synchronized) at the fastest frequency available (10 s). After an 8-day sample period, the temperature sensors were retrieved through the rumen-cannula.

Temperature Response Algorithm

Using the temperatures recorded with the HOBO U12 loggers, the temperature response (ΔT) associated with each drinking event was calculated with the following algorithm. The time of each drinking event was used as a trigger to begin calculation of the temperature response (ΔT) for each sensor as follows:

$$\Delta T = \left(T_{\min} - T_i\right)$$

Where T_{min} = minimum temperature

T_i = 10-min average before drinking event

The temperature T_{min} was the minimum temperature determined within 30 min after a drinking event for the reticulum floor and rumen floor and within 1 hr after a drinking event for the tethered sensor as determined by an initial examination of the data.

Sampling Interval

The sampling rate may affect the temperature profile recorded. Because the loggers can only store a limited amount of data, the sample rate also determines the length of monitoring period. Using the measured 10-s temperature data set (experiment 2) for all six steers, the data were subdivided to create data sets at sampling intervals of 10, 30, 60, 150, 300, 450, 600 or 900 s. The same temperature response algorithm described above was again used to determine the change in temperature for each drinking event at each sample interval.

Drinking Event Detection Algorithm

An algorithm was created to determine the occurrence of a drinking event using changes in reticulum temperature in experiment 2. First, a frequency analysis on the rate of temperature change (˚C/min) between all reticulum temperatures was conducted using the 6-day training data. To determine the onset of a drinking event, a rate of change (negative) was chosen in excess of the normal fluctuations in rumen temperature. When the reticulum temperature exceeded the threshold value, the temperature response algorithm was applied to determine ΔT. Using the regression equations developed for each steer, an estimate of drinking volume could be calculated.

Data Analysis

Experiment 1

For the two steers, one-way analysis of variance (ANOVA) was performed with the PROC GLM procedure (SAS, 2000) to determine if the mean ΔT for a drinking event differs for VOL, LOCATION, WTEMP and THI. The variables WTEMP and THI were divided into three categories (LOW, MEDIUM and HIGH) based on the 25% and 75% percentiles for means comparison. Means and pair-wise comparisons were obtained and separated using the LSMEANS. Temperature response (ΔT) was regressed against VOL and WTEMP for each LOCATION using the PROC REG procedure. The null hypothesis that the slope and intercept of each parameter was equal to zero was tested at alpha = 0.05 level.

Experiment 2

The six steers served as experimental units in a completely randomized design. The eight-day period of experiment 2 was divided into training data (6 days) and validation data (6-Oct and 10-Oct) for the drinking event detection algorithm. One-way ANOVAs were performed with the PROC GLM procedure to: 1) determine if the ΔT to a drinking event differs for VOL WTEMP, THI, FEED, and STEER and 2) determine if ΔT to a drinking event is different for sample interval. The variables WTEMP and THI were divided into three categories (LOW, MEDIUM and HIGH) based on the 25% and 75% percentiles for means comparison. Means and pair-wise comparisons were obtained and separated using the LSMEANS and PDIFF commands. The total feed (DM) consumed (morning or evening) was assigned to each drinking event within that period. The PROC REG procedure was used to create a multiple regression model to describe the relationship between ΔT and the independent variables VOL, STEER, WTEMP, and THI. Parameters were considered significant at $p \leq 0.05$ level.

RESULTS AND DISCUSSION

Experiment 1

The temperature measurements were recorded for each location over three consecutive days for two steers. The three sensors were retrieved from their respective locations. The HOBO U12 loggers produced quality continuous data for the duration of the experiment.

Figure 4 illustrates the temperature profile of each location and the corresponding drinking activity of steer 432 over the three monitoring days. The TET shows the most fluctuation in base line temperature for both animals. The consumption of feed and/or rumen motility and the mixing of the ingesta raft material might be the cause of the TET fluctuation. The tether prevented the sensor from falling to the rumen floor but allowed the sensor to move up into the fermenting ingesta raft or down into the rumen liquid along a radius from the cannula. The RET and RUM sensors were continuously submerged in rumen liquid, thereby providing more stable temperatures.

Drinking activities for these two steers are summarized in table 2. On 30-Sep from 09:21h to 13:11h, a four-hour period of drinking data was missing from the CR10 logger. Two large temperature drops (apparent drinking event) illustrated in Figure 4 were missed in steer 432 and three drinking events in steer 743 due to this error. These drinks were not included in table 2. An initial test determined that a 0.95-L drinking event was required to activate the tank float. Drinking events smaller than 0.95 L were removed from the data. One drinking event (0.08 L) was removed from steer 432 and 10 drinking event with a mean volume of 0.08L (± 0.03) from steer 743. These events were most likely associated with the animals bumping the watertank or sloshing the water as no visual response was seen in the temperature profiles. Water temperatures were classified as LOW, MEDIUM and HIGH based on the 25% and 75% percentiles of 17.6˚C and 21.0˚C, respectively. Similarly, THI were classified as LOW, MEDIUM and HIGH at values 59 and 72.

Due to rumen content stratification, the mean temperature gradient was highest in the fermenting ingesta raft (TET) and lowest in the reticulum (RET) for steer 432. Steer 743 showed a 1.6 ˚C higher RUM than Steer 432. Temperature differences between LOCATION were greatest between TET and RET; 1.9˚C and 1.4˚C for steers 432 and 743, respectively. Steer 432 showed similar mean LOCATION differences (TET-RUM = 1.4˚C) to those recorded by Dale et al. (1954) of 2.2˚C from 0 cm to 30.5 cm above the rumen floor.

Figure 5 shows a 4-h window of steer 432 illustrating the temperature response (ΔT) by LOCATION to a 14-L drinking event. The mean ΔTs over the 3-day period were -1.7˚C (±0.125), -1.0˚C (±0.125) and -0.8˚C (±0.125) for RET, RUM and TET, respectively. The difference in the mean ΔT was significant for reticulum floor temperature ($p < 0.001$), but not so for rumen floor or tethered sensor temperatures. The mean ΔTs for the WTEMP categories were -1.6˚C (±0.158), -0.8˚C (±0.100) and -1.0˚C (±0.139) for LOW, MEDIUM and HIGH, respectively. The difference in mean ΔT was significant for LOW ($p < 0.05$), but not for MEDIUM or HIGH. The variable THI did not have an effect on mean ΔT.

The temperature response at RET was the most responsive to VOL due to the ingested water filling the small reticulum cavity first and then diffusing throughout the larger rumen. Though Dale et al. (1954) did not measure temperature response in the reticulum, the ΔT was measured in locations similar to RUM and TET for a 6.6 L (WTEMP = 18.3˚C) volume of water placed through a stomach tube. The ΔT in the rumen at 0, 15.2 and 30.5 cm from the rumen floor where approximately 3.5˚C, 9.4˚C and 13.4˚C, respectively. Dale et al. (1954) stated that the highest and warmest part of the ingesta was most affected by the addition of water. This statement was in direct contradiction to the profiles measured in this study. The length of stomach tube and placement of the hose end was not stated by Dale et al. (1954) in the single cow and could have lead to the differing result. The warmest location near the fermenting ingesta raft (TET) had the smallest ΔT, while RET and RUM, farther from raft, had the largest ΔT.

When the animal imbibes a volume of water, heat is exchanged mostly through conduction heat transfer between the water and rumen fluid. As the water absorbs energy from the rumen fluid, the temperature gradient is reduced and thus the rate of heat conduction is reduced. As the water diffuses from the reticulum (RET) throughout the rumen the temperature gradient is reduced, slowing the temperature responses seen at RUM and TET. The results seen by Dale et al. (1954) may be a result of: a) thermocouple wires placed in reverse order, or b) the length of stomach tube may have been sufficiently long allowing the induced drinking event to be discharged in the rumen near the top of the probe, diffusing downward.

A regression model for ΔT was developed using VOL, WTEMP, and interactions for each LOCATION (fig 6). Dummy variables were created for intercept and slope of LOCATION. The variables of VOL, WTEMP, and dummy variables for slope of LOCATION were significant ($p < 0.05$), interactions were not. The multiple regression model accounted for 59% of total variation in the data. The temperature response to VOL (L) for each location are as follows:

Reticulum floor: $\Delta T = -0.469 \times VOL$

Rumen floor: $\Delta T = -0.349 \times VOL$

Tethered: $\Delta T = -0.310 \times VOL$

Experiment 2

Temperature measurements were recorded in the reticulum for six steers over an 8-day period. The sensors were retrieved from their respective locations. Data for 4-Oct and 10-Oct were removed for validation of the drinking event model. Figure 7 illustrates individual steer RET profiles and associated drinking activity for each steer and THI over the study period. Mean RET temperatures are shown in table 3 for each steer over the period. An observation showed the steer temperature profiles falling into group 1 (150, 432 and 743) and group 2 (245, 958 and 793). The animals within the two groups had similar mean (±SD) RET temperatures, 39.5 (±0.2)˚C and 37.7 (± 0.1)˚C for groups 1 and 2, respectively. The temperature grouping showed no correlation with animal weight, feed or pen location.

In viewing the RET profiles (fig 7), the first drinking event of the day typically produced the largest ΔT for a drinking event. This could be attributed to cooler morning WTEMP and less microbial activity on the depleted ingesta in the rumen.

Differences in mean feed consumed ($p < 0.05$) were found among steers (table 4). Steer 245 was the largest steer of the group and consumed the most feed (19.1 kg DM). Feed consumed on 5-Oct and 7-Oct were different ($p < 0.05$) than the remaining days (table 4). Drinking activity for each steer is summarized in table 5. As with experiment 1, drinking events smaller than 0.95 L were removed from the data. Eighty-five drinking events were removed from the six steers with a mean (±SD) volume of 0.45 (±0.30) L. Fifty-five drinking event with mean VOL (±SD) of 0.46 (±0.29) L were associated with positive temperature responses (0.3˚C ± 0.4˚C). The remaining 30 drinking events with mean VOL (±SD) of 0.44 (±0.33) L were associated with negative temperature responses (-2.0 ± 2.23˚C). The mean volume for the removed drinking event is half that required to activate the tank floats. It is hypothesized these small drinking event were the result of water sloshing or bumping of the tanks.

Though there was not a significant difference in mean daily drinking event for steer, differences were seen ($p < 0.01$) in mean daily volume for steer (table 5). Figure 8 illustrates the drinking event frequency for each hour of the day. The histogram shows a bimodal distribution of drinking event with the majority of drinking event occurring during daylight hours. Possibly, the reduced drinking activity around 14:00 hr arose from the steers resting in the warm afternoon before the second feeding. Drinking activity peaked a second time at 17:00 hr during feeding. A Pareto histogram of VOL per drinking event is displayed in figure 9. All steers show 95% of drinking event having VOL between 1 and 11 L.

Water temperatures were classified as LOW, MEDIUM and HIGH based on the 25% and 75% percentiles of 14.3˚C and 17.1˚C, respectively. Similarly, THI were classified as LOW, MEDIUM and HIGH at values 54 and 63.

There were differences ($p < 0.01$) in mean temperature response for each steer, as shown in Table 3. Mean ΔT for WTEMP were -5.3˚C, -4.0˚C and -3.6˚C for LOW, MEDIUM and HIGH, respectively. The difference in ΔT was significant ($p < 0.0001$) for LOW but not so for MEDIUM and HIGH. The variables FEED and THI did not affect mean ΔT.

The ΔT was regressed against VOL and WTEMP for each STEER. Dummy variables were created for intercept and slope of VOL by STEER. The multiple regression model accounted for 84% of total variation in data. The temperature response (˚C) to VOL (L) and WTEMP (˚C) for each steer is as follows:

Steer 150: $\Delta T = -4.52 - 0.810 \times VOL + 0.207 \times WTEMP$

Steer 245: $\Delta T = -4.52 - 0.551 \times VOL + 0.207 \times WTEMP$

Steer 432: $\Delta T = -4.52 - 0.170 \times VOL + 0.207 \times WTEMP$

Steer 743: $\Delta T = -4.52 - 0.211 \times VOL + 0.207 \times WTEMP$

Steer 793: $\Delta T = -6.23 - 0.491 \times VOL + 0.207 \times WTEMP$

Steer 958: $\Delta T = -2.89 - 0.810 \times VOL + 0.207 \times WTEMP$

Steers 150 and 958 showed the largest ΔT to VOL while 432 showed the smallest ΔT. While installing and retrieving the HOBO U12 sensors, the consistency of the ingesta in steer 432 was much less viscous than the other five steers while steer 150 had the driest ingesta. In viewing Table 5, steers 432 and 958 drank the largest and steer 150 drank the smallest volumes of water. Therefore, an equal volume of water would produce a smaller ΔT in steer 432 compared to steer 150. Transfer functions were created for each regression equation to be used in the prediction of water consumption for each steer (Table 6).

Effects of Sampling Interval

The measured 10-s temperature dataset were subdivided to create data sets at sample intervals of 10, 30, 60, 150, 300, 450, 600 or 900 s (fig. 10). The temperature response algorithm was applied to each dataset to determine the ΔT for each measured drinking event at each sample interval. The mean ΔT for each sample interval is shown in Table 8. Sample intervals less than 300 s (5 min) were not different. Increasing the sample interval from 10 s to 300 s would extend the monitoring time from approximately 4.6 days to 149 days before downloading the HOBO U12 sensors. The 900 s sample interval was significantly different ($p < 0.05$) from all other sample intervals.

Drink Event Detection

The frequency analysis of the rates of temperature change showed that normal body fluctuations fell within ± 0.2˚C/min for all steers. Therefore, the drinking event detection was initiated when the RET fell below the -0.2˚C/min threshold.

Validation of the drinking event detection algorithm to determine drinking event from changes in RET was performed on data from 6-Oct and 10-Oct. The results of the predicted drinking event for each steer are summarized in Table 7. The algorithm detected (D) 64 observed (O) drinking events and 3 not-observed (NO) drinking events.

Of the 3 not observed but detected (NO-D) drinking events, one drinking event had a volume of 0.8L and had been removed from the data. There were 14 observed but not detected (O-ND) drinking events. Twelve of these drinking events had a mean VOL of 1.2 (±0.05) L and followed a previous drinking event within 17.4 (±4.5) min. Though the temperature algorithm calculated ΔT ranging from -2.5˚C to 0.82˚C due to the close proximity of a previous drinking event, no drop in RET was associated with these 12 drinking events. Another 1.3L drinking event showed no response in RET though no other drinking event occurred near. The final drinking event of the 14 O-ND showed a ΔT of -1.4˚C but did not exceed the -0.2˚C/min threshold.

Applying the transfer functions for each steer to the predicted ΔT of each drinking event provided an estimate of water volume consumed over the validation period (Table 7). There were variations among individuals and days. The algorithm predicted 48.4% more water volume for steer 150 over the two days. However, the best prediction was in steer 743 at 2.4% difference. The algorithm under-predicted (-6.7%) the total volume on 6-Oct and over-predicted (10.5%) the volume on 10-Oct. The total volume consumed by all steers over the validation period was 375.7 L. The algorithm predicted a 10.5% higher volume at 415.2 L. These differences may decrease if the sampling period is increased.

To increase the accuracy of quantifying water consumption using RET in a study, multiple animals could be tested to determine which animals best predict total volume consumed. If the three steers (432, 743 and 958) with the smallest difference between actual and predicted volume were used in a field study with similar conditions, water consumption could be predicted within 1.4% over the two day period.

SUMMARY AND CONCLUSIONS

The rumen temperature and temperature responses to drinking activity were characterized. The use of rumen temperature response as a measure of drinking activity was assessed.

1. Mean temperature change (ΔT) in response to ingested water volume (VOL) were -1.7˚C (±0.125), -1.0˚C (±0.125) and -0.8˚C (±0.125) for RET, RUM and TET, respectively. RET was significantly different from RUM and TET ($p < 0.001$). Mean ΔT's were different ($p < 0.001$) for all steers.
2. Multiple regression of temperature response against water volume and water temperature explained 84% of the total variation. The total predicted volume consumed by the six steers over 2 days, using the drinking event algorithm, was 10.5% greater than actual volume.
3. The use of reticulum temperature response to a drinking event may provide a means to remotely quantify drinking patterns of individual animals in remote or group settings over a period of time.

ACKNOWLEDGEMENTS

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REFERENCES

Bicudo, J.R., J.D. Davis, R.S. Gates. 2004. Monitoring Grazing Dairy Heifers Water Intake During Hot and Humid Weather. Procs. Of the 2nd Technical Section of CIGR on New Trends in Farm Buildings, May 2-6, Evora, Portugal (on CD-ROM).

Bicudo, J.R., C.T. Agouridis, S.R. Workman, R.S. Gates, and E.S. Vanzant. 2003. Effects of air and water temperature, and stream access on grazing cattle water intake rates. Paper for the 2003 ASAE International Meeting, Paper #034034, July 27-30. Las Vegas, NV.

Buffington, D.E., A. Collazo-Arocho, G.H. Canton, and D. Pitt. 1981. Black globe-humidity index (BGHI) as comfort equation for dairy cows. Trans of the ASAE 24(3): 711-714.

Dado, R.G., M.S. Allen. 1993. Continuous computer acquisition of feed and water intakes, chewing, reticular motility, and ruminal pH of cattle. J. Dairy Sci. 76:1589-1600.

Dale, H.E., R.E. Stewart and S. Brody. 1954. Rumen temperature I. temperature gradients during feeding and fasting. Cornell Vet. 44(3): 368-374.

Davis J.D. 2002. Unpublished data. Lexington, KY: University of Kentucky.

Dyce, K.M. and C.J.G. Wensing. 1971. Essentials of bovine anatomy. J.H. de Bussy, Amerstam.

Hafez, E. S. E., and M. F. Boissou 1975. The behaviour of cattle. In The behaviour of domestic animals. 3rd ed. E. S. E. Hafez, ed. Bailliere Tindall, London, UK.

Houpt, K.A. 2005. Domestic animal behavior – 4th ed. Blackwell Publishing, Ames, IA.

Jeter, M.B. 2001. Drinking water intake by finishing yearling beef steers. M.S. Thesis, Canyon, TX: West Texas A&M University, Department of Animal Science.

Mathew, S.R. 2000. Changes in rumen temperature, vaginal temperature and drinking behavior throughout the estrous cycle in tie-stalled dairy cattle. M.S. Thesis, Winnipeg, MB, Canada: University of Manitoba, Department of Animal Science.

Mayer, K., K. Ellis, K. Taylor. 2004. Cattle health monitoring using wireless sensor networks. 2nd IASTED International conference on communication and computer networks, Cambridge, MA, USA.

Onset Computer Corp. 2003. HOBO U12 Stainless Temp Data Logger. Doc # 7938-D, MAN-U12-015. Bourne, MA.

Phillips, C. 2002. Cattle behaviour and well-being – 2nd ed. Blackwell Publishing, Ames, IA.

Phillips, P.A., D. Fraser, J.M. Leclerc, B.K. Thompson. 1990. Measurement of individual water intake by group-housed piglets. Trans. of the ASAE 33(3): 912-916

Puma, M.C., H. Xin, R.S. Gates, D.J. Burnham. 2001. An instrumentation system for studying feeding and drinking behavior of individual poultry. Applied Engineering in Agriculture 17(3): 365-374.

Reece, W.O. 1997. Physiology of domestic animals – 2nd ed. Lippencott Williams & Wilkins, Baltimore, MD.

SAS. 2000. User's Guide. V8. SAS Institute, Inc., Gary, NC.

Swenson, M.J. and W.O. Reece. 1993. Dukes' physiology of domestic animals - 11th ed. Cornell University Press, Ithaca, NY.

Winchester, C.F. and M.J. Morris. 1956. Water intake rates of cattle. J. Anim. Sci. 15: 722-740.

Table 1: Pen location, electronic identification number, weight and sensor identification number for each steer.

Pen	Steer ID	Weight kg	HOBO-U12 ID
1	432	945	33
2	793	616	31
3	958	855	29
4	150	770	28
5	743	907	30
6	245	1008	32
	Average (SE)	850 (±57)	

Table 2: Descriptive statistics of drinking activity, mean temperature and temperature response for each measurement location.

Description		Steer	
		432	**743**
29-Sep	No. DE	6	9
	Ave VOL (L)	6.8	3.5
	Total VOL (L)	40.7	31.6
30-Sep*	No. DE	3	5
	Ave VOL (L)	8.5	3.3
	Total VOL (L)	25.4	16.5
1-Oct	No. DE	7	8
	Ave VOL (L)	5.6	4.2
	Total VOL (L)	39.3	34.1
Mean Location Temperature (˚C)	RET	37.3 (±.005)[a]	37.4 (±.005)[a]
	RUM	37.8 (±.005)[b]	39.4 (±.005)[b]
	TET	39.2 (±.005)[c]	38.8 (±.005)[c]
Location Difference (˚C)	TET-RET	1.9	1.4
	RUM-RET	0.5	2.0
	TET-RUM	1.4	-0.6
Mean ΔT (˚C)	RET	-1.6[a]	
	RUM	-0.9[b]	
	TET	-0.6[b]	
Water Temperature (˚C)	Min	9.8	
	Ave	18.9	
	Max	22.2	
THI	Min	54	
	Ave	65.7	
	Max	74	

*missing 4 hours of flowmeter data from 9:21 to 13:11 on 9/29/05

[a, b, c] Denotes significant difference ($p < 0.001$).

Table 3: Mean temperature and temperature response for each steer.

Steer	n	Mean Temperature (˚C)	SE (˚C)	n	Mean ΔT (˚C)	SE (˚C)
150	23040	39.8	0.007	29	-5.9^{a}	0.24
245	23040	37.7	0.007	27	-4.7^{b}	0.25
432	23040	39.5	0.007	32	-2^{c}	0.22
743	23040	39.2	0.007	36	-2.6^{c}	0.21
793	23040	37.6	0.007	25	-5.8^{a}	0.25
958	23040	37.8	0.007	32	-4.5^{b}	0.22

n = sample number.

$^{a, b, c}$ Denotes significant difference ($p < 0.01$).

Table 4: Mean feed consumption for steer and day.

Description		Mean Feed Consumed kg	SEM kg
Steer	150	15.1^{ac}	0.73
	245	19.1^{b}	0.73
	432	16.1^{ac}	0.73
	743	16.6^{ac}	0.73
	793	13.58^{a}	0.73
	958	15.1^{ac}	0.73
Day	5-Oct	16.9^{a}	0.73
	7-Oct	21.8^{b}	0.73
	8-Oct	14.4^{c}	0.73
	9-Oct	14.2^{c}	0.73
	11-Oct	14.7^{c}	0.73
	12-Oct	13.5^{c}	0.73

^{a,b,c} Denote significant difference ($p < 0.05$).

Table 5: Descriptive statistics of drinking activity for six steers over 6 training days.

Description		Steer 150	245	432	743	793	958	Daily Mean
5-Oct	No. DE	5	5	6	5	6	5	5.3
	Daily Vol (L)	20.8	28.2	22.1	20.9	25.6	29.8	24.6
7-Oct	No. DE	7	5	5	7	5	6	5.8
	Daily Vol (L)	25.6	33.7	33.2	28.6	26.1	33.6	30.1
8-Oct	No. DE	6	4	4	5	2	5	4.3
	Daily Vol (L)	22.5	31.2	39.2	37.4	20.3	38.37	31.5
9-Oct	No. DE	4	4	5	5	4	6	4.7
	Daily Vol (L)	21.7	36.2	47.2	29.1	28.1	35.3	32.9
11-Oct	No. DE	4	6	8	8	4	5	5.8
	Daily Vol (L)	17.7	38.7	44.4	33.2	18.5	30.6	30.5
12-Oct	No. DE	3	3	4	6	4	5	4.2
	Daily Vol (L)	18.4	19.8	25.5	37.2	22.7	25.4	24.8
Total	Mean DE	4.8	4.5	5.3	6.0	4.2	5.3	
	Mean Volume (L)	21.1^a	31.3^b	35.3^b	31.1^b	23.6^a	32.2^b	
	Total DE	29	27	32	36	25	32	
	Total Volume (L)	126.7	187.8	211.6	186.4	141.3	193.1	

$^{a, b, c}$ Denote significant difference ($p < 0.05$).
DE = drinking event, VOL = water volume comsumed.

Table 6: Transfer function to predict volume from ΔT and WTEMP for each steer.

Steer	Transfer Function
150	Vol = -1.23 × (ΔT) + 0.256 × (WTEMP) - 5.58
245	Vol = -1.81 × (ΔT) + 0.376 × (WTEMP) - 8.20
432	Vol = -5.88 × (ΔT) + 1.218 × (WTEMP) - 26.6
743	Vol = -4.74 × (ΔT) + 0.981 × (WTEMP) - 21.4
793	Vol = -2.04 × (ΔT) + 0.422 × (WTEMP) - 12.7
958	Vol = -1.23 × (ΔT) + 0.256 × (WTEMP) - 3.57

Table 7: Drinking event prediction results.

Description		Predicted Drinking Event O-D* No.	O-ND No.	NO-D No.	Actual Volume (L)	Predicted Volume (L)	Difference (%)
Steer	**150**	13	1	2	39.5	58.6	48.4
	245	10	1	0	50.6	59.2	17.0
	432	9	3	0	84	89.1	6.1
	743	12	2	0	72	73.7	2.4
	793	11	4	0	54.9	63.3	15.3
	958	9	3	1	74.7	71.3	-4.6
Day	**6-Oct**	31	8	3	198.1	184.9	-6.7
	10-Oct	33	6	0	177.6	230.4	29.7
	Total	64	14	3	375.7	415.2	10.5

*D = detected, ND = not detected, O = observed, NO = not observed.

Table 8: Mean temperature response for all steers at each sample interval.

Sample Interval (sec)	Mean ΔT (˚C)	SEM (˚C)
10	-3.9[a]	0.104
30	-3.8[a]	0.104
60	-3.8[a]	0.104
150	-3.7[ab]	0.104
300	-3.6[ab]	0.104
450	-3.5[bc]	0.104
600	-3.3[c]	0.104
900	-2.9[d]	0.104

[a, b, c] Denotes significant difference ($p < 0.05$).

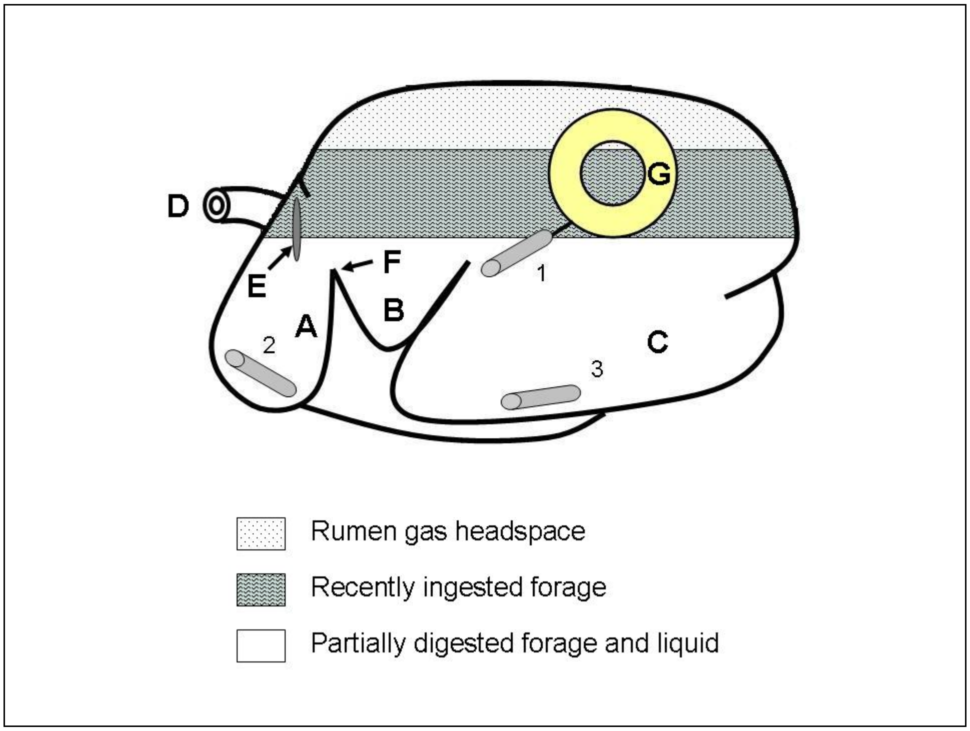


Figure 1: Topography of ruminant stomach; reticulum (A), cranial sac of rumen (B), rumen (C), esophagus (D), esophageal groove (E), rumino-reticular fold (F), rumen-cannula (G), temperature bolus locations 1-3. Adapted from Swenson and Reece, 1993.

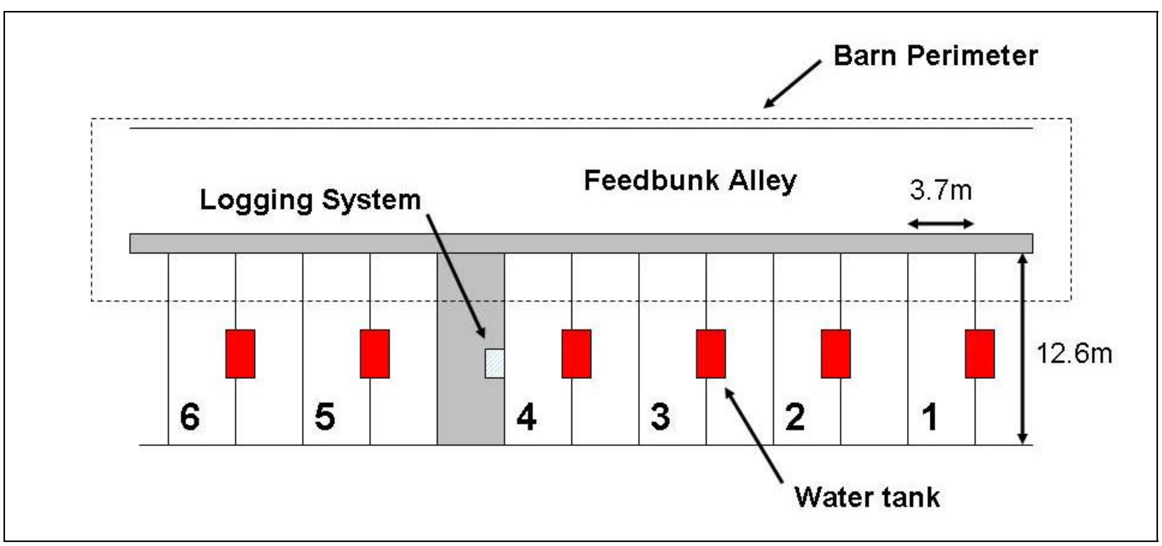


Figure 2: Experimental schematic of partially covered pens at ISU Beef Nutrition Center. Steers were located in the numbered pens 1-6.

Figure 3: Steer 245 (pen 6) standing near Omnifount 500 water tank.

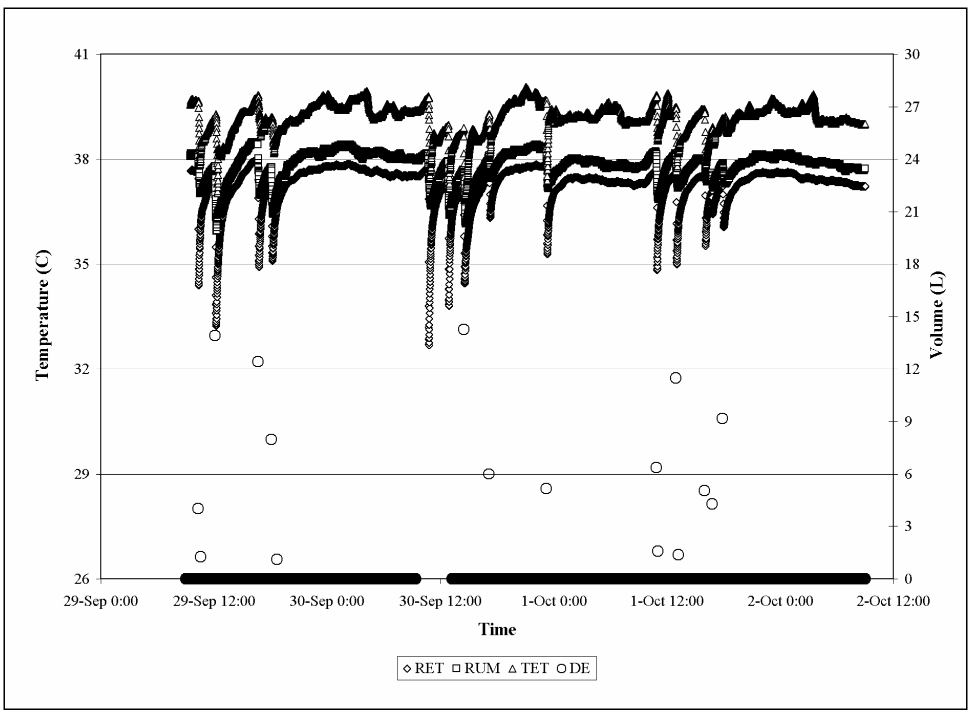


Figure 4: Temperature comparison for 3 locations (reticulum floor, rumen floor and tethered) associated with drinking activity for steer 432. Missing drinking data (9/29/05 9:21h - 13:11h)

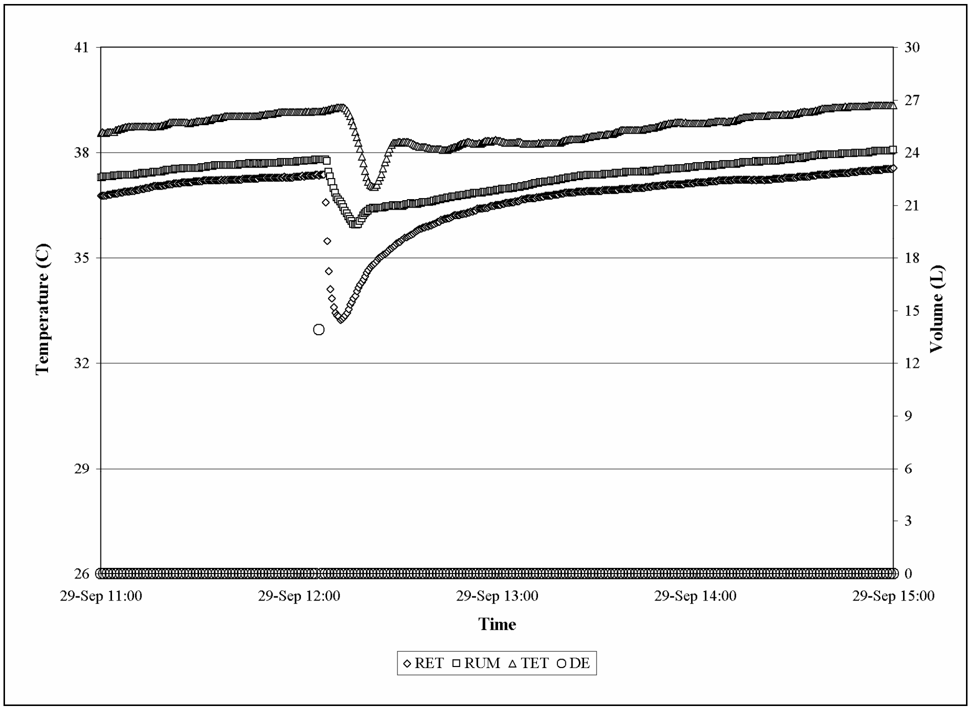


Figure 5: Temperature comparison by location associated with one drinking event for steer 432.

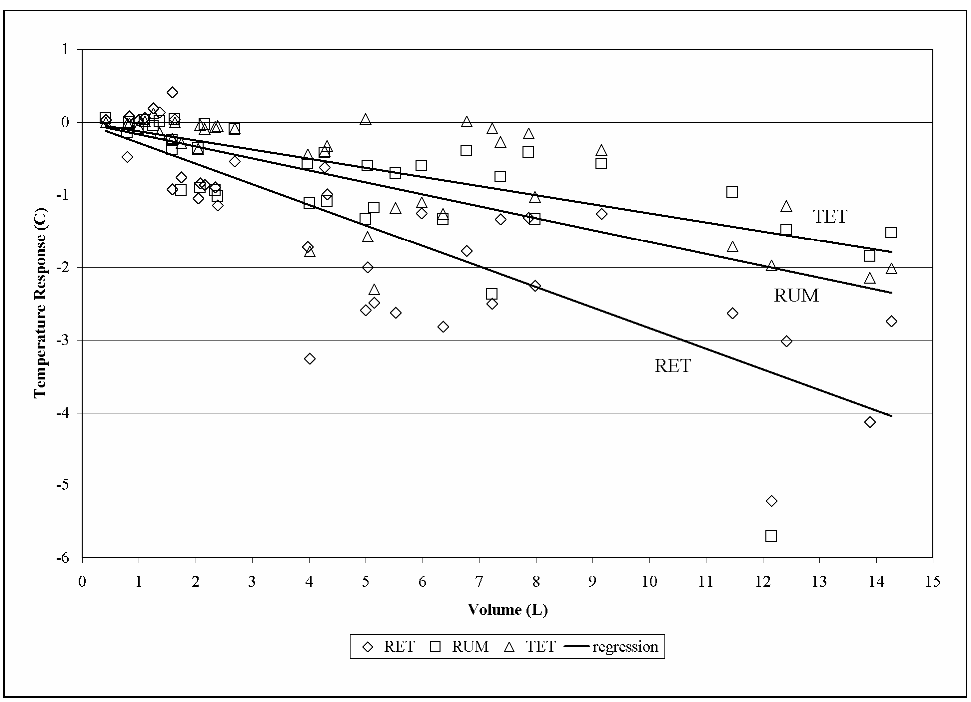
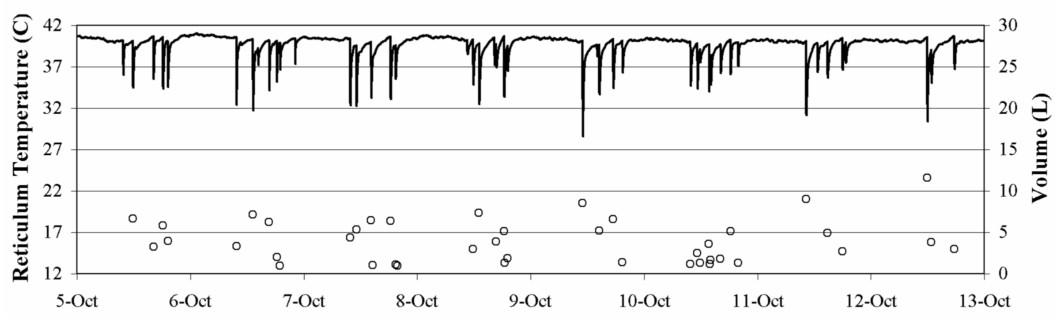


Figure 6: Temperature response regressed against volume of DE for each location.


Reticulum Temperature (C)
Volume (L)
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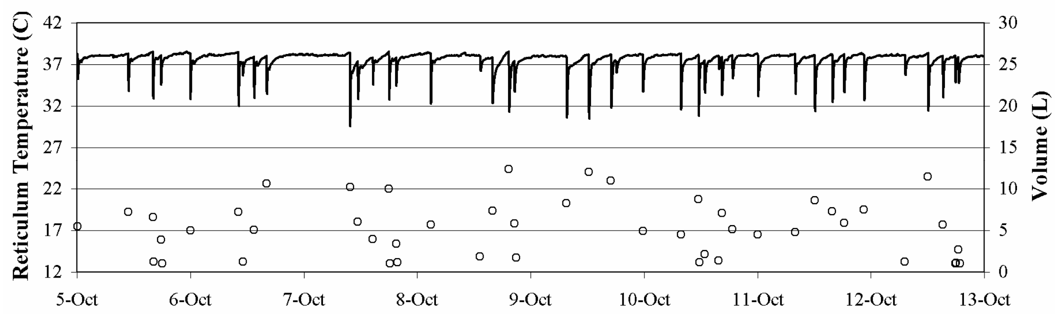
(a)


Reticulum Temperature (C)
Volume (L)
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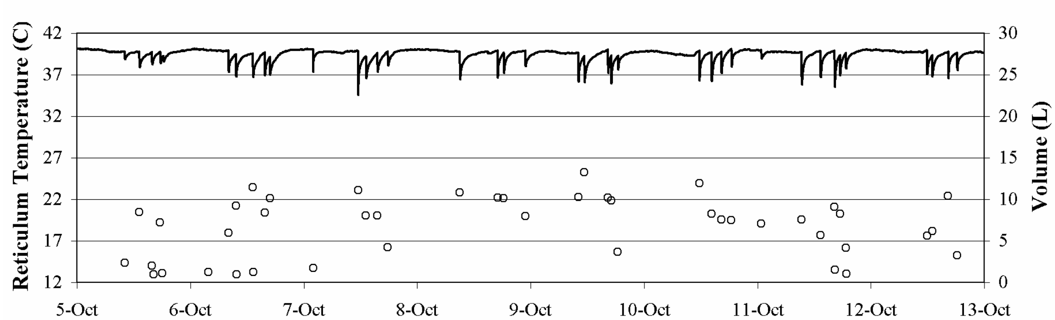
(b)


Reticulum Temperature (C)
Volume (L)
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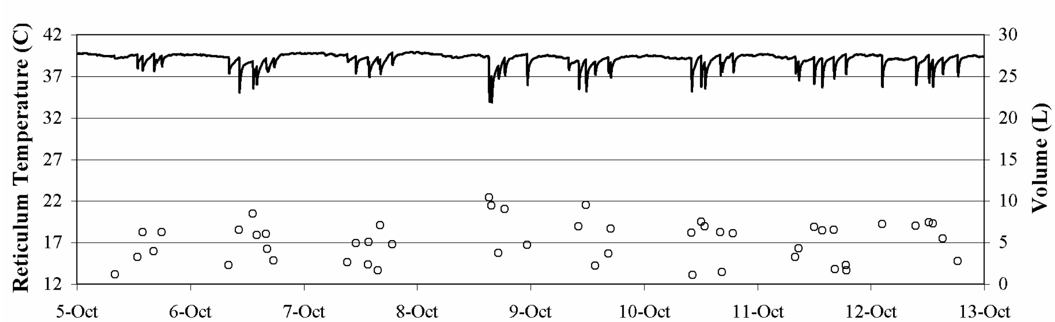
13-Oct

(c)


Reticulum Temperature (C)
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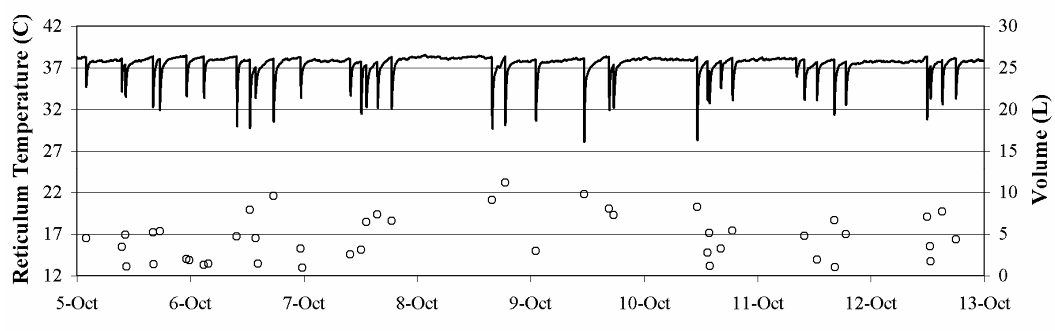
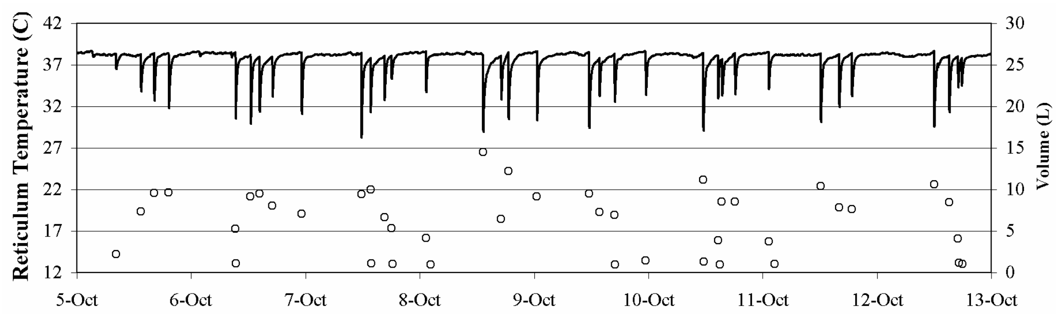
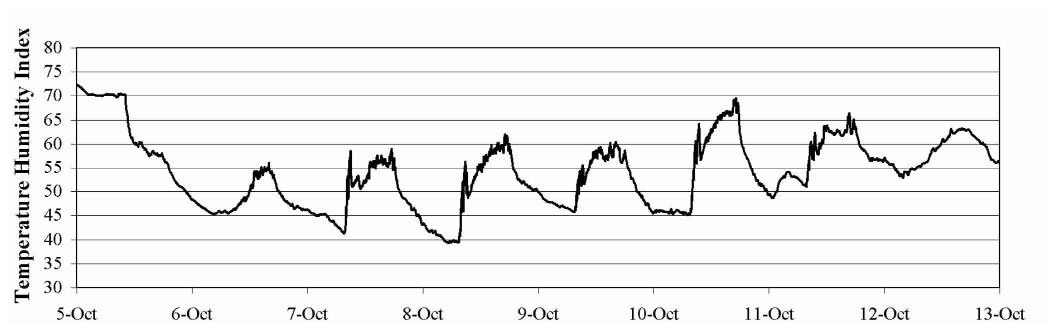
(d)



(e)



(f)



(g)

Figure 7: Drinking activity and temperature profiles for each of six steers; a) S150, b) S245, c) S432, d) S743, e) S793, f) S958 and g) Temperature-Humidity-Index (THI) for the 10-day study period.

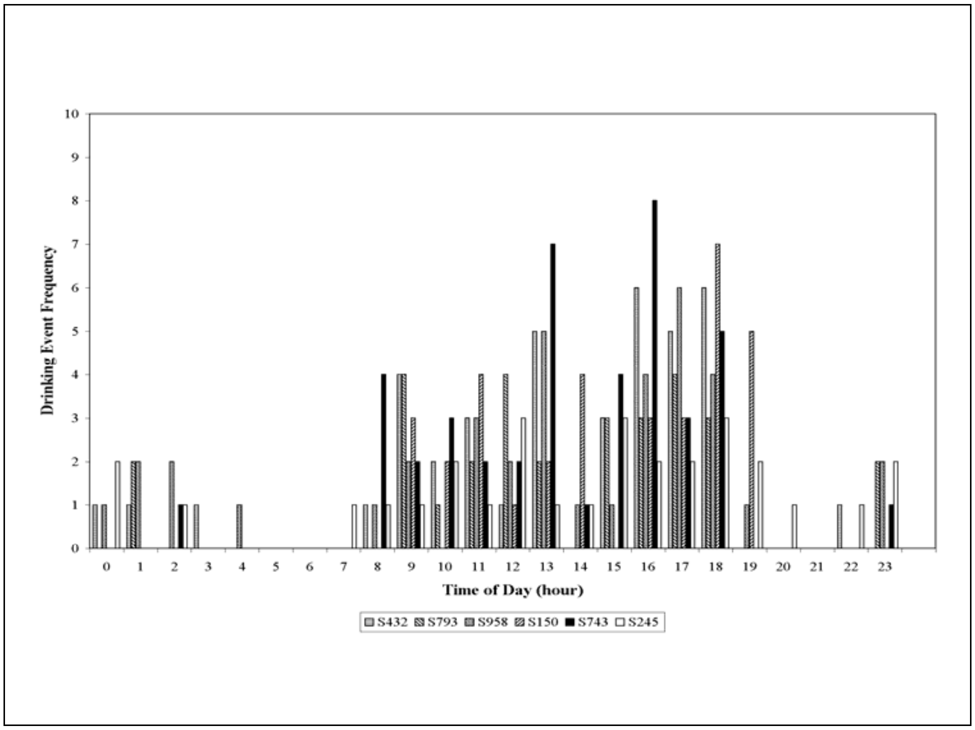


Figure 8: Histogram illustrating steer DE frequency for each hour of day.

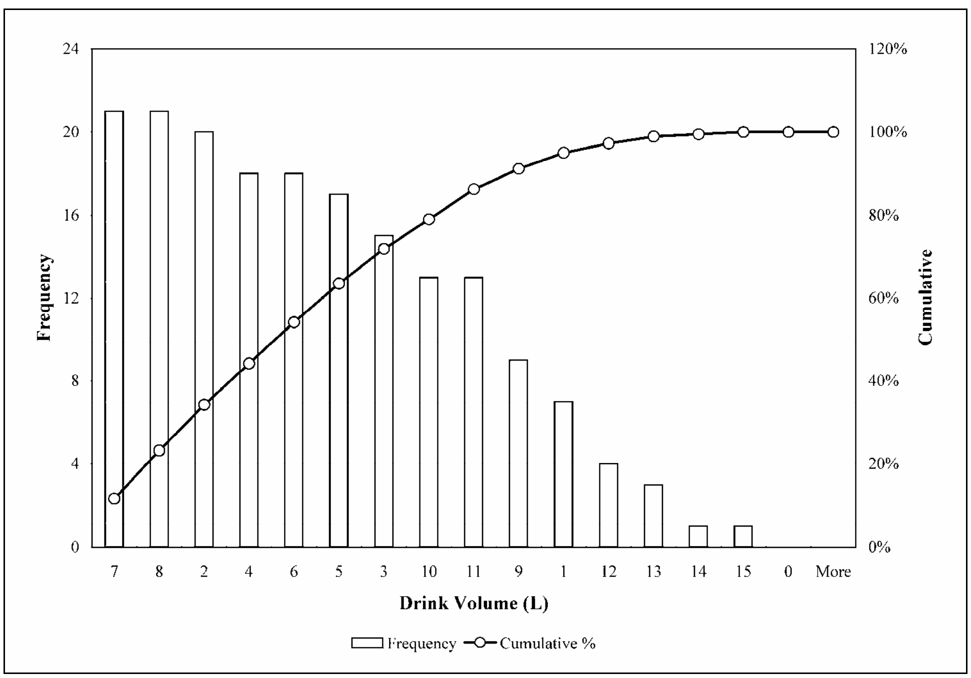


Figure 9: Pareto histogram of VOL per DE for six steers. Secondary axis shows Cumulative frequency.

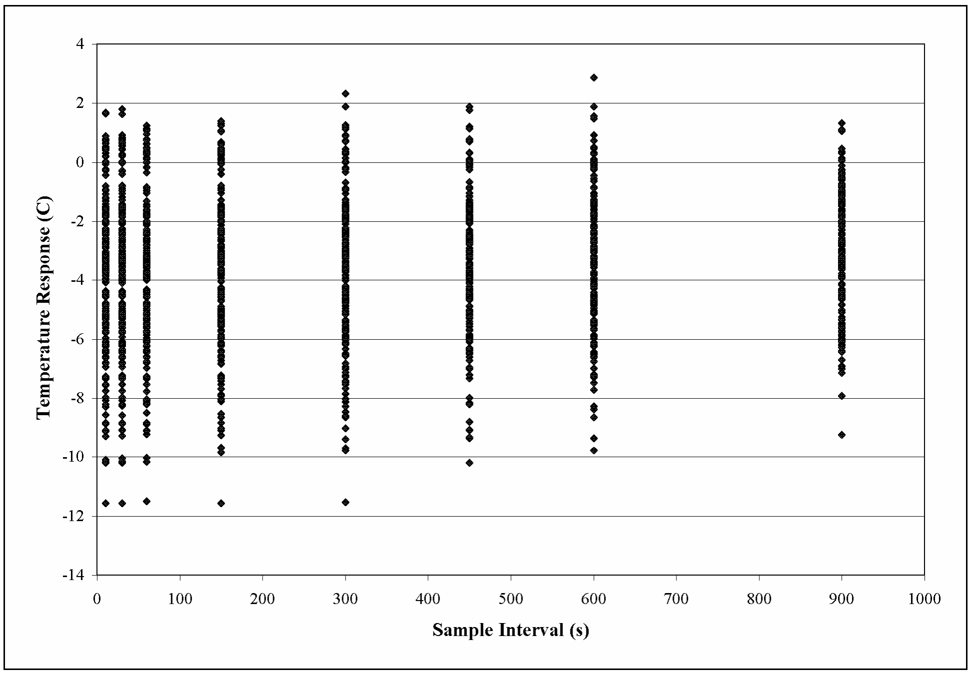


Figure 10: The effect of sampling interval on temperature response to drinking event. Sampling intervals less than 300 sec are not different.

CHAPTER 5. OVERALL SUMMARY AND CONCLUSIONS

1. A low-cost GPS herd activity and well-being kit (GPS HAWK) was developed as an alternative to commercial GPS tracking collars. The operational goal of the GPS HAWK was to collect GPS location data at a user-specified frequency and store the data in a secure format. The GPS HAWK utilizes a Garmin 12-channel low-power GPS receiver powered by a 6V, 7.2 Ah sealed-lead acid battery housed in a shoulder-mounted aluminum enclosure. Operation of the GPS HAWK was commanded by a micro-controller based system equipped with six external sensor ports. Data was stored to compact flash media for retrieval. The locomotion behavior of multiple cows was monitored at 20-s intervals. The high-frequency sampling data were used to delineate grazing behavior of the cows on pasture including cumulative travel distance, travel velocity and acceleration. Behavior data of this nature could be useful to efficient pasture management and assessment of herd health/well-being.

2. Locomotion behavior of cattle on pasture was delineated with the aid of a newly developed GPS monitoring unit. Use of one animal to represent herd behavior and the effect of GPS sampling rate on the characterization of the animal locomotion behavior were assessed. Though the percentage of time spent at each activity varied over days, cows spent 33.2%, 25.5%, 40.4% and 0.9% of four 8-hr observation periods on lying (L), standing (S), grazing (G) and traveling (T), respectively. Cows within the herd in this study spent 56.7% of the time performing the same activity simultaneously; however, mean daily duration for each activity was similar for cows. Use of a cow location vector (CLV) provided

a simplistic method to illustrate the dynamic locomotive behavior of cows over time. The CLV provided a visual means to discern grouping of cows based on locomotion. Though differences in location occurred due to sub-grouping of cows throughout each day, the cumulative distances traveled were similar across cows. Therefore, monitoring a single cow will suffice in the quantification of average time spent at activities of L, S, G and T and CTD. However, a single animal would not be not sufficient to illustrate dynamics in herd location.

3. The rumen temperature and temperature responses to drinking activity were characterized. The use of rumen temperature response as a measure of drinking activity was assessed. Mean temperature change (ΔT) in response to ingested water volume (VOL) were -1.7˚C (±0.125), -1.0˚C (±0.125) and -0.8˚C (±0.125) for RET, RUM and TET, respectively. RET was different ($p < 0.001$) than RUM and TET. Mean ΔT's were different ($p < 0.001$) for all steers. Multiple regression of temperature response against water volume and water temperature explained 84% of total variation. The total predicted volume consumed by the six steers over 2 days, using the drinking event algorithm, was 10.5% greater than actual volume. The use of reticulum temperature response to a drinking event may provide a means to remotely quantify patterns in drinking activity for individual animals in remote or group settings over a period of time.