GRAZING BEHAVIOR OF BEEF STEERS GRAZING ENDOPHYTE-INFECTED, ENDOPHYTE-FREE, AND NOVEL ENDOPHYTE INFECTED TALL FESCUE, AND LAKOTA PRAIRIE GRASS

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(ABSTRACT)

Endophyte infected Tall fescue (*Festuca arundinacea Schreb.*) is the most dominant grass used for pasture in the Southeastern U.S. As a result, fescue toxicosis is a major concern. Producers need alternative forages for grazing cattle that do not have this negative aspect. The objective of this experiment was to determine the grazing behavior of cattle grazing Lakota (L) prairie grass (*Bromus catharticus* Vahl.), endophyte infected (E+), endophyte free (E-), and novel endophyte (Q) tall fescues. Angus-crossbred steers (279±8 kg) steers wore electronic behavior data recorders in four sampling periods, and direct visual appraisals of behavior were taken in five sampling periods during the months of May to September, 2004. Overall, during the visual appraisal phase steers grazing L spent most time (P<0.05) grazing while E+ spent the least time grazing. Overall, steers grazing E+ spent more time (P<0.05) idling than those on L, E-, or Q. Steers grazing E+ spent more time (P<0.05) standing than steers grazing Q. Steers grazing Q and E- spent more time (P<0.05) lying than those grazing E+. During the data recorder phase there were no significant differences between treatments for time spent grazing. Steers grazing E+ spent less time (P<0.05) lying and ruminating than steers grazing Q or L. Conversely, time spent standing and idling for steers grazing E+ was higher (P<0.05) than for steers grazing Q or L. These results indicate that L, E-, and Q may offer benefits to producers due to more time spent in productive activities during summer months.

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DEDICATION

I dedicate this to my grandmother, Hester Mankins King, and to my parents Anthony and Estelle Terry.

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INTRODUCTION

Tall fescue is the most dominant grass used for pasture in the Southeastern U.S. covering over 14 million ha (Ball et al., 2002). Fescue toxicosis is a major concern among producers, especially during the summer months when the symptoms are most pronounced. Fescue toxicosis can be separated into three main syndromes: fescue foot, bovine fat necrosis, and summer slump/fescue toxicity. Over 8.5 million cattle are maintained on tall fescue and are at risk of suffering from fescue toxicosis (Ball et al., 2002). It has been estimated that fescue toxicosis costs producers approximately $345 million due to the reduction in calf numbers and approximately $255 million due to reduction of calf weaning weight every year (Hoveland, 1993). Producers need alternative forages for grazing cattle that do not have the negative effects associated with endophyte infected tall fescue. Different varieties of endophyte free and novel endophyte tall fescues have the potential to improve cattle performance and production compared to endophyte infected tall fescue. Only recently have producers started to use prairie grass in the US and very little research has been conducted on beef cattle grazing this forage. Prairie grass has the potential to extend grazing seasons by being more adaptable to cool weather. It produces forage earlier in the spring and remains productive until later in the fall compared to tall fescue. Cattle grazing endophyte infected tall fescue have been shown to have grazing behavior different from cattle grazing endophyte free and novel endophyte infected tall fescue, however there has been no research on grazing behavior of cattle when grazing prairie grass. There are several methods available for the evaluation of cattle grazing behavior such as direct visual observations as well as the use of electronic equipment. Understanding the behavior of cattle grazing these forages and comparing the nutritive values of the forages can provide insight for producers currently grazing cattle on endophyte infected tall fescue. The objectives of this research was to determine the grazing behavior of cattle grazing different types of tall fescue or prairie grass, relate the behavior to the nutritive value of the forage and compare electronic and visual grazing behavior data.

REVIEW OF LITERATURE

Techniques for evaluation of animal behavior

Monitoring animal behavior has been a common task for researchers over the years and its methods have been a much explored topic. The basic method is that of direct observation. Biting is one of the most often observed actions in order to obtain bite rate which is then used to estimate intake. Erlinger et al. (1990) observed beef heifers grazing bermudagrass (*Cynodon dactylon* L.) during June and July at random times between dawn and dusk for 1 to 2 min intervals. They counted the number of prehensions with a hand-held tally counter and a stop watch. Chilibroste et al. (1997) used the technique described by Hodgson (1982) and recorded biting rate of lactating dairy cows grazing perennial ryegrass (*Lolium perenne* L.) during June and September for 1 min every 10 min in a grazing session.

Erlinger et al. (1990) observed animals continuously, recording grazing time to the nearest minute. If biting ceased for longer than 30 s they recorded that grazing had stopped. They noted that their measure of grazing time should be considered different than total amount of time spent foraging since an animal may be searching for food longer than 30 s and that time should be included in a measure of foraging time. Chilibroste et al. (1997) monitored the activity of lactating dairy cows on 2 min intervals and defined the action of grazing differently. An animal was grazing when the head was down and either biting or searching for food. Grazing was considered to have stopped only when the animal lay down, began rumination, or did not graze for a 15 min period. Visual monitoring of the amount of time spent eating or ruminating in dairy cow research has been performed by watching cows in individual stalls for a 24 h period and noting the activity every 5 min assuming that the activity noted continued for the full 5 min (Maekawa et al., 2002; Beauchemin et al., 2003). Even more specifically than just grazing time, some researchers have studied different type of bites from different ruminants (Dumont et al., 1995; Agreil and Meuret, 2004). Dumont et al. (1995) observed up to eight different bite types of goats and llamas when browsing shrubs such as kermes oak (*Quercus coccifera*) from April through June. Agreil and Meuret (2004) observed the behavior of goats and sheep grazing various shrub and tree species (*Quercus humilis* Mill., *Genista cinera* DC., *Pinus sylvestris* L., *Cytisus purgans* L., Benth., etc.) in three experiments, one in April-May and two in August and recorded 41 different categories of bites which were used to develop a coding system to be used by observers. More activities than just grazing or ruminating have also been studied.

Hart et al. (1993) recorded the time cows spent nursing, resting, walking, distance walked, and location at 15 min intervals from dawn to dusk. Sprinkle et al. (2000) looked at location of resting, whether in the shade or in the sun in addition to grazing time and biting rate on 5 min intervals in a herd of lactating and non-lactating beef cows grazing Kleingrass (*Panicum coloratun* L.) during summer months. The intervals between observations vary between experiments just as the activities observed also vary. Garry et al. (1970) studied the behavior of Charolais cattle on Kentucky bluegrass (*Poa pratensis* L.) pastures during July and August and the frequency with which observations should be made to accurately report behavior. Gary et al. (1970) compared continuous observation to 15, 30, and 45 min intervals and concluded that a 15 min interval was acceptable for longer duration activities such as grazing, loafing, lying, consuming supplement, and nursing. However, when looking at activities of short duration such as defecation, urination, and the number of nursing, it was concluded that to be accurate a continuous observation was needed.

Mitlöhner et al. (2001) compared different observation intervals (1, 5, 10, 15, 30, and 60 min) and continuous observation of feedlot cattle. They found that when observing cattle in a feedlot setting for standing, feeding, drinking, and walking, an interval of no more than 15 min should be used. If lying time was the only behavior activity of interest an interval of 30 or 60 min could be used. Activities such as drinking time, which have a short duration decrease in accuracy as the time interval increases. A study was conducted comparing observation intervals of 5, 10, 15, or 20 min in a herd of beef cattle grazing kikuyu (*Pennisetum clandestinum* Hochst. *ex* Chiov.) during winter months (Hassoun, 2002). They found that when looking at time spent grazing, ruminating, or resting there were no significant differences among time intervals, but noted numerical differences at the 15 and 20 min intervals for grazing and rumination time. It was determined that a 10 min interval was optimum for the activities of grazing, ruminating, or resting and other activities could be recorded during the time between recording one activity and the next (Hassoun, 2002).

Hirata et al. (2002) conducted a study with beef cow-calf pairs grazing bahiagrass (*Paspalum notatum* Flueggé) looking at recording intervals of 1, 2, 3, 4, 5, 10, 15, 20, and 30 min. They found that the intervals between 1 and 5 min were the most accurate for all variables. The intervals between 10 and 30 min overestimated resting time and underestimated grazing and rumination time. Mitlöhner et al. (2001) noted that just as methods of measuring physiological functions must be selected based on the individual study and its objectives, so do the methods used for direct observation.

A common complaint among many researchers has been that direct observation of animals to learn about their behavior is a very tedious and time-consuming activity (Anderson and Urquhart, 1986; Mosley et al., 1987; Gordon, 1994; Langbein et al., 1996; Mitlohner et al., 2001; DeVries et al., 2003; Muller and Schrader, 2003). This is due mainly to the overall time involved to get accurate measures of animal activity. This has to be done without disturbing the animal and altering its natural behavior in the process. Because of the attention that must be devoted to one animal to get proper accounts of its behavior, the overall number of animals that can be observed is limited by manpower capabilities (Gordon, 1994; Langbein et al., 1996).

Researchers have tried to find ways to overcome these obstacles. One common method used for decades has been video recording as described by Friend et al. (1977). In this case a video camera was set to record one frame per minute to observe feeding behavior of dairy cows in free stalls. This may be a useful tool because if there is some question about an observed behavior, the video can be reviewed as many times as necessary. As noted by DeVries et al. (2003), the time it takes to review the videos for the needed information is substantial; hence there is considerable effort involved. Another problem noted was that when time-lapse videography is used there may be errors in the exact recorded times of behavior occurrence due to the fact that the video is not recording continuously (DeVries et al. 2003). If a researcher is interested in reporting total times of certain behaviors and the interval between recordings is too big then there may be an error associated with the total times reported. There may also be limitations in terms of the types of behaviors that time-lapse videography is suitable for recording. For example, if an animal starts drinking immediately after the video camera stops recording and the animal finishing drinking before the video camera starts recording again, then that behavior would not be known to have occurred. DeVries et al. (2005) only used the time-lapse video recordings to measure time spent lying and incidences of aggressive behaviors. The camera can be a limitation to the use of this technology in research. The area that can be recorded is restricted due to the camera resolution and lens focal length. Video recording may be suitable in feedlot pens or barns where the overall area is smaller, but in range situations where the total area is considerably larger and the topography can potentially block the view of an animal, the benefit of video recording would most likely be limited if useful at all (Gordon, 1994).

Using a laptop computer to record behaviors as they are occurring has the capability to make the job of observation less tedious by being more accurate and taking less time than using pen and paper (Demment and Greenwood, 1987). One problem they encountered was the lack of computer memory and only 30-45 min of observation information could be stored at one time. This limited the total number of observations that could be recorded. With the advancement of computers, memory space would not be an issue today; however, battery life could be. Using a laptop when making observations may reduce the amount of time that would be spent later entering hand written data into a computer for analysis (Demment and Greenwood 1987). A more recent development is a software program called Outdoor Explorer (www.biobserve.com) that is used with a Personal Digital Assistant (PDA) handheld computer. It can be used to monitor the location of the animal and spatial distribution, feeding and social behaviors, and environmental conditions, among others. The information is then downloaded to a computer and analyzed with Microsoft® Windows™ based software. Solar power units are available to use with PDAs allowing data to be recorded without battery limitation.

Devices that record the activities as they occur to be later analyzed have been developed to be worn by the animal reducing the need for constant observation. Balch (1952) developed a system using the inner tube of a bicycle tire that was slightly inflated attached to a halter and placed under the jaw of two Shorthorn dairy cows. An electrical switch was operated by the change in air pressure that occurred as the cow opened and closed the jaw against the rubber tube. This switch controlled a solenoid that moved a pen that drew on a paper chart as the jaw moved. The charts were interpreted by looking at the pattern of lines drawn. Areas of many lines with few pauses were determined to be eating, while ruminating was identified as patterns of lines that at regular intervals had short pauses.

Welch and Smith (1969) criticized this methodology indicating that the rubber balloon used as the sensor for jaw movement would not work as well during temperature changes because the contraction or expansion of the air in the closed system would cause a malfunction. In order to avoid this limitation they developed a device made on similar principles however it was modified to allow for air pressure to be equalized by way of a small leak allowing air to move in or out as needed. The device was successfully used to compare rumination time in sheep eating different types of harvested forages: early-cut orchardgrass, late-cut mixed grass, weedy oat straw, second cutting mixed alfalfa grass, or oat straw. They concluded that for every gram of cell wall constituents in a feed, sheep needed 1.05 min of time to ruminate, and for every gram of crude fiber in a feed, sheep would need 1.63 min of time to ruminate.

Stobbs and Cowper (1972) developed a more precise device that could not only record total time of jaw activities (grazing and ruminating) but also record the number of jaw movements (bites and mastications). The devices developed by Balch (1952) and Welsh and Smith (1969) were used on animals kept in stalls and were not very practical for use on grazing animals. The Stobbs and Cowper (1972) device consisted of two switches, the jaw switch and a mercury switch, and an electronic counter functioning as an electronic system as opposed to a pneumatic system used by Balch (1952) and Welsh and Smith (1969). A wire covered with plastic tubing was placed under the jaw and operated the halter mounted jaw switch. The switch was attached to a coil spring that was stretched when the jaw moved and distended the wire under the jaw. The mercury switch was located between the jaw switch and the electronic counter assembly recording the jaw movements. The mercury switch acted as the “on-off” button turning on when the head lowered when grazing. One of the problems with this device was battery power, which would last about 3 d. The devices were tested on dairy cows grazing Rhodes grass (*Chloris gayana* Kunth), pangola (*Digitaria decumbens* Stent), setaria (*Setaria sphacelata* (Schumacher) Moss), and alfalfa hay (*Medicago sativa* L.). The device was validated by comparing the data it recorded to visual recordings and achieved a correlation coefficient as high as $r = 0.97$, with the lowest being $r = 0.86$ over 25 recording sessions ($P<0.001$).

One of the more simple devices used in research to measure distance traveled has been the digital pedometer (Anderson and Urquhart, 1986; Walker and Heitschmidt, 1989). Anderson and Urquhart (1986) reported the average of readings from two pedometers placed one on each foreleg of 34 beef cows grazing arid rangeland. For several reasons, including pedometer malfunction, only 28 cows had data that could be analyzed. Data were calculated through an equation they developed for this experiment with a unique adjustment factor (A_F) that acted as a calibration for the pedometers. It was concluded that the distance traveled was dependent on management decisions that involve the area they are allowed to graze or stocking density. Overall the pedometers were a useful device. Scheibe et al. (1998) stated that to get an accurate explanation of behavior it is preferable to be able to measure at least two distinct patterns of behavior.

Vibracorders have been found to be useful to researchers over the years (Stobbs, 1970; Walker and Heitschmidt, 1989; Abaye et al., 1994; Seman et al. 1999). Vibracorders possess a pendulum that which swings, corresponding to the movement of the animal's head and the pendulum movement creates a series of marks on a paper chart that correspond to different activities. However, they have disadvantages in that they are heavy and the paper chart inside that must be changed periodically (Mosley et al., 1987).

Walker and Heitschmidt (1989) used a vibracorder and direct observation in conjunction with the pedometers to study the effect of different rotation stocking systems (14 paddocks vs 42 paddocks) and continuous stocking on behavioral patterns of a herd of beef cows grazing rangeland in Texas. Grazing time was divided into categories of intense and search grazing because of the different markings made on the vibracorder chart. Intense grazing was grazing time where the head was down for the majority of the time and search grazing was defined by more time with the head up during grazing. Grazing, walking, and sleeping time as well as daily distance traveled and individual animal space were estimated in trials conducted during each of the four seasons. There were significant differences between seasons for the different activities due mainly to differences in forage nutritive value. There was no difference in total time spent grazing between stocking treatments. However, cows in the continuous and 14-paddock treatments spent more time intense grazing. Time spent walking and distance traveled increased linearly from the continuous stocking, 14 paddock, and 42 paddock treatments. There was no difference in time spent sleeping between treatments.

Mosley et al. (1987) validated the use of electronic grazing clocks as a lightweight and economical alternative to vibracorders, but they had drawbacks. The device itself uses a mercury switch and a pulse generator to measure grazing time. They could not run for more than 24 h or document the exact time at which the grazing activity occurred. The setup of the clocks on the animals was not an easy task because the device had to be at a precise angle to the ground and this varied on each animal due to differences in animal height. Five yearling beef steers grazing weeping lovegrass (*Eragrostis curvula* (Shrad.) Nees) were fitted with both a grazing clock and a vibracorder. They found that grazing clocks underestimated total time grazing by 12.5% while the vibracorders overestimated it by 7.5%, compared to simultaneous visual observations made at 10 min intervals (Mosley et al., 1987).

Among researchers the guideline has been not to place devices such as these on animals if they weigh over 5% of BW (Cuthill, 1991). Blanc and Brelurut (1997, cited by Müller and Schrader, 2003) found that a GPS collar weighing 3.5% of red deer total body mass would result in a decrease in grazing activity. Langbein et al. (1996) used a passive infrared detector that detects animal presence through thermal gradients and then stores the information in a data logger. The device was placed at a commonly visited site such as a watering or saltlick location and gave information regarding diurnal and nocturnal activity of mouflon sheep during summer months. An infrared video camera was used to validate the activity data logger. They found a high percentage of activity at night contrary to that previously hypothesized.

Müller and Schrader (2003) used a device called the Actiwatch® activity monitoring system. This device was originally developed for human actigraphy studies looking at issues such as sleep disorders, Attention Deficit Hyperactivity Disorder (ADHD), pain assessment, and physical therapy (http://www.minimitter.com). These devices, placed on the distal metatarsus of 12 dairy cows in a free stall barn, were used for two-10 d periods to record the activity at 1 min intervals. The output from the devices was compared to time-lapse video recording for validation. It was useful in giving a general measure of the overall activity level in cows, but it could not discern more specific behavior patterns such as grazing or ruminating (Müller and Schrader, 2003).

The most common theme among the more recent devices has been a type of unit attached to the animal that will automatically record activities and the time at which they occurred, similar to a vibracorder, but with much more detail. Objectivity can be maximized with these type devices as compared with direct observation where biases can occur (Patterson et al., 1993). Error attributed to human involvement in the monitoring process could be reduced due to measurements instead being recorded by the device (Champion et al., 1997). Many of these devices can record for a full 24 h period. Visual observations over a full 24 h period have been made by humans in the past, however, this requires the use of night vision equipment (Langbein et al., 1996) or artificial light during the night (Hassoun, 2002) and/or the use of multiple observers which can increase the possible error as well (Martin and Bateson, 1993).

Dado and Allen (1993) recorded chewing activities of dairy cows in individual stalls with a device constructed of a halter mounted rubber bicycle tube filled with water connected to a pressure transducer and analog converter. Movement of the cow's jaw gave an output that could be translated as chewing or ruminating. Another rubber tube filled with water forming a balloon that was place in the reticulum via rumen fistula was used to monitor reticular motility. This produced an output similar to the jaw sensor. They compared the data recorded to visual observations made at 5-min intervals and found a high correlation between the two.

Matsui (1993) developed a data logger that worked on principals of electrical current being passed through a transducer constructed of silicone tubing packed with carbon granules fitted around an animal's jaw. The electrical resistance changed as the jaw opened and closed, stretching the transducer. Information from the data loggers was transferred to a computer and analyzed. Grazing and ruminating were differentiated by the length of pauses between jaw movements. They tested the device on a dairy heifer grazing Italian ryegrass (*Lolium multiflorum* Lam.), on a ewe fed hay, and on a goat fed a mixed diet. The device was similar to a previously used device which was validated compared to visual observations (Matsui and Okubo, 1990). This device was improved over the previous model weighing only 135 g and could record the total time spent grazing or ruminating for a 3 wk period.

Similar to the device of Matsui (1993), Rutter et al. (1997) developed a data logger and jaw movement sensor that in combination with a leg movement sensor developed by Champion et al. (1997) can measure time spent eating, ruminating, lying, standing, and number of steps taken. More specifically it can measure the number of prehensions and mastications by the animal while eating, and the number of mastications and boli during rumination for a 24 h period. The equipment for cattle weighs 1.5 kg (halter-mounted) while for sheep it weighs 2.0 kg (harness mounted on the back). They tested their device on ewes grazing white clover (*Trifolium repens* L.) and perennial ryegrass and compared results to visual observations made at 5-min intervals, obtaining a correlation of 0.91.

There may be an effect on animal behavior because of the extra handling that animals may be subjected to in order to get information out of devices, to change batteries, or for general repairs (Scheibe et al., 1998). Scheibe et al. (1998) designed their own unique data loggers. Their objective was to be able to record activity level and time spent feeding on a long-term basis without affecting the animal behavior. The system is called ETHOSYS®, and consists of a collar called the ETHOREC®, and a download station called the ETHOLINK®. The ETHOREC® collar had sensors to measure acceleration and head position and were placed on sheep and Przewalski horses. The collars could store data for a minimum of 1 wk and a maximum of 85 d. Data can be downloaded from the collars by way of a transmitter/receiver station, the ETHOLINK®, powered by solar panels. This makes the device suitable for use in wild animals that are not going to be easily accessible to retrieve the collars and periodically download recorded data. The station could function without maintenance for several months before the memory would reach the maximum capacity of data that it could download from the collars. Scheibe et al. (1998) conducted concurrent visual observations of horses on 15-min intervals with the use of a laptop computer and software called Observer 2.0 (www.noldus.com) on which the activity of one focal animal was recorded in nine sessions for validation purposes. To test correlation of activities in sheep a jaw movement sensor and data logger (APEC described below by Abijaoudé et al. 1999) were used. There were variations in some activities being over or under estimated. It was concluded that the system was useful for evaluating the diurnal patterns of animals, but not as useful for total time determination of specific activities such as grazing or ruminating (Scheibe et al., 1998).

Abijaoudé et al., (1999) used a device called the APEC (Appareil Portatif pour l'Etude du Comportement) consisting of a data logger and jaw movement sensor weighing 350g. It was a pneumatic system that could record continuously for 48 h. Jaw movements were recorded as the silicone tube under the jaw was compressed and air pulses traveled to the data logger and were changed into electrical signals. These signals could be stored and later analyzed as eating, rumination, number of boli, idling (no jaw movement), or other unidentified jaw movement. The device was tested on dairy goats placed in individual stalls and results validated by comparison to video recordings ($r = 0.99$).

Laca and Wallis DeVries (2000) stated that the work of Stobbs and Cowper (1972) and Rutter (1997) lacked one more dimension, to use the recorded sound produced during grazing to give a measure of intake in grams. Several studies were conducted in which a wireless microphone was attached to the forehead of the animal and the sound was recorded. Certain bandwidths were identified as corresponding with prehensions and mastications, or a compound jaw movement (prehensions and mastications simultaneously). They used the energy flux density of the recorded sound to estimate the bite mass. They concluded that this technology, with further research and improvement, could be a valuable tool for measuring forage intake.

Tall Fescue

Tall fescue is the most dominant grass used for pasture in the Southeastern U.S. covering over 14 million ha (Ball et al., 2002). There are three types of tall fescue: endophyte-infected (E+), endophyte-free (E-), and novel endophyte-infected. The endophyte (*Neotyphodium coenophialum*) is a fungus that has a symbiotic relationship with the plant making the plant hardier. However, this endophyte produces ergot alkaloids, the most predominant being ergovaline (Bacon, 1995). These alkaloids cause fescue toxicosis in cattle, which can be separated into three main syndromes: fescue foot, bovine fat necrosis, and summer slump/fescue toxicity (Ball et al., 2002). Hoveland (2003) described the appearance of beef cows grazing E+ tall fescue as being emaciated and having a haircoat covered with mud due to the time spent standing in water. One way to get tall fescue plants that do not have these toxic effects (E-) is to obtain E+ seeds that have been stored for several years in an area exposed to the environment under which conditions the endophyte dies. However, the strength that the endophyte gave the plant is lost, and it loses much of the tolerance for drought, heavy grazing, and resistance to disease and pests.

Peters et al. (1992) found that lactating Angus and Simmental x Angus cows grazing E+ compared with those grazing E- or orchardgrass (*Dactylis glomerata* L.)

during summer months had lower (*P*<0.01) milk production (6.0, 8.0, and 8.0 kg/d, respectively), higher BW losses (42, 9, and 13 kg, respectively) and lower calf ADG (0.72, 0.89, 0.88 kg·d-1, respectively). Forage availability and the average *in vitro* OM digestibility were not different (*P*>0.1) among treatments in June and August. Forage intake only differed (*P*<0.05) between the treatments when the temperature was above 32 ºC on a regular basis, at which point there was a decline in OM intake among those grazing E+ (1.6% of BW) compared to E- (1.9% BW) or orchardgrass (2.0% BW).

Howard et al. (1992) performed a study comparing the intake and behavior of six Angus steers grazing low-endophyte fescue (<1% infection) and E+ from May through September. Endophyte infected fescue had numerically greater forage mass than the low-endophyte fescue and this difference increased as the study progressed, which they explained by E+ having greater persistence in stressed conditions. Average OMI, NDF intake, and OM digestibility were similar (*P*>0.1) between treatments and across periods. No differences between treatments were found for percent OM, NDF, ADF, or CP. Between 0630 and 2130 visual observations were conducted and behavior was recorded for 1-min on 20-min intervals. When steers were grazing, only the number of bites taken during the 1-min observation period was counted. Steers grazing E+ spent less (*P*<0.05) time grazing (270 vs 335 min), more time idling (250 vs 190 min), more time standing (537 vs 507 min), less time lying (123 vs 164 min), and took less bites (9,100 vs 12,900 bites $\cdot$ d^{-1}) than cattle in the low-endophyte treatment. Howard et al. (1992) concluded that the differences in standing and idling could be explained as a response to environmental stress, and cited Low et al. (1981) suggesting that animals suffering from high temperatures spent more time standing to allow for evaporative cooling to increase. This is reasonable considering one of the symptoms of fescue toxicosis is heat intolerance (Ball et al., 2002). Weather conditions (maximum and minimum daily temperature, relative humidity, and temperature-humidity index (THI)) were also recorded and a linear regression equation for grazing time against these variables as well as forage mass and %DM was obtained. An interaction (P<0.01) between treatment and the THI was found, showing that E+ steers were sensitive to an increase in THI, reducing the time spent grazing.

Paterson et al. (1995) noted that in 10 studies conducted between 1983 and 1991 comparing steers grazing E+ to those grazing low endophyte tall fescue pastures there was a 30 to 100% decrease in ADG in steers grazing E+ compared to those grazing low endophyte fescue. A decrease of 0.045 kg in ADG and 0.15 kg/d in milk production for every 10% increase in the endophyte infection rate of a sward was observed (Garner et al., 1984; Crawford et al., 1989; Danilson et al., 1986). Annual loss of revenue due to reduced conception rate and thus reduced number of calves is estimated at $354 million while the reduction of calf weaning weights are another $255 million in loss (Hoveland, 1993).

A grazing study was conducted by Seman et al. (1997) with yearling Angus steers allotted to either E+ or E- Kentucky 31 tall fescue. For two periods during the month of May in two consecutive years, direct observations of behavior (grazing, standing, or lying) were conducted by trained observers on 1-min intervals for two 48 h periods. In order to observe the animals at night infrared scopes were used. During both years of the study steers in the E- treatment spent more time (P<0.05) grazing (1042, 1044, 1014, and 1095 min·48 h^{-1}; year 1- periods 1 and 2, year 2- periods 1 and 2, respectively) than in the E+ (799, 869, 701, 887 min·48 h^{-1}). Steers grazing E- also spent more (*P*<0.05) time lying (1237, 1461, 989, 1221 min·48 h^{-1}) than the E+ steers (918, 1097, 844, 955 min·48 h^{-1}), and the E- steers spent less (*P*<0.05) time standing (553, 369, 877, 563 min·48 h^{-1}) than E+ steers (1115, 900, 1335, min·48 h^{-1}). With further analysis of the data it was concluded that as the solar radiation reached its highest levels around 1200 MJ·$m^{2\ -1}$, the steers in the E- treatment grazed continuously while E+ steers discontinued their grazing activity. Additionally, the negative impact of temperature (average temperatures for the two years ranged from 18 to 22 ºC) and solar radiation on the grazing time of E+ steers was not only a function of current conditions but also from those of the previous 4 h as well.

A combination of characteristics between the two fescues (E+ and E-) has been found in novel endophyte infected fescue. It consists of inserting non-toxic strains of the fungus into E- tall fescue. Ball et al. (2002) explained that the novel endophyte infected fescue will have the persistence and hardiness of the E+, but without the toxic effects. Parish et al. (2003) showed that Angus crossbred heifers and steers grazing different varieties of non-toxic endophyte infected fescue (Jesup AR542- Kentucky 31 AR542, and Jesup AR502-Kentucky 31 AR502) had greater (*P*<0.05) ADG (0.82 kg) than those grazing E+ fescue (Kentucky 31 E+ and Jesup E+) (0.41 kg) from September to December with similar (*P*>0.05) gain (0.84 kg) in steers grazing E- (Jesup E- and Kentucky 31 E-) compared to non-toxic. Results from February to July also showed that ADG of steers grazing E+ (0.49 kg) was lower (*P*<0.05) than those grazing the two non-toxic varieties (0.73, 0.72 kg) and E- (0.71 kg).

Parish et al. (2003) also reported that the ADG of Hereford steers grazing different varieties of non-toxic endophyte infected fescue (Jesup AR542- Kentucky 31 AR542, Georgia 5 AR542, and Jesup AR502-Kentucky 31 AR502) were similar (*P*>0.05) (0.81, 0.92, 1.00) to those on E- (Jesup E- and Kentucky 31 E-) (0.87 kg) and greater (*P*<0.05) than E+ (0.56 kg) from September to December. Similar ADG were found from February to July, also showing non-toxic treatments (0.78, 0.95, 0.96 kg) were similar to E- (0.97 kg) and greater (*P*<0.05) than E+ (0.31 kg). Water usage by Hereford steers was higher (*P*<0.10) in the E+ treatment (0.168 $L \cdot kg\ BW^{-1} \cdot d^{-1}$) during April/May/June, compared with E- (0.098 $L \cdot kg\ BW^{-1} \cdot d^{-1}$) or non-toxic treatments (0.109 $L \cdot kg\ BW^{-1} \cdot d^{-1}$). Crude Protein (20.2, 20.0, and 20.4% of DM), NDF (48.2, 47.7, and 50.3% of DM), and ADF (27.6, 26.6, and 29.3% of DM) were similar between non-toxic, E-, and E+ respectively from March to June. Behavior data recorders (described by Rutter et al., 1997; Champion et al., 1997) were used on 12 steers for 5-d periods every month from March to June, and from September to November for the treatments of E+ (Jesup E+), E- (Jesup E-) and novel endophyte infected tall fescue (Jesup 542). Time spent idling for the months of April/May/June were higher (*P*<0.10) for E+ (31.5% of daily activity) compared to and non-toxic and E- (21.7 and 23.4%, respectively). Time spent ruminating was lower (*P*<0.10) for cattle grazing E- and E+ (34.7 and 32.4%, respectively) than cattle grazing non-toxic (39.7%) during April/May/June, with all other months being similar (*P*>0.10) among treatments. Time spent grazing was similar (*P*>0.10) among treatments for the months of March and September, however in April/May/June, steers grazing E+ had the lowest time spent grazing (36.1% of daily activity) similar to non-toxic (38.6%) but different (*P*<0.10) from E-(41.9%), E- being similar to non-toxic. During October/November steers grazing E+ had a grazing time of 40.5% of daily activity, similar to E- (41.2%), but less (P<0.10) than non-toxic (44.1%). Time spent lying and standing were similar (P>0.10) among treatments for September, and October/November. In March, time spent lying was lowest (P<0.10) in E+ (54.8% of daily activity), similar to E- (60.1%), but was highest in non-toxic (63.8%), non-toxic and E- being similar. In April/May/June, time spent lying was again lowest (P<0.10) in E+ (40.5% of daily activity) being different from E- (52.9%) and non-toxic (54.7%). The remaining percentages of the days were calculated as time spent standing. Biting rate and number of prehensions was lower (P<0.10) in E+ (48.4, 51.6 bites·min^{-1} grazing) (25024, 30130 bites·d^{-1}) than E- (56.3, 66.2 bites·min^{-1}grazing) (33973, 39264 bites·d^{-1}) or non-toxic (59.4, 65.7 bites·min^{-1} grazing) (33047, 41740 bites·d^{-1}) in April/May/June and October/November respectively.

Nihsen et al. (2004) found similar results to Parish et al. (2003). During the summer months steers grazing E+ had lower (P<0.05) ADG (0.34 kg) than those grazing two cultivars of novel endophyte infected fescue, HiMag4 and HiMag9 (0.60 and 0.54 kg, respectively) which had comparable gains to E-, HiMag- (0.61 kg). This higher ADG was attributed to a higher rate of forage intake, although this was not measured. Respiration rate was also higher (P<0.05) in E+ (107 breaths·min^{-1}) compared to novel (83, 83 breaths·min^{-1}) or E- (79 breaths·min^{-1}) treatments. It was also noted that steers stood longer in the shade or by the waterer when grazing E+ compared to those grazing novel endophyte or E- (Nihsen et al., 2004). These observations are consistent with those of Parish et al. (2003) who recorded that steers on E+ pastures spent more time standing and had a higher water intake than steers grazing E- or novel endophyte infected fescue.

Prairie Grass

Prairie grass is a relatively new grass to the Southeastern U.S. Its origins are traced to South America in the Pampas region of Uruguay and Argentina (Stewart, 1996). The cultivar 'Grasslands Matua' prairie grass was developed commercially in New Zealand in 1973 by Rumball et al. (1974) and listed as *Bromus catharticus* Vahl., however there has been confusion over the years relating to the proper taxonomic names to use (Stewart 1996). Currently Matua is referred to as *Bromus willdenowii* Kunth and the cultivar 'Grasslands Lakota' prairie grass has been released under the name *Bromus catharticus* Vahl. (Rumball and Miller 2003). Compared to 'Matua', 'Lakota' is not as susceptible to powdery mildew (*Blumeria graminis* (DC) Speer) because it has a more open and wider crown (Rumball and Miller 2003). It also has a less erect structure and does not head as early as 'Matua'. Stewart (1996) described prairie grass, *Bromus willdenowii* Kunth, as being palatable, high quality and endophyte free, but it needs a longer period of rest between grazing periods due to its intolerance to overgrazing. It is a cool-season bromegrass that grows better in cooler temperatures than many other types of forage (Abaye et al., 2002). Because of this it has the capability of being acceptable for winter grazing (Stewart, 1996). Abaye et al. (2002) also described prairie grass as being a good forage for producers to extend the grazing season because it is well adapted to growing the early spring and late fall.

In experiments conducted over 2 yr to determine forage yield in the Blacksburg, VA area the forage yield of Matua was higher (16 $t{\cdot}ha^{-1}$) than that of Kentucky 31 tall fescue (13.5 t·ha^{-1}) in 1998, and yields for both were just under 20 t·ha^{-1}in 1999 (Abaye et al., 2002). Adequate rainfall and lower temperatures may have been responsible for these yields compared to lower yields of Matua in other study locations in Orange and Blackstone, VA which experienced higher temperatures and less rainfall. They also conducted field trials to determine how compatible Matua was with different legumes and how these mixtures compare with monocultures. The yield of Matua/ alfalfa, Matua/ annual lespedeza (*Lespedeza stipulacea* Maxim.), or Matua monoculture were higher than Matua/ ladino clover (*Trifolium repens*) or Matua/ red clover (*Trifolium pratense* L.). Neutral detergent fiber was highest where the Matua was the highest percentage of the mixture, with the lowest being found in the red clover mixture.

LaCasha et al. (1999) compared Matua, coastal bermuda grass (*Cynodon dactylon* L.) and alfalfa hays as feed for horses. Nutritive values of the three hays were found to be similar. Alfalfa had the highest (P<0.001) voluntary DMI (3.1% BW), digestible DMI (6.9 kg·d^{-1}), and OMI (9.6 kg·d^{-1}) followed by Matua (2.8% BW, 5.1 kg·d^{-1}, and 8.8 kg·d^{-1}, respectively) which was higher (P<0.001) than bermudagrass (2.1% BW, 3.3 kg·d^{-1}, and 7.1 kg·d^{-1}, respectively). A selection trial was also conducted and horses preferred alfalfa (P<0.05) more than the other two grasses and preferred (P<0.05) Matua more than bermudagrass.

Xia et al. (1994) conducted a trial with Matua prairie grass/white clover mixtures to determine its persistence and productivity under different dairy cow management strategies in periods during the months of September, November, and January. Hard grazing was classified as having a 6 cm residual height and 1.5-2.5 t DM·ha^{-1}, and lax grazing was classified as having a 12 cm residual height and 2.5-3.5 t DM·ha^{-1}. Hard grazing on prairie grass lowered the number of tillers by 22% per plant ($P<0.08$) and by 37% per unit area ($P<0.06$). A higher ($P<0.01$) proportion of prairie grass (71.9% DM) was found in plots of the lax grazing treatment compared to hard grazing (61.0%). There was a greater ($P<0.001$) amount of dead material (36.4 vs 28.0% DM) as well as lower ($P<0.05$) percentage of the white clover present (12.2 vs 16.5% DM) in the lax grazing treatment compared to hard grazing. Total herbage mass was higher ($P<0.001$) in the lax grazing treatment in all three periods of the study (344.5, 267.7, and 199.2 g $DM{\cdot}m^{2-1}$, respectively) compared to hard grazing (155.2, 69.6, and 87.1 g $DM{\cdot}m^{2-1}$, respectively).

Shaffer et al. (1994) compared physical characteristics of Matua prairie grass with tall fescue and smooth brome grass (*Bromus inermis* Leyss). Over the 2yr study prairie grass plots had longer tillers ($P<0.05$) compared to tall fescue and smooth brome grass (51 vs 38 and 26 cm, respectively), a greater ratio of stem to leaf (0.95 vs 0.14 and 0.01, respectively), and more seed heads (15 vs 0.3 and 0.1, respectively). Over the 2 yr of the experiment, and after first harvest there were no differences ($P>0.05$) in mean tiller population, leaf yield and area, and stem yield; however, prairie grass had higher ($P<0.0001$) percentage of roots (from 130 to 310%) than the other two treatments at all depths measured.

Lowe et al. (1999a, 1999b) conducted a grazing trial with multiparous Holstein-Friesian cows grazing perennial ryegrass, Matua prairie grass, tall fescue, and Italian ryegrass, looking at pasture yield, persistence and quality, and milk production. Prairie grass and fescue had higher ($P<0.05$) average yields (2191 and 1980 kg $DM{\cdot}ha^{-1}$, respectively) than the Italian and perennial ryegrasses (1641 and 1567 kg $DM{\cdot}ha^{-1}$, respectively), average over the three years of the study. Italian, perennial ryegrass, and prairie grass had significant (*P*<0.05) weed encroachment (539, 477, and 535 kg $DM{\cdot}ha^{-1}$) compared with tall fescue (98 kg $DM{\cdot}ha^{-1}$). Nitrogen content, IVDMD, NDF, ADF, and ME were lowest (*P*<0.05) in tall fescue, highest for Italian ryegrass which was similar to perennial ryegrass, and in most seasons prairie grass was also similar. In some seasons prairie grass was similar to tall fescue. Milk yield was highest (*P*<0.05) for cows grazing perennial ryegrass and Matua (16.7 and 16.2 $kg{\cdot}cow^{-1}{\cdot}d^{-1}$, respectively) in year 1. Milk yield for cows grazing Matua were similar to Italian ryegrass (15.9 $kg{\cdot}cow^{-1}{\cdot}d^{-1}$) with tall fescue being the lowest (15.2 $kg{\cdot}cow^{-1}{\cdot}d^{-1}$). In year 2 all values were similar, and in year 3 Matua produced the highest milk yield (*P*<0.05) (22.6 $kg{\cdot}cow^{-1}{\cdot}d^{-1}$), with tall fescue and perennial ryegrass (22.4 and 22.4 $kg{\cdot}cow^{-1}{\cdot}d^{-1}$) being similar but numerically lower, and Italian ryegrass (21.0 $kg{\cdot}cow^{-1}{\cdot}d^{-1}$) was lowest.

Fulkerson et al. (2000) conducted a 3 yr grazing study comparing yield and nutritive value of Matua prairie grass, tall fescue, and perennial ryegrass under different grazing management. It was concluded that the DM yield of prairie grass (23.8 t $DM{\cdot}ha^{-1}$) was higher (*P*<0.001) than that of tall fescue (8.9 t $DM{\cdot}ha^{-1}$) or perennial ryegrass (7.7 t $DM{\cdot}ha^{-1}$). Heavy grazing significantly (*P*<0.05) reduced the amount of prairie grass surviving in the pasture for the next season. The Mg level in prairie grass was lower than that recommended for dairy cows (0.2% DM). Forage nutritive value was otherwise comparable to perennial ryegrass so they concluded that if grazing were to continue for extended periods, Mg supplementation would be necessary (Fulkerson et al., 2000).

OBJECTIVES

The objectives for this experiment were to: 1) determine the grazing behavior of cattle grazing different forages; 2) relate grazing behavior to nutritive value of forage, and 3) compare data collected from electronic behavior data recorders with data from visual appraisal of cattle grazing behavior.

EXPERIMENTAL PROCEDURES

Treatments

The forages for this experiment included Lakota prairie grass (L), Kentucky 31 endophyte infected tall fescue (E+), Kentucky 31 endophyte free tall fescue (E-), and Q4508-AR542 novel endophyte tall fescue (Q). These pastures were established during September 2002. Seeding rates were as follows: L 39.2 kg·ha^{-1}, E+ and E- 24.6 kg·ha^{-1}, and Q 23.5 kg·ha^{-1}at a planting depth of 1.3 cm for E+,E-, and Q, and 0.6 cm for L. Harmony® GT herbicide (Dupont™, Wilmington, DE) was sprayed in March 2003 at a rate of 3.65 ml·ha^{-1}. On March 30, 2004 paddocks of E- were reseeded at a rate of 21 kg/ha. On April 6, 2004, 33.6 kg·ha^{-1}of liquid nitrogen fertilizer was applied to all paddocks. On May 3, 2004 Grazon® P+D herbicide (Dow AgroSciences LLC, Indianapolis, IN) was applied to L paddocks. Approximately 74 kg/ha of 46-0-0 fertilizer were applied to each sub-paddock of L after being grazed by the steers for 7-10 d. Half of each paddock (3 sub-paddocks) was mowed for hay during the first week of June, 2004. On August 20, 2004, 56 kg·ha^{-1}of 46-0-0 fertilizer was applied to each treatment paddock.

The experimental area consisted of four pasture blocks each divided into four paddocks, one for each of the four treatments. Each treatment paddock was approximately 1.2 ha, divided into six sub-paddocks of approximately 0.19-0.20 ha. Steers were rotationally stocked between the sub-paddocks, grazing in each sub-paddock approximately 7-10 d before being moved to the next. Overall stocking rate was 2.7 steers·ha^{-1}, and the stocking density was 16.2 steers·ha^{-1}.

Animals

This research was conducted with 24 steers which were part of an experiment with 48 Angus and Angus crossbred steers. These steers were purchased December 1, 2003 at a Virginia feeder cattle sale and shipped to Smithfield Farm, Virginia Tech, Blacksburg, VA. Steers (BW = 207 ± 3.1 kg) were vaccinated for Infectious Bovine Rhinotracheitis (IBR), Bovine Viral Diarrhea (BVD), Bovine Respiratory Syncitial Virus (BRSV), Parainfluenza3 (PI3) with Pyramid 4® (Fort Dodge Animal Health, Fort Dodge, IA), and with Vision 7® (Intervet, Millsboro, DE) for *Clostridium chauvoei* (Blackleg), *septicum* (Malignant edema), *novyi* (Black disease), *sordellii* and *perfringens* Types C &D (Enterotoxemia). Steers were kept in dry lot from the date of purchase until May 4, 2004. From January 6 to May 4, 2004, steers were fed a diet consisting of 51% barley straw, 37% corn, and 5% molasses, with the remaining portion containing soybean meal, feather meal, and urea. Average daily gain (ADG) for steers during the drylot period was 0.64 kg.

All 48 steers were assigned to the four blocks and were allotted at random within blocks to the four treatments. Two of the four blocks were used for this experiment, hereafter referred to as Blocks 1 and 2. Twelve halter broken steers were allotted among three of the treatments (L, E+, and Q) with four steers per treatment, two steers in each of Blocks 1 and 2. Twelve behavior data recorders were available for use during the experiment. For proper statistical replication only three of the treatments could be used for the data recorder portion of this experiment. Steers (BW = 279 ± 8 kg) began grazing on May 5, 2004.

Trace mineral salt was not provided during the study due to the requirements of a concurrent experiment. At least one steer in every treatment had to be treated for infectious bovine keratoconjunctivitis (pinkeye) during the course of the experiment. These steers were treated with Bio-Mycin® 200 (Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO) at the prescribed dose of 0.1 ml/kg BW. Steers were also treated with Cydectin® (moxidectin) (Fort Dodge Animal Health, Fort Dodge, IA) for internal and external parasites at the beginning and midway through the study and with Elector® (spinosad) (Elanco™ Animal Health, Greenfield, IN) as needed for external parasites. Steers were also weighed on the day they were moved to the sub-paddocks for the behavior data recorder period, at 28 d intervals, for calculations of ADG.

Schedule for the experiment

The research consisted of two phases, an electronic behavior data recorder and a direct visual observation phase. The electronic behavior data recorder phase included the 12 trained steers in three treatments: L, E+, and Q. The direct visual observation phase included all 24 steers in Blocks 1 and 2, in the four treatments: L, E+, Q, and E-.

Visual appraisals of behavior activities were taken for four consecutive days from May through September at 28 d intervals. During the week following the visual appraisals, the behavior data recorders were placed on the animals for five consecutive days of data recording sessions from June through September. Animals were in one sub-paddock for each of the 4 d visual appraisal periods, and moved to the next sub-paddock 2 d before the beginning of the subsequent 5 d behavior data recorder session.

Electronic behavior data recorder phase

Training period Thirteen of the 48 steers were chosen on the basis of temperament and halter broken during the months of March and April 2004 (12 were needed for the behavior data recorder portion of the experiment and one additional). These animals were halter broken for ease of handling and to reduce the possibility of injury to people handling them during utilization of the behavior data recorders.

For several weeks prior to the start of the experiment, the 13 halter broken steers were familiarized to the behavior data recorders by wearing simulated versions of them in order to become accustomed to the weight and attachment of the various sensors during use of the true behavior data recorders during the experiment. These simulated versions consisted of the same custom halters that were used with the data recorders, a heavy-duty plastic box of similar size and weight as the data recorders. Also, coiled plastic cording of similar size and weight to the coiled wiring used to connect the leg sensor to the data recorder was used. Finally, plastic tubing attached to a Velcro® strap of similar size and weight to the true leg sensor was used to simulate the presence of the leg sensor was used.

Behavior data recorders Behavior data recorders developed by the Institute of

Grassland and Environmental Research (IGER) and made by Ultra Sound Advice, London, U.K. were used (Champion et. al, 1997; Rutter et al., 1997). The data from the devices were analyzed with Microsoft® Windows™ based software GRAZE, version 0.801 (Ultra Sound Advice, London, U.K.) (Rutter, 2000). The devices consisted of a computerized data logger, halter mounted jaw movement sensor, a leg position sensor, and a custom made halter. The data logger was attached to the halter on the left side of the neck. The jaw sensors fitted as a noseband on the animal and were a special construction of rubber tubing filled with graphite powder and attached to the data logger with electrical cable. Electrical current passed through the sensor and movement of the jaw resulted in a change in electrical resistance that when analyzed by the software was reported as a prehension, mastication, or other jaw movement dependent on the size and shape of the resultant energy waveforms when translated graphically.

The leg sensor was attached around the left front fetlock just above the fetlock joint on a Velcro® strap. The electrical cable from the leg sensor was attached to the leg just above the knee with elastic tape (Elastikon®), from there to another attachment point between the elbow and shoulder under a girth strap (Fisherbrand® Cohesive Flexible Bandages), and then was connected to the data logger. The leg sensor consisted of a mercury tilt switch encased in a 4 cm CPVC tube filled with flowable silicone all of which was surrounded with heat shrink tubing and attached to the data recorder with coiled electrical cording. If the sensor was in a vertical position, as when standing, the circuit was complete and the software analyzed the signal recorded in the data logger as standing. If the sensor was in a horizontal position, as when lying, the circuit was not complete and the software analyzed the signal recorded in the data logger as lying. Smaller movements of the leg, such as those occurring while walking, were distinguishable by the smaller intervals of time between which the circuit changed from complete to incomplete. The software analyzed the signal recorded in the data logger and distinguished the number of steps taken. Data were recorded onto 32 Mb CompactFlash™ memory cards in the data logger and downloaded to a personal computer through a USB 2.0 Flash Card Reader (StarTech.com). Each file was named according to the animal identification number and date of recording when downloaded.

GRAZE software analyses Specific settings in the GRAZE software (Rutter, 2000) were as follows:

Analyze Jaw Movement Settings

1. Minimum jaw movement Size (adc units): 30
2. Minimum inter-jaw movement interval (1/20s): 10

Identify Bouts

1. Minimum inter-bout interval (s): 3
2. Minimum number jaw movt per bout: 10

Identify steps and lying

1. Minimum step duration (number samples): 10
2. Maximum number inactive samples per step: 5
3. Minimum number of inactive samples between steps: 6

Auto-Mark Bouts

1. Minimum jaw movement size (adc units): 30
2. Minimum prehension sub-peak (adc units): 4
3. Minimum inter-jaw movement interval (1/20s): 10
4. Minimum no. jaw movement per bout: 10
5. Minimum inter-bout interval fixed at 3 s

Join Ruminating bouts

1. Minimum inter-ruminating bout interval (s): 20
   (bouts concatenated)

Join Grazing bouts

1. Minimum inter-meal interval for grazing (s): 420

Cattle bout analysis

1. Minimum pause between boli (s): 3
2. Minimum prehension sub-peak (adc units): 4
3. Minimum rise:total ratio for mastication (%): 40
4. Use 24 hr clock for times (checked box)

These were the default settings of GRAZE and deemed acceptable for the analysis. GRAZE output consisted of time spent in the following activities: grazing, ruminating, idling, and any undetermined jaw activity (could be assumed to be drinking, grooming, etc.). Number of grazing prehensions, grazing mastications, ruminating mastications, and ruminating boli were also calculated. The number of steps and time spent lying was also calculated by GRAZE and time spent standing was calculated with Microsoft® Office Excel™ by subtracting the total time lying from the total recording time.

Behavior data recorder sessions Data were collected in approximately 24 h periods over the 5 d session for the month of June. In July, August, and September the recording period was 48 h due to the availability of an EPROM (Erasable Programmable Read Only Memory) upgrade for the devices. Each animal was assigned a particular data recorder and only that animal wore that recorder throughout the experiment to eliminate any differences in output due to possible calibration differences between recorders. Animals were handled so that the memory cards could be removed and the batteries replaced, while still allowing for a full 24 or 48 h of recording time (Parish et al., 2003). On d 0 the recorders were placed on the animals starting at 0730. Animals were arranged in the working chute so that the animals in the treatment paddock furthest from the working facility were first and the other animals followed in order of decreasing distance of their treatment paddock from the working facility. When all the animals in one replicate group had been fitted with the individual data recorders that group was then walked from the working facility back to the treatment sub-paddock. This minimized the amount of time the animals were away from the grazing areas. Animals in the last replicate group were fitted with the data recorders and back in their pastures no later than 0915 on d 0. On d 1 in June animals in the first replicate group, those located furthest from the working facility, were walked from their pasture to the working facility starting at 0830. Each subsequent group was brought to the working facility, in order of decreasing distance from the working facility, in approximately 10 to 15 min intervals, making sure that no animals were taken from their pasture before a full 24 h period had passed since they were placed in their pasture on the previous day. On d 2 this process was repeated starting at 0930, d 3 at 1030, d 4 at 1130, and starting at 1330 on d 5 the devices were removed. Every day memory card data were downloaded to a computer, to be later analyzed with GRAZE software. For the months of July, August, and September, this process was repeated, except at 48 h intervals. Animals were handled on d 0 starting at 0730, d 2 at 0930, d 4 at 1130, and at 1330 on d 5 the devices were removed.

Direct visual observation phase

Observations started at dawn (0600) and continued until dusk (2000). On several of the observation dates there was heavy fog over the experimental area blocking a clear view of the animals so observations could not start until the fog cleared. The starting time on these days ranged anywhere between approximately 0615 and 0915. Animals were individually identified by wearing red, yellow, or white identification neck collars (Nasco™, Fort Atkinson, WI). For better observation of the animal activities binoculars (Bushnell®, Lenexa, KS, 8 X 30, model 11-8313CB) were used. Care was taken to observe animals from a great enough distance (50-150 m) so that they were not disturbed from their normal behavior. Datasheets with a coding system were utilized to make recording of observations as quick as possible. The activities recorded and their corresponding codes were as follows: Standing (S), Lying (L), or Walking (W) and Grazing (G), Ruminating (R), Drinking (D), or Idling (I). Standing was defined as the animal standing upright and feet stationary. Lying was defined as body touching the ground. Walking was defined as feet in motion. Grazing was defined as the harvest of forage. Ruminating was defined as masticating without taking additional forage into the mouth, also distinguishable by the distinct difference in the jaw movement as compared to mastications during grazing. Idling was defined as not grazing or ruminating, periods with no jaw movement (Howard et al., 1992). There were instances when it was not possible to observe the action of the jaw due to the position of the animal in relation to the position of the observer. In these instances the code "?" was used to indicate that jaw activity could not be identified.

Two trained observers per block were assigned to Blocks 1 and 2. One observer in each block recorded animal activities from 0600 until 1300, and the next observer recorded animal activities from 1300 until 2000. The observer watched all 12 animals in the block, recording the behavior code corresponding with the activity and the time to the nearest minute that the animal started the activity. The observers would then watch for a change in activity, note the new activity code and the new starting time on the datasheet and repeat this process throughout the day. Before the experiment began, observers were trained to recognize all the behaviors to be recorded. During these practice observation sessions it was found that one observer could keep track of all twelve animals in a block continuously.

Forage sampling and evaluation of pastures

On the day prior to animals being moved to a new sub-paddock, forage samples for nutritive value analysis were taken by walking an “X” pattern across the sub-paddock and taking a handful of forage every 10 to 15 steps. Samples were collected in individually labeled paper bags and dried in a forced draft oven at 60º C for a minimum of 48 h. Forage availability measurements were taken 24 to 48 h before both the 4 d visual appraisal periods and the 5 d behavior recording sessions began. Measurements were taken from each pasture treatment in the sub-paddock steers would be grazing during the visual and data recorder periods. Forage availability was determined by clipping three circular areas of 0.25m^2 at 2.5 cm above ground level. These clippings were placed in individually labeled cloth bags and dried in a forced draft oven at 60º C for a minimum of 72 h and then weighed. Forage samples from the E+, E-, and Q treatments were taken and analyzed for endophyte infection level at the end of the experiment (Agrinostics Ltd. Co., Watkinsville, GA). Pastures were evaluated for botanical composition on June 3, 2004 using the Double DAFOR scale (D=Dominant, A=Abundant, F=Frequent, O=Occasional, and R=Rare occurrences of both forages and weeds) (Abaye et al., 1997).

Forage analyses

The dried samples for nutritive value analysis were ground through a 1 mm screen using a Wiley mill (Thomas Wiley, Laboratory Mill model 4, Arthur H. Thomas Co. Philadelphia, PA). Percent DM was determined by placing samples in a 100º C oven for 24 h. After DM determination, percent ash was determined by placing these samples in a 500º C muffle furnace for 3 h (AOAC, 2000). Crude protein was calculated by analyzing N content of samples with a Perkin Elmer 2410 Nitrogen Analyzer utilizing the combustion method (AOAC, 2000). Neutral detergent fiber and ADF were analyzed with the ANKOM^{200} Fiber Analyzer (ANKOM Technology, Macedon, NY) (Goering and Van Soest, 1970). Cellulose and lignin were analyzed with the ANKOM Daisy II Incubator (ANKOM Technology, Macedon, NY, Goering and Van Soest, 1970). In vitro dry matter digestibility was determined with the Daisy II Incubator (Tilley and Terry, 1963). To determine mineral content, samples were first digested with a 2:1 (v/v) concentration of HNO_3:$HClO_4$ (Muchovej et al., 1986). Samples were then analyzed for Ca, Mg, K, Cu, and Zn with the flame method on a Perkin Elmer AAnalyst 800 Atomic Absorption Spectrometer (Perkin Elmer, Boston, MA). Phosphorus was determined by colorimetric procedure and analyzed on a Titertek Multiskan® MCC/340 (Titertek Instruments, Inc., Huntsville, AL, AOAC, 2000).

Environmental conditions

There were no areas of shade available within any of the treatment areas. Air temperature (ºC), soil temperature (ºC), relative humidity (RH, %), wind speed ($km{\cdot}h^{-1}$), solar radiation ($kW{\cdot}m^{2-1}$), and precipitation (mm) were also recorded on an hourly basis for the experimental period (VAES, 2005). Heat stress in cattle was measured by the Temperature Humidity Index which was calculated using the following equation (NOAA, 1976):

Air Temperature °F-(0.55 - (0.55 * RH % / 100)) * (Air Temp °F - 58.8)

Statistical analyses

Behavior data were analyzed with the MIXED procedure in SAS for analysis of variance for a randomized block design with a Tukey's adjustment. The model included treatment and treatment by month interaction. Month was the repeated measure and paddock was the experimental unit for the data recorder phase and steer was the experimental unit for the visual phase. Values are reported as least squares means.

Forage nutritive value data were analyzed using the GLM procedure in SAS. The model included treatment. Values are reported as least squares means.

The relationships between grazing behavior and forage nutritive value were analyzed using the CORR and REG (allowing only three variables in the model and using "maxr" for their selection) procedures in SAS. Variables included ruminating time, grazing time, idling time, rumination mastication, grazing mastications, prehensions, number of steps, lying time, CP, NDF, ADF, cellulose, lignin, Cu, Zn, P, forage mass, and IVDMD.

Data from the visual phase and data recorder phase were compared using the CORR procedure in SAS. Variables used were visual phase grazing time and recorder phase grazing time.

RESULTS AND DISCUSSION

Environmental conditions

Experimental period dates are presented in Table 1. Weekly averages for air temperature and precipitation during the experimental period are presented in Table 2. Hourly values for air temperature, soil temperature, relative humidity, wind speed, precipitation, and temperature humidity index are presented in Appendix 1. Air temperatures during the experiment did not deviate greatly from the normal temperatures for this area (NASS, 2005). Precipitation during the experiment varied between periods both above and below normal rainfall. Peters et al. (1992) reported that only when temperatures exceeded 32 ºC consistently during the month of August, there was a decline in DMI in cows consuming E+. On the other hand, when temperatures were consistently below 32 ºC there were no differences in DMI among cows grazing E+, E-, or orchardgrass. Aldrich et al. (1993) conducted a temperature controlled chamber experiment designed to mimic the environment conditions of the grazing trial of Peters et al. (1992). They fed diets containing E+ or E- seed to give a level of ergovaline similar to those found in the grazing trial. In one experiment with Angus heifers (BW = 244 kg) diurnal variations in temperature and humidity were evaluated and no differences in DMI were observed between heifers consuming E+ (3.45% BW) and E- (3.61% BW). In another experiment using Holstein steer calves (BW=114 kg) where temperature and humidity were held constant, skin vaporization was measured, concluding that calves consuming E+ were unable to dissipate excess heat only when temperatures were elevated and maintained at 32 ºC (E+, 47.1 kcal·m $^{2-1}$· h^{-1}; E-, 87.2

Table 1. Dates of behavior data collection periods.

Visual phase	Data recorder phase
May 24-27	
June 21-24	June 27- July 2
July 19-22	July 24-29
August 16-19	August 22-27
September 18-21	September 25-30

Table 2. Weather summaries for data collection periods[a]

Week ending	Phase	Temperature (ºC) High	Low	Avg	Departure from normal	Precipitation (mm) Total	Departure from normal
May 30	Visual	28.3	12.2	20.0	+3.9	68.8	+46.2
June 27	Visual	27.8	10	19.4	-1.1	33.8	+13.5
July 4	Recorder	28.9	11.7	20.6	-1.1	6.1	-16
July 25	Visual	28.3	12.8	20.6	-1.7	13.7	-9.4
August 1	Recorder	28.9	13.3	21.7	0	14.0	-9.1
August 22	Visual	29.4	13.3	20.0	-1.1	23.1	+1.8
August 29	Recorder	30.6	11.7	21.1	+1.1	5.8	-15.5
Sept 19	Visual	26.1	5.6	18.3	+1.7	40.6	+19.6
Sept 26	Vis/Rec	28.3	3.9	16.1	+1.1	0	-21.3
Oct 3	Recorder	25.6	10.6	16.7	+3.3	119.4	+98.0

[a] Adapted from NASS, 2005.

kcal·m $^{2-1}$· h^{-1}; significantly different P<0.05). When calves were maintained at 22 ºC heat dissipation was not different between cattle consuming E- (41.9 kcal·m $^{2-1}$· h^{-1}) and E+ (34.3 kcal·m $^{2-1}$· h^{-1}) (Aldrich et al., 1993).

In the present experiment (Table 3), while not significant, E- and E+ steers were consuming numerically less forage (1.67 and 1.78% BW, respectively) than those in E- (2.20% BW), or L (1.99% BW) during a week in which temperatures never were above 29.7 ºC. Throughout the study the temperature was never above 30.7 ºC, however a distinct difference in activity of steers consuming E+ compared to steers in the other treatments was observed with cattle in E+ exhibiting signs of heat stress. Brody et al. (1955) suggested that the critical low temperature of the day must be 21 ºC or less in order for cattle to lose the excess body heat gained during high daytime temperatures. Low temperatures in the present study were well below 21 ºC, ranging between 3.9 ºC and 13.3 ºC. This indicates that cattle should have been able to effectively dissipate excess body heat during the low temperature periods of the day; however steers consuming E+ were still showing signs of heat stress.

Temperature humidity index (THI) values for the experimental periods are presented in Table 4 and a THI chart with related heat stress levels are presented in Appendix 2. Under the conventional definition these values indicated that the majority of the time the cattle were not experiencing temperatures and humidity levels that would cause heat stress (NOAA, 1976). In this study, cattle grazing E+ pastures were exhibiting symptoms of fescue toxicosis (heat stress and reduced DMI) under environmental conditions considered to be mild to no stress for cattle. The use of the conventional THI for beef cattle in this experiment was not explanatory of the physical

Table 3. Bite mass and dry matter intake [a] of steers during July 7th to13th (2004) determined using a controlled release device with C_{32} and C_{36}.

	Intake			
Forage	kg · d^{-1}	% of BW	g · kg $BW^{-1} \cdot d^{-1}$	Bite mass, g · $bite^{-1}$
E+	5.17	1.78	17.2	0.14
E-	6.11	2.20	18.8	-
L	6.44	1.99	18.4	0.15
Q	5.10	1.67	16.0	0.12

[a]Adapted from Gregory and Scaglia, 2005.

Table 4. Percentage of time at which Temperature Humidity Index (THI) values fell within different heat stress levels.

Phase	Period	Heat Stress Level			
		No stress	Mild	Moderate	Severe
		----------------------% of observation period-----------------			
Visual	May	64	36	0	0
	June	77	23	0	0
	July	66	34	0	0
	August	68	29	3	0
	September	100	0	0	0
Recorder	June	72	28	0	0
	July	57	43	0	0
	August	66	33	1	0
	September	93	7	0	0

condition of the animals in the E+ treatment, indicating that their thresholds for heat stress should be considered differently from those consuming non-toxic forages. Cattle showing symptoms of fescue toxicosis are much more sensitive to heat and humidity than those not suffering from the toxicosis due to reduction of blood flow to peripheral tissues (Rhodes et al., 1991). The THI values probably should not be used to determine if cattle were suffering from heat stress but rather if the environmental conditions were a causative agent of the stress.

Forage composition, IVDMD, and pasture evaluation

Forage nutritive values are presented in Table 5. Crude protein, NDF, and ADF values for tall fescue were comparable to values reported by the NRC (2000). Mortimer et al. (1999) analyzed tall fescue samples from eight states in the southeast and reported an average value of 9.8% CP for tall fescue, lower than values reported in this study, and 44.0% ADF, higher than the values in this study. Nutritive values for L are not available in the NRC (2000). Results from minerals analyses are presented in Table 6. Calcium values were on average lower for tall fescue than those reported by the NRC (2000) and by Mortimer et al. (1999), who reported a Ca value of 0.51%, and Fisher et al. (2003), who compiled tall fescue samples from 72 locations in Tennessee, and reported a Ca value of 0.49% in spring. Values for Mg, K, and P were similar to the values reported by the NRC (2000) and Fisher et al. (2003), who reported similar values of Mg (0.22%), K (2.7%), and P (0.34%) in tall fescue. Mortimer et al. (1999) reported a value of 0.27% for P for tall fescue which is lower than values reported here. Copper levels for all pastures were lower than the NRC(2000) recommendation of 10 $mg \cdot kg^{-1}$ for

Table 5. Nutritive value least squares means for Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Kentucky 31 endophyte free tall fescue (E-), and Q4508-AR542 novel endophyte tall fescue (Q).

Period	Forage	Dry matter	Ash	Crude protein	NDF	ADF	Cellulose	Lignin	IVDMD
		---%---	---%[a]---						
May	E+	93.8[b]	7.7[b]	12.6[b]	62.2	33.9[c]	13.9[bc]	2.5	62.3[b]
	L	93.5[bc]	6.6[c]	10.6[cd]	65.5[bc]	35.7[bc]	14.5[bc]	2.8	57.4[c]
	Q	93.1[c]	7.6[b]	12.4[bc]	61.8[d]	34.4[c]	13.1[c]	3.5	57.3[c]
	E-	93.2[c]	6.7[bc]	9.8[d]	66.9[b]	37.0[b]	15.3[b]	2.7	54.6[c]
	SEM	0.10	0.20	0.41	0.74	0.49	0.38	0.40	1.00
June	E+	94.2	8.8[b]	15.7	63.4[d]	37.8[d]	13.2[c]	4.9[d]	59.9[b]
	L	93.9	7.8[cd]	14.5[b]	69.5[b]	43.8[b]	12.9[c]	8.3[b]	52.0[c]
	Q	94.1	8.2[c]	13.1[c]	66.8[c]	40.8[c]	13.4[c]	6.1[c]	54.1[c]
	E-	94.2	7.6[d]	11.3[d]	68.6[bc]	42.7[bc]	15.0[b]	5.5[cd]	51.7[c]
	SEM	0.08	0.15	0.46	0.69	0.67	0.25	0.35	1.05
July	E+	95.5[bc]	8.3[bc]	13.6[bc]	57.4[d]	31.9	13.1[c]	2.1	65.7[b]
	L	95.9[b]	7.3[c]	14.1[b]	62.2[b]	36.5	13.9[b]	3.7	60.6[c]
	Q	95.7[b]	8.8[b]	12.7[c]	61.2[bc]	33.5	13.0[c]	2.7	60.3[c]
	E-	94.5[c]	7.9[bc]	14.0[b]	58.6[cd]	32.7	12.3[d]	3.5	63.8[b]
	SEM	0.21	0.24	0.23	0.72	0.90	0.18	0.40	0.73
Aug	E+	94.0	8.7[b]	12.6[d]	62.6[b]	34.5	11.7	4.8	60.4[bc]
	L	94.2	8.1[bc]	15.4[b]	62.1[c]	36.1	13.0	4.6	65.7[b]
	Q	94.2	8.4[b]	14.7[bc]	64.8[b]	34.9	13.0	3.8	55.9[cd]
	E-	94.0	7.1[c]	13.9[c]	65.9[b]	36.4	13.2	4.4	53.5[d]
	SEM	0.09	0.22	0.31	0.66	0.46	0.37	0.25	1.50
Sept	E+	95.0	8.1[b]	21.3[b]	55.9[b]	27.0[cd]	11.6	1.4	70.7
	L	95.1	9.1[b]	22.5[b]	55.4[c]	28.3[b]	12.0	1.7	70.9
	Q	94.9	8.0[c]	18.7[c]	57.5[b]	28.1[bc]	11.7	1.8	68.1
	E-	95.1	8.1[b]	22.4[b]	55.5[c]	26.7[d]	11.6	1.4	69.7
	SEM	0.04	0.14	0.44	0.32	0.26	0.15	0.19	0.78
Overall	E+	94.5	8.3[b]	15.2	60.3	33.0	12.7	3.2	63.8[b]
	L	94.5	7.7[cd]	15.4	62.9	36.1	13.3	4.2	61.3[c]
	Q	94.4	8.2[bc]	14.3	62.4	34.3	12.8	3.6	59.1[d]
	E-	94.1	7.5[d]	14.3	63.1	35.1	13.5	3.5	58.6[d]
	SEM	0.10	0.10	0.41	0.51	0.56	0.16	0.23	0.75

[a] Dry matter basis

[bcd] Different superscripts within column within period are significantly different (*P*<0.05)

Table 6. Mineral composition least squares means for Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Kentucky 31 endophyte free tall fescue (E-), and Q4508-AR542 novel endophyte tall fescue (Q) [a].

Period	Forage	Ca	Mg	K	P	Cu	Zn
		------------------------%		-----------------------		------- mg·kg^{-1}-----	
May	E+	0.28	0.24 ^{b}	2.6 ^{bc}	0.35	1.7 ^{c}	17.2 ^{b}
	L	0.33	0.19 ^{c}	2.1 ^{d}	0.27	3.1 ^{b}	18.3 ^{b}
	Q	0.26	0.24 ^{b}	2.8 ^{b}	0.34	2.1 ^{b}	18.2 ^{b}
	E-	0.27	0.24 ^{b}	2.3 ^{cd}	0.31	2.2 ^{b}	15.3 ^{c}
	SEM	0.01	0.01	0.11	0.02	0.23	0.40
June	E+	0.28 ^{c}	0.29 ^{b}	2.85	0.46	1.6 ^{c}	17.6
	L	0.44 ^{b}	0.22 ^{d}	2.54	0.37	2.4 ^{b}	18.1
	Q	0.30 ^{c}	0.28 ^{bc}	2.54	0.41	2.2 ^{b}	19.5
	E-	0.23 ^{d}	0.26 ^{c}	2.63	0.37	1.5 ^{c}	18.7
	SEM	0.02	0.01	0.07	0.02	0.13	0.68
July	E+	0.39 ^{c}	0.37 ^{b}	2.3	0.52	2.5 ^{c}	15.3 ^{c}
	L	0.46 ^{b}	0.24 ^{d}	2.2	0.46	3.7 ^{b}	18.1 ^{bc}
	Q	0.32 ^{d}	0.30 ^{c}	2.8	0.50	2.6 ^{c}	15.2 ^{c}
	E-	0.37 ^{c}	0.34 ^{b}	2.3	0.50	3.1 ^{bc}	20.9 ^{b}
	SEM	0.01	0.01	0.12	0.03	0.16	0.88
Aug	E+	0.33 ^{c}	0.33 ^{b}	3.2 ^{b}	0.46	2.9 ^{d}	15.5 ^{c}
	L	0.53 ^{b}	0.27 ^{c}	2.6 ^{b}	0.40	4.5 ^{b}	20.3 ^{b}
	Q	0.32 ^{c}	0.31 ^{b}	2.8 ^{b}	0.46	3.5 ^{cd}	18.3 ^{b}
	E-	0.31 ^{c}	0.33 ^{b}	2.0 ^{c}	0.45	3.6 ^{c}	18.2 ^{bc}
	SEM	0.02	0.01	0.17	0.03	0.19	0.60
Sept	E+	0.40 ^{c}	0.38 ^{b}	2.5	0.45	6.7 ^{bc}	22.7 ^{c}
	L	0.47 ^{b}	0.32 ^{c}	2.8	0.38	7.1 ^{b}	26.0 ^{b}
	Q	0.34 ^{d}	0.31 ^{c}	2.5	0.41	6.0 ^{c}	22.6 ^{c}
	E-	0.39 ^{cd}	0.34 ^{bc}	2.7	0.42	7.0 ^{b}	26.1 ^{b}
	SEM	0.01	0.01	0.07	0.02	0.17	0.57
Overall	E+	0.34 ^{c}	0.32 ^{b}	2.7 ^{b}	0.45	3.1	17.7 ^{c}
	L	0.45 ^{b}	0.25 ^{d}	2.4 ^{bc}	0.38	4.2	20.2 ^{b}
	Q	0.31 ^{c}	0.29 ^{c}	2.7 ^{b}	0.43	3.3	18.8 ^{bc}
	E-	0.31 ^{c}	0.30 ^{bc}	2.3 ^{c}	0.41	3.5	19.9 ^{bc}
	SEM	0.01	0.01	0.05	0.01	0.21	0.41

[a] Dry matter basis

[bcd] Different superscripts within column within period are significantly different (P <0.05)

growing and finishing cattle. Copper has been shown to be lower in E+ pastures compared to E- in previous research (Dennis et al., 1998). They reported Cu concentrations of Kentucky 31 tall fescue in full bloom to be higher ($P<0.05$) in E- (4.1 $mg \cdot kg^{-1}$) than E+ (3.6 $mg \cdot kg^{-1}$). In the present study, during the months of May and June tall fescue was in full bloom while in July, August, and September was in the regrowth stage. Dennis et al. (1998) reported Cu concentrations for Kentucky 31 tall fescue in regrowth stage of 5.7 mg/kg in E- and 5.4 $mg \cdot kg^{-1}$ in E+. Zinc levels in the present study were below the NRC recommended level of 30 $mg \cdot kg^{-1}$ in all pastures, but were comparable to the value reported for tall fescue by the NRC (2000). However, Fisher et al. (2003) reported a slightly higher value compared to the present study (24.92 $mg \cdot kg^{-1}$).

Evaluation of pastures using the DAFOR procedure is presented in Table 7. There was an encroachment of orchardgrass (*Dactylis glomerata*) in all forage treatments at “Abundant”, “Frequent”, and “Occasional” levels on the DAFOR scale. Kentucky bluegrass (Poa pratensis) and quackgrass (*Elytrigia repens*) were also present in most forage treatments at lower abundance than orchardgrass, at levels of “Occasional” and “Rare” in most instances. Percent ground cover was above 92% in all replicates and only 1% weed encroachment was observed.

Forage mass and forage allowance are presented in Table 8 for the visual phase and in Table 9 for the data recorder phase. In the present study, overall E- tended to have the lowest forage mass but within month differences between treatments were observed. Forage mass during all periods for all treatments were not at levels considered to be limiting animal performance. Paterson et al. (1994) suggest that when

Table 7. DAFOR evaluation for Kentucky 31 endophyte infected tall fescue (E+), Kentucky 31 endophyte free tall fescue (E-), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q) from June 3, 2004.

	Forage and replicate							
	E+		E-		L		Q	
Parameters	1	2	1	2	1	2	1	2
Ground Cover, %	95	97	90	93	95	92	95	95
Grass, %	99	99	99	99	99	99	99	99
Legume,%	0	0	0	0	0	0	0	0
Weed, %	1	1	1	1	1	1	1	1
Visual $kg \cdot ha^{-1}$	4500	5500	3500	4200	4000	3700	3250	4500
<u>Grasses</u>	Relative abundance[a]							
E+	5	5	0	0	0	0	0	0
E-	0	0	5	5	0	0	0	0
L	0	0	0	0	5	5	0	0
Q	0	0	0	0	0	0	5	5
Orchardgrass	4	3	3	4	2	5	2	1
Bluegrass	1	1	1	1	1	3	0	1
Bromus spp.	0	0	1	0	0	0	0	0
<u>Weeds</u>								
Quackgrass	0	0	0	1	1	1	0	0

[a]Dominant=5, Abundant=4, Frequent=3, Occasional=2, Rare=1, Not present=0

Table 8. Forage mass (FM) and forage allowance (FA) for visual phase for Kentucky 31 endophyte infected tall fescue (E+), Kentucky 31 endophyte free tall fescue (E-), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).

		Forage				
Period	Dry matter mass	E+	E-	L	Q	SEM
May	FM, kg·ha^{-1}[a]	5244 [b]	4248 [c]	4148 [c]	5312 [b]	186
	FA, kg · kg BW^{-1}	1.25	0.99	0.91	1.19	
June	FM, kg·ha^{-1}[a]	3260	3948	3232	3684	197
	FA, kg · kg BW^{-1}	0.77	0.92	0.70	0.82	
July	FM, kg·ha^{-1}[a]	3020 [bc]	2572 [c]	3484 [b]	2844 [bc]	158
	FA, kg · kg BW^{-1}	0.69	0.56	0.70	0.60	
August	FM, kg·ha^{-1}[a]	3628	3588	3924	3660	138
	FA, kg · kg BW^{-1}	0.82	0.75	0.77	0.76	
September	FM, kg·ha^{-1}[a]	3652 [bc]	3288 [c]	3728 [bc]	4076 [b]	127
	FA, kg · kg BW^{-1}	0.78	0.63	0.68	0.81	
Overall	FM, kg·ha^{-1}[a]	3760	3528	3703	3915	83
	FA, kg · kg BW^{-1}	0.85	0.76	0.75	0.83	

[a] Least squares means
[bc] Different superscripts within row within period for kg·ha^{-1} are significantly different (P<0.05)

Table 9. Forage mass (FM) and forage allowance (FA) for data recorder phase for Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).

		Forage			
Period	Dry matter mass	E+	L	Q	SEM
June	FM, kg·ha^{-1}[a]	4276	3736	4304	164
	FA, kg · kg BW^{-1}	1.01	0.81	0.96	
July	FM, kg·ha^{-1}[a]	2660 [c]	3716 [b]	2600 [c]	189
	FA, kg · kg BW^{-1}	0.60	0.75	0.55	
August	FM, kg·ha^{-1}[a]	2924	3075	2892	147
	FA, kg · kg BW^{-1}	0.66	0.61	0.60	
September	FM, kg·ha^{-1}[a]	3880	4120	4028	201
	FA, kg · kg BW^{-1}	0.82	0.75	0.80	
Overall	FM, kg·ha^{-1}[a]	3435	3661	3456	101
	FA, kg · kg BW^{-1}	0.78	0.74	0.73	

[a] Least squares means
[bc] Different superscripts within row within period for kg·ha^{-1} are significantly different (P<0.05)

IVDMD is above 60% and forage availability is at or below 500 kg·ha^{-1}, or when IVDMD is between 50-60% that forage availability at 1000 kg·ha^{-1}or below a negative effect on performance could be observed. Parish et al. (2003) reported forage availability for spring and summer months of E+ (3689 kg·ha^{-1}) to be higher (*P*<0.05) than E- (2,759 kg·ha^{-1}) and novel endophyte infected tall fescue (2778 kg·ha^{-1}). In the present study there was no difference overall in forage mass however there were some differences found in certain months. Howard et al. (1992) reported forage availability of low endophyte infected tall fescue (3027 kg·ha^{-1}) to be numerically lower than E+ (3649 kg·ha^{-1}). Peters et al. (1992) reported forage availability in June in two years for E+ (4789 kg·ha^{-1}and 5561 kg·ha^{-1} respectively) to be numerically higher than E- (3890 kg·ha^{-1}and 3436 kg·ha^{-1}), while in August E- (2796 kg·ha^{-1} and 3133 kg·ha^{-1}) was numerically higher than E+ (2053 kg·ha^{-1}and 2518 kg·ha^{-1}).

Endophyte infection levels are presented in Table 10. In the present study E+ pastures were 80 and 85% infected, while Q was 90% infected. The E- pastures were endophyte-free with a 0% infection rate. Parish et al. (2003) reported mean endophyte infection levels of 94.5% for E+, 87.3% for novel endophyte, and 2.7 % for E- from February to July. Howard et al. (1992) reported E+ endophyte infection level of 60% and <1% for low-endophyte infected pastures.

Direct visual observation phase

Results for the visual appraisal phase are presented in Table 11. No interactions of treatment by month were found for grazing time, but treatment effects (*P*<0.05) were found. Overall, time spent grazing was higher (*P*<0.05) for steers grazing L compared

Table 10. Endophyte infection level of Kentucky 31 endophyte infected tall fescue (E+), Q4508-AR542 novel endophyte tall fescue (Q), and Kentucky 31 endophyte free tall fescue (E-).

	Forage		
Replicate	E+	Q	E-
	---% ---		
Block 1	85	90	0
Block 2	80	90	0

Table 11. Least squares means for time spent grazing (G), drinking (D), ruminating (R), idling (I), unidentified jaw activity (U), lying (LY), and standing (S) for visual observation phase (0600 to 2000) for Kentucky 31 endophyte infected tall fescue (E+), Kentucky 31 endophyte free tall fescue (E-), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).

		Jaw activity					Leg activity	
Period	Forage	G	D	R [a]	I [a]	U [a]	LY	S
		$min \cdot d^{-1}$						
May	E+	443	6	44	71	230	178	618
	E-	426	9	28	85	246	213	583
	L	464	10	75	109	136	196	599
	Q	456	12	126	73	127	251	545
June	E+	441	8	75	152	164	220	621
	E-	409	6	16	77	333	343	498
	L	486	14	116	147	76	283	558
	Q	440	9	80	80	231	326	515
July	E+	326	13	163	198	77	228	550
	E-	362	8	202	145	58	290	486
	L	396	13	85	72	209	271	506
	Q	332	12	126	115	191	336	441
Aug	E+	370	13	83	159	148	165	609
	E-	414	10	113	95	141	255	519
	L	452	12	93	139	78	204	572
	Q	389	18	134	145	88	277	498
Sept	E+	265	28 [b]	105	246	80	174	552
	E-	328	9 [c]	152	198	40	215	513
	L	341	11 [c]	136	160	78	237	489
	Q	359	13 [c]	99	144	106	248	574
All months	SEM	22	2	18	20	27	25	33
Overall	E+	369 [d]	13 [c]	94	165 [c]	140	193 [d]	590 [c]
	E-	388 [cd]	8 [d]	102	120 [d]	163	263 [c]	520 [cd]
	L	428 [c]	12 [cd]	101	125 [d]	115	238 [cd]	545 [cd]
	Q	395 [cd]	13 [c]	113	112 [d]	149	288 [c]	515 [d]
	SEM	12	1	12	10	14	16	17

[a] Statistical analysis only reported for months overall for R, I, and U, not individual months

[b] d =14 h

[cd] Different superscripts within column within period are significantly different (*P*<0.05)

to steers grazing E+. Grazing time for L was numerically, but not significantly higher than Q and E-. Steers grazing E+ had numerically lower grazing time than Q and E-. Parish et al. (2003) reported that steers grazing E+ spent less (P<0.10) time (36.1% of daily activity) grazing in April/May/June than cattle in E- treatments (41.9%), while spending a similar amount of time grazing when compared to steers in novel endophyte infected tall fescue treatment (38.6%). During September grazing times were similar across all treatments (34.9, 36.4, and 34.5% for E+, E-, and novel, respectively). Seman et al. (1997) conducted visual observations of Angus steers (BW = 242 kg in yr 1, 259 kg in yr 2) and reported that grazing time (average of two observations in 2 yr converted from 48 h format to a 24 h format) for steers grazing E- (524 $min \cdot d^{-1}$) was higher (P<0.05) than for those grazing E+ (477 $min \cdot d^{-1}$). In addition they noted that cattle in E+ stopped grazing during the hotter periods of the day while cattle in E- continued grazing. Average high temperature of the observation periods of the 2 yr ranged between 18.3 to 22.4º C. This was observed in the present study as well with temperatures higher than they reported. Howard et al. (1992) reported comparable results from visual observations of Angus steers (BW = 326 ± 14.7 kg) conducted from 0630 to 2130. Steers grazing E+ spent less time (P<0.05) grazing (270 min) than cattle grazing low-endophyte infected tall fescue (335 min). The maximum temperature reached 32º C and the low temperature was 12º C.

Overall, time spent drinking was higher (P<0.05) for steers grazing E+ and Q (13 and 13 $min \cdot d^{-1}$, respectively) than steers grazing E- (8 $min \cdot d^{-1}$) with drinking time for steers grazing L being intermediate (12 $min \cdot d^{-1}$). While the amount of water intake was not measured in this study it could be assumed that there is a correlation between amount of time spent drinking and amount of water intake. Parish et al. (2003) reported that steers grazing E+ in April/May/June had higher water consumption (0.168 L · kg $BW^{-1} \cdot d^{-1}$) than steers grazing E- (0.098 L·kg $BW^{-1} \cdot d^{-1}$) or novel endophyte infected tall fescue (0.109 L·kg $BW^{-1} \cdot d^{-1}$). In that study in-line water flow meters were used to record the water usage by the cattle. In the present study this type of meter could not be used due to the type of waterer used. The open tub design of the waterers (Figure 1) allowed steers to splash water out of the tubs, which was observed in the E+ treatment. During the visual observation phase time spent playing in the waterers by steers in the E+ treatment was not reported as drinking time and was delineated separately during the recording of activities.

Upon analysis of the data collected during the direct visual observations it was determined that due to the high amount of time that was defined as “unidentified” behavior (time when the observer’s view of jaw activity was obstructed), accurate statistical analyses of time spent ruminating or idling could not be performed for individual periods. These “unidentified” times were always when the steers were either laying down or standing with head up and were never during times when the animal was standing with head down and grazing. Therefore grazing time can stand alone in the statistical analyses. These missing observations are a drawback to the direct visual observation technique as a tool to monitor animal behavior. If this method is to be used in research, arrangements should be made to minimize the likelihood of obstructed views thus ensuring the accountability of all different behaviors. Possible solutions to the problem in this particular experiment would have been to have multiple observers from different vantage points as well as remove possible obstructions from the

Figure 1. Picture taken on July 13, 2004 in mid-afternoon, of E+ steers (in foreground) suffering heat stress due to fescue toxicosis, cooling themselves in water they splashed out of waterers (shown to the right). In the background, steer grazing E- are shown grazing and not suffering from heat stress.

experimental area, such as overgrowth along the fences, and not allowing forage to become overgrown in the paddocks. Some obstructions would not be removable such as fence posts, or another animal standing in the line of sight.

Assuming that with all months combined there were no differences between the least squares means of unidentified activity time for all four treatments, then the overall time spent idling and ruminating could be compared with reasonable accuracy. In this case time spent idling for steers grazing E+ was higher (P<0.05) than all other treatments, with ruminating time being similar across treatments (Table 11). These results are comparable to several previous studies. Howard et al. (1992) reported that during daily observations from 0630 to 2130, Angus steers grazing E+ spent more time (P<0.05) idling (250 min) than cattle grazing low-endophyte infected tall fescue (190 min). Parish et al. (2003), reported that steers in E+ treatments spent more time (P<0.10) idling (31.5% of daily activity) than steers in E- (23.4%) and novel endophyte infected tall fescue treatments (21.7%), and reported similar time spent ruminating among those three treatments (32.5, 34.7, and 39.7% for E+, E-, and novel, respectively).

In the present study steers grazing Q and E- spent more (P<0.05) time lying (288 and 263 $min{\cdot}d^{-1}$, respectively) than those grazing E+ (193 $min{\cdot}d^{-1}$) while time spent lying in L was intermediate (238 $min{\cdot}d^{-1}$). Similar results were reported by Seman et al. (1997) where steers grazing E- spent less (P<0.05) time standing (295 $min{\cdot}d^{-1}$), and more time lying (477 $min{\cdot}d^{-1}$) than steers grazing E+ (549 $min{\cdot}d^{-1}$ and 614 $min{\cdot}d^{-1}$, for standing and lying time, respectively). Howard et al. (1992) reported that between 0630 and 2130, steers grazing low-endophyte infected tall fescue spent more time (*P*<0.05) lying (164 min) than cattle grazing E+ (123 min).

Electronic behavior data recorder phase

Data recorders used in this experiment are shown in Figure 2. Results for jaw activity of individual periods of the data recorder phase are presented in Figure 3 and overall results are presented in Figure 4. No effect of treatment and no interactions of treatment by month were found for grazing time. Overall, grazing time for steers grazing L (644 $min{\cdot}d^{-1}$) was numerically higher than for those grazing Q (588 $min{\cdot}d^{-1}$) or E+ (584 $min{\cdot}d^{-1}$). While the differences were not statistically significant, combining the months of July through September, E+ steers grazed a total of 121 h less than those grazing L, while those grazing Q grazed 113 h less than those on L. Using data from Fig. 3 for grazing $time{\cdot}d^{-1}$ and assuming that the mean grazing times from the 5 d recorder periods is representative of the time spent grazing every day in that month, then the difference between the grazing time of steers consuming L from those grazing E+ or Q can be used to estimate the number of days each group of steers would have been grazing. Using this calculation, the difference in time spent grazing can be estimated and transformed into days of representative grazing activity. This showed that from the months of June through September steers consuming L were grazing the equivalent of 13 d more than steers in E+ and 12 d more than steers in Q.

Data from an intake trial conducted (Gregory and Scaglia, 2005) during the month of July on the steers from the present study (Table 3), estimated that steers grazing E- and L consumed numerically more forage (18.8 and 18.4 $g\ DM{\cdot}kg\ BW^{-1}{\cdot}d^{-1}$,

Figure 2. Behavior data recorders used during the experiment.

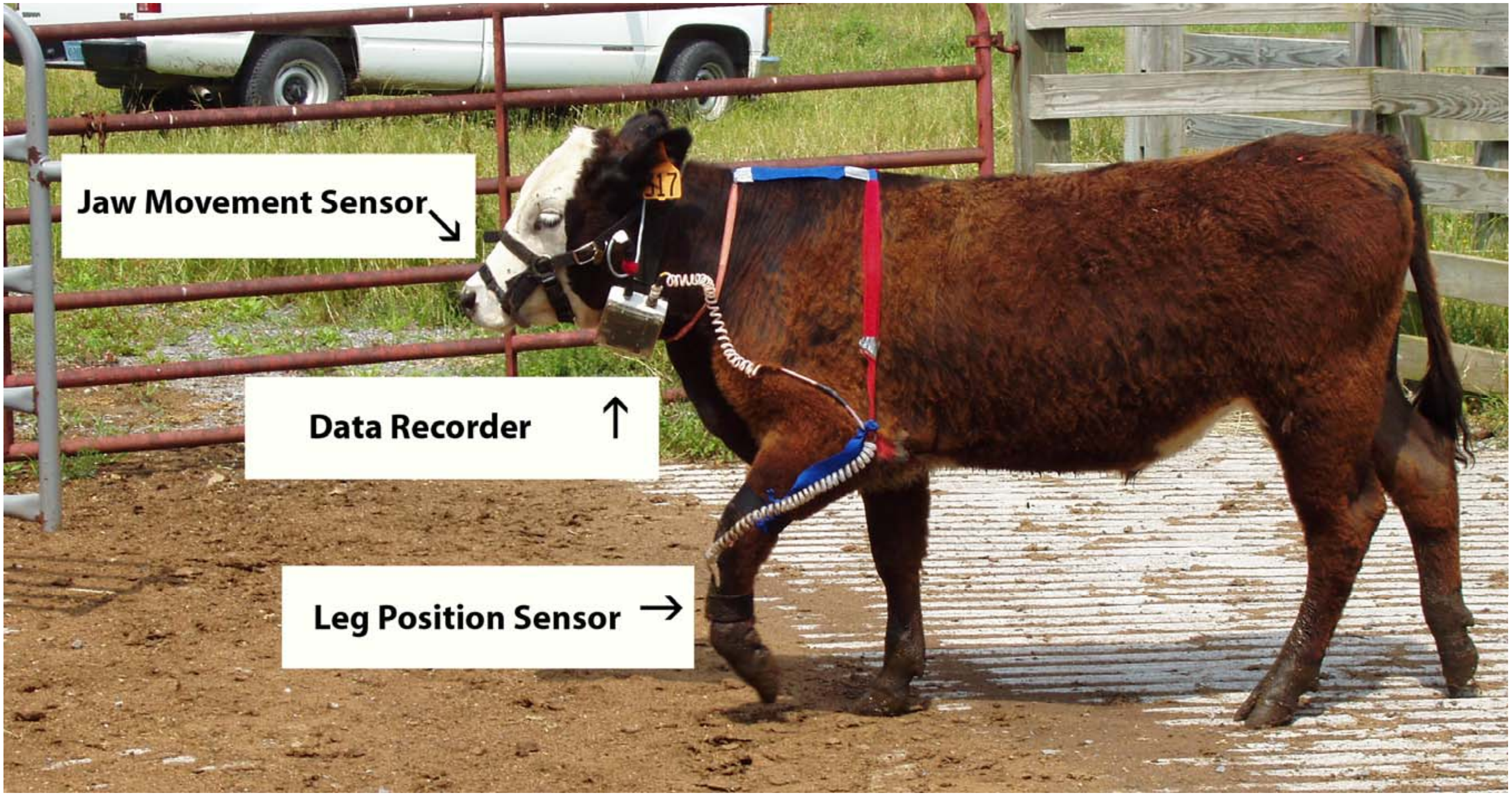


Figure 3. Least squares means of jaw activity (time spent grazing, ruminating, or idling) during data recorder phase in minutes and as a percentage of a 24 h period. (SEM reported in minutes) Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).

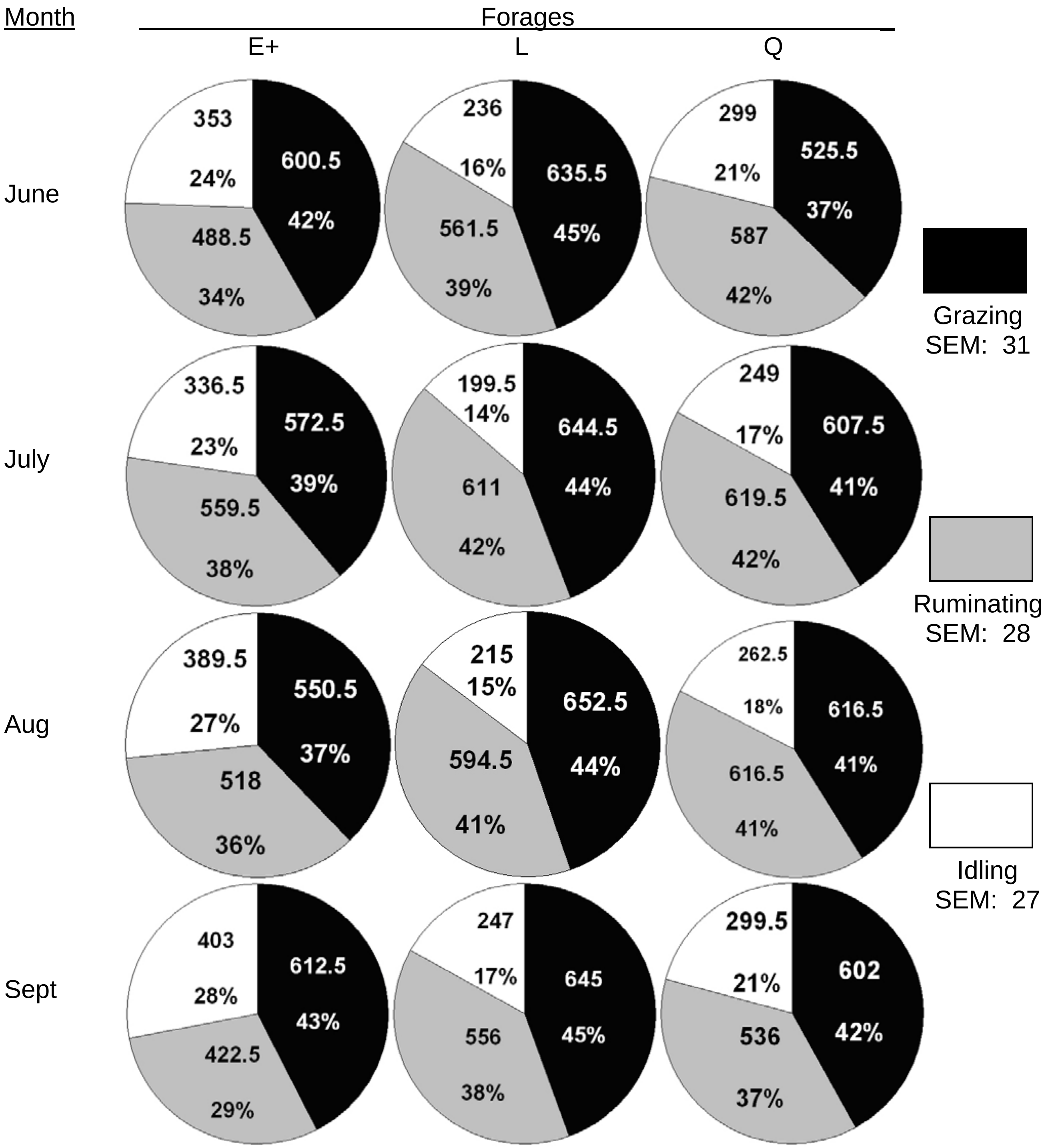
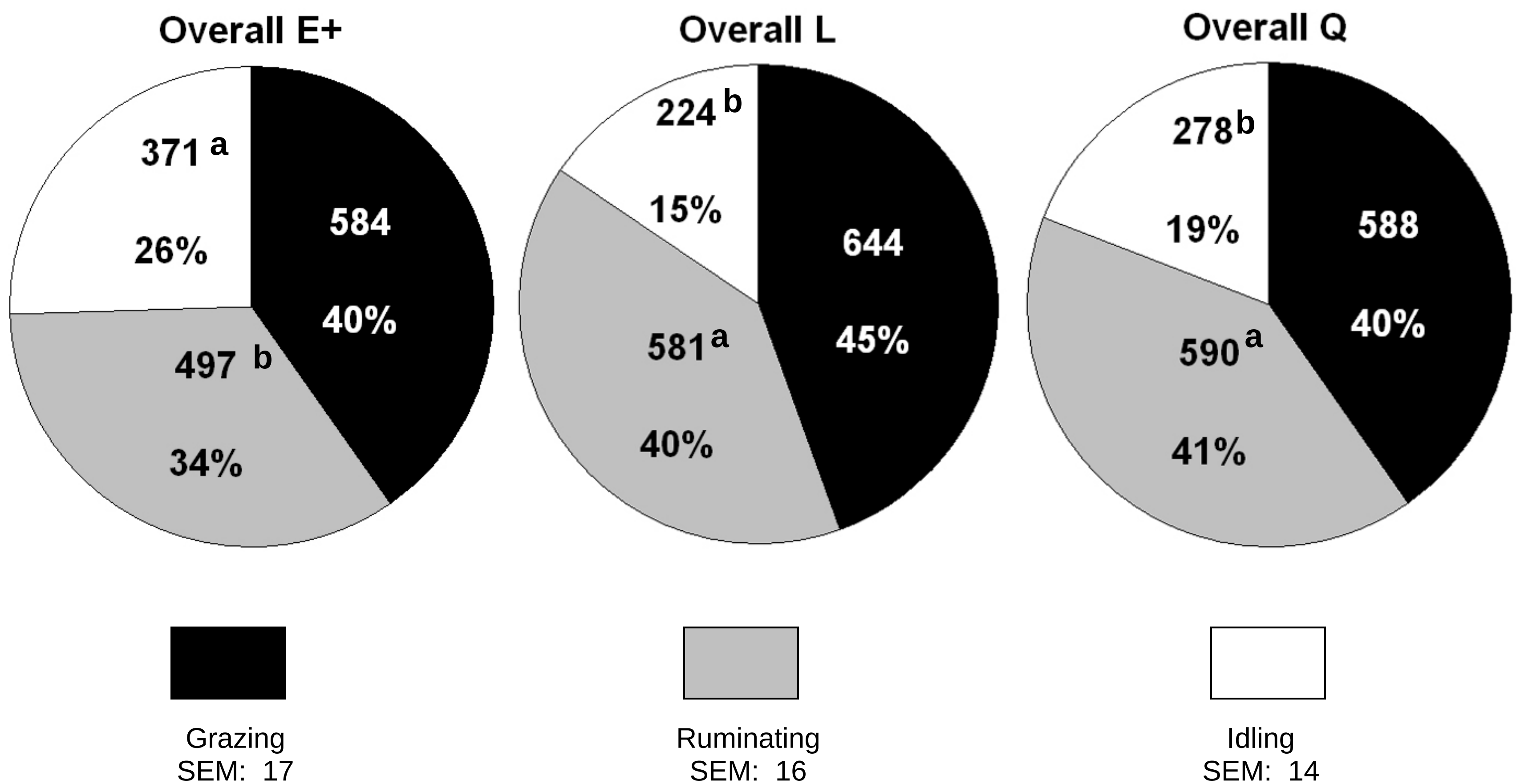


Figure 4. Overall least squares means of jaw activity (time spent grazing, ruminating, or idling) during data recorder phase in minutes and as a percentage of a 24 h period. (SEM reported in minutes) Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).



[ab] Different superscripts within activity are significantly different (P<0.05)

respectively) than steers grazing E+ (17.2 g DM·kg BW^{-1}·d^{-1}) and Q (16.0 g DM·kg BW^{-1}·d^{-1}). The low DMI of steers grazing Q was not expected considering the results of other studies that showed that cattle grazing novel endophyte infected fescues generally have DMI comparable to that of E- and higher than E+. Parish et al (2003) reported a lower (P<0.10) DMI in steers consuming E+ (10.2 g DM·kg BW^{-1}·d^{-1}) compared to E- (14.6 g DM·kg BW^{-1}·d^{-1}) and novel endophyte infected tall fescue (14.1 g DM·kg BW^{-1}·d^{-1}). The explanation for why time spent grazing and DMI for steers grazing Q is comparable to E+ and numerically less than E- is not clear. These steers were not visibly suffering from any symptoms of fescue toxicosis as cattle consuming E+. It is possible that Q is not as palatable to cattle as E- or L. Cheeke (1995) indicated that endophytic fungi produce toxins, such as alkaloids, as a defense mechanism against herbivores. Novel endophyte infected tall fescue may not be producing the toxic alkaloids that induce fescue toxicosis, but perhaps they are still producing alkaloids that lower the palatability of the forage.

There was a significant effect on ruminating time due to treatment. Overall, steers grazing E+ spent less (P<0.05) time ruminating (497 min·d^{-1}) than steers grazing Q or L (590 and 581 min · d^{-1}, respectively) (Figure 4). Parish et al. (2003) reported that in April/May/June steers grazing novel endophyte infected tall fescue spent more time ruminating than steers in E- or E+ treatments; however, in September all steers spent similar amount of time ruminating. There were treatment effects for idling time, but no interaction of treatment by month. Time spent idling for steers grazing E+ (371 min·d^{-1}) was higher (P<0.05) than for steers grazing Q or L (278 and 224 min·d^{-1}, respectively). Parish et al. (2003), reported similar results showing that steers grazing E+ spent more

(*P*<0.10) time idling (31.5% of daily activity) than steers grazing novel endophyte infected tall fescue (21.7% of daily activity).

Results from the data recorder phase for individual periods for standing and lying time are presented in Figure 5 and overall results are presented in Figure 6. There were treatment effects for lying and standing time, but no interaction of treatment by month. Overall, time spent lying was lower (*P*<0.05) for steers grazing E+ than for those grazing L or Q (Figure 6). Conversely time spent standing was higher (*P*<0.05) for steers grazing E+ compared to those grazing L or Q. Parish et al. (2003) found a similar pattern of activity with cattle consuming E+ spending more time idling and more (*P*<0.01) time standing than cattle consuming E- or novel endophyte tall fescue. Howard et al. (1992) also reported cattle grazing E+ spent more time (*P*<0.05) idling (250 min) and standing (537 min) during a daytime observation period than cattle consuming low-endophyte infected fescue (190 and 507 min for idling and standing, respectively).

Number of prehensions, biting rate, grazing mastication, and ruminating mastications are presented in Table 12. Overall, steers consuming E+ (34,918 bites·d^{-1}) took less (*P*<0.05) prehensions than cattle grazing L (44,351 bites·d^{-1}), with number of prehensions for cattle grazing Q (38,550 bites·d^{-1}) being intermediate. Parish et al. (2003) also reported that steers consuming E+ took less (*P*<0.10) prehensions (25,024 bites·d^{-1}) than cattle on E- (33,973 bites·d^{-1}) or novel endophyte infected tall fescue (33,047 bites·d^{-1}). Howard et al. (1992) reported steers consuming E+ fescue took less number of bites (12,900 bites·d^{-1}) from 0630 to 2130 than cattle grazing low-endophyte tall fescue. (9,100 bites·d^{-1}). In the present study biting rate was not significantly

Figure 5. Least squares means of leg sensor data (time spent standing or lying) during data recorder phase in minutes and as a percentage of a 24 h period. (SEM reported in minutes) Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).

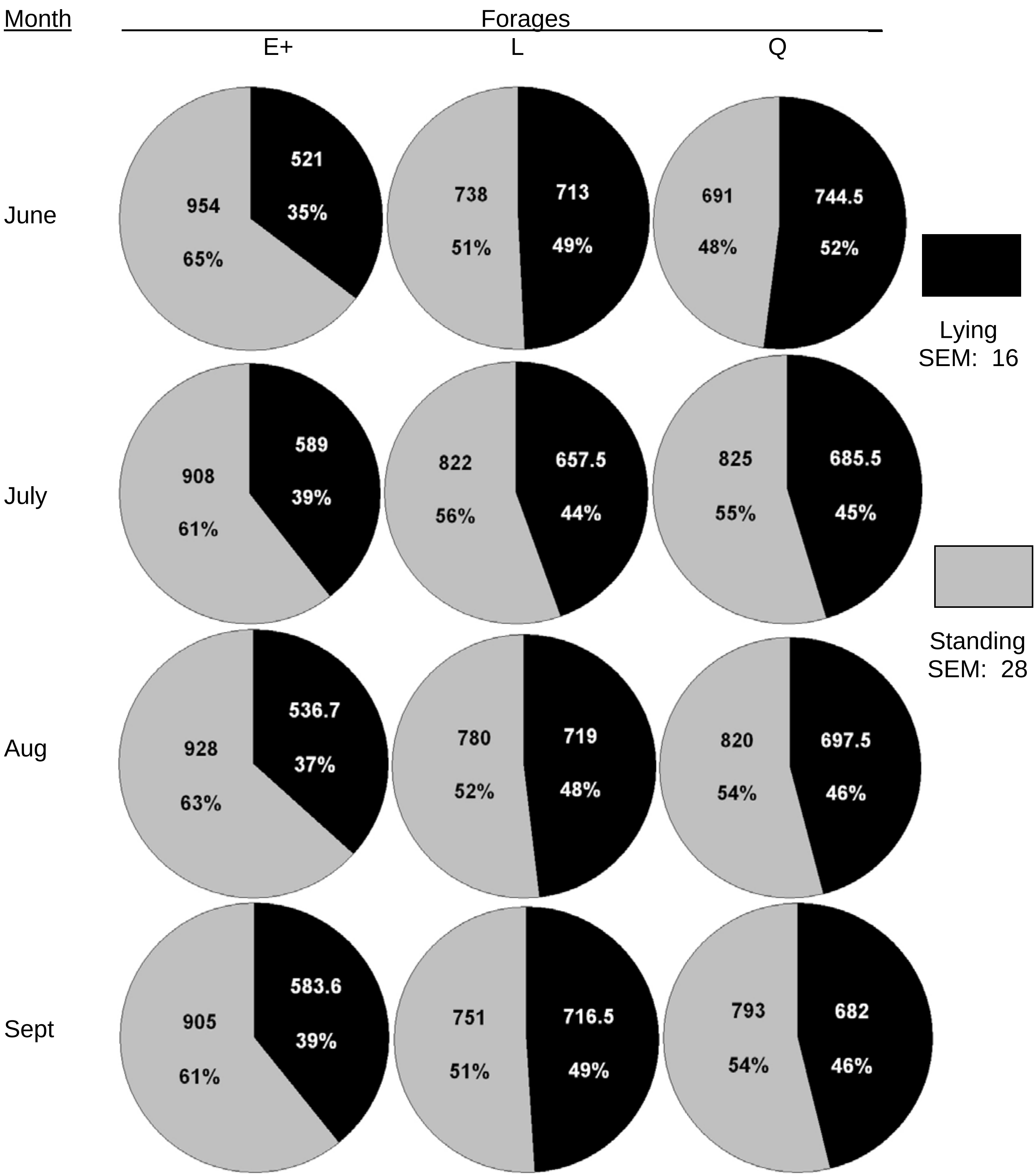
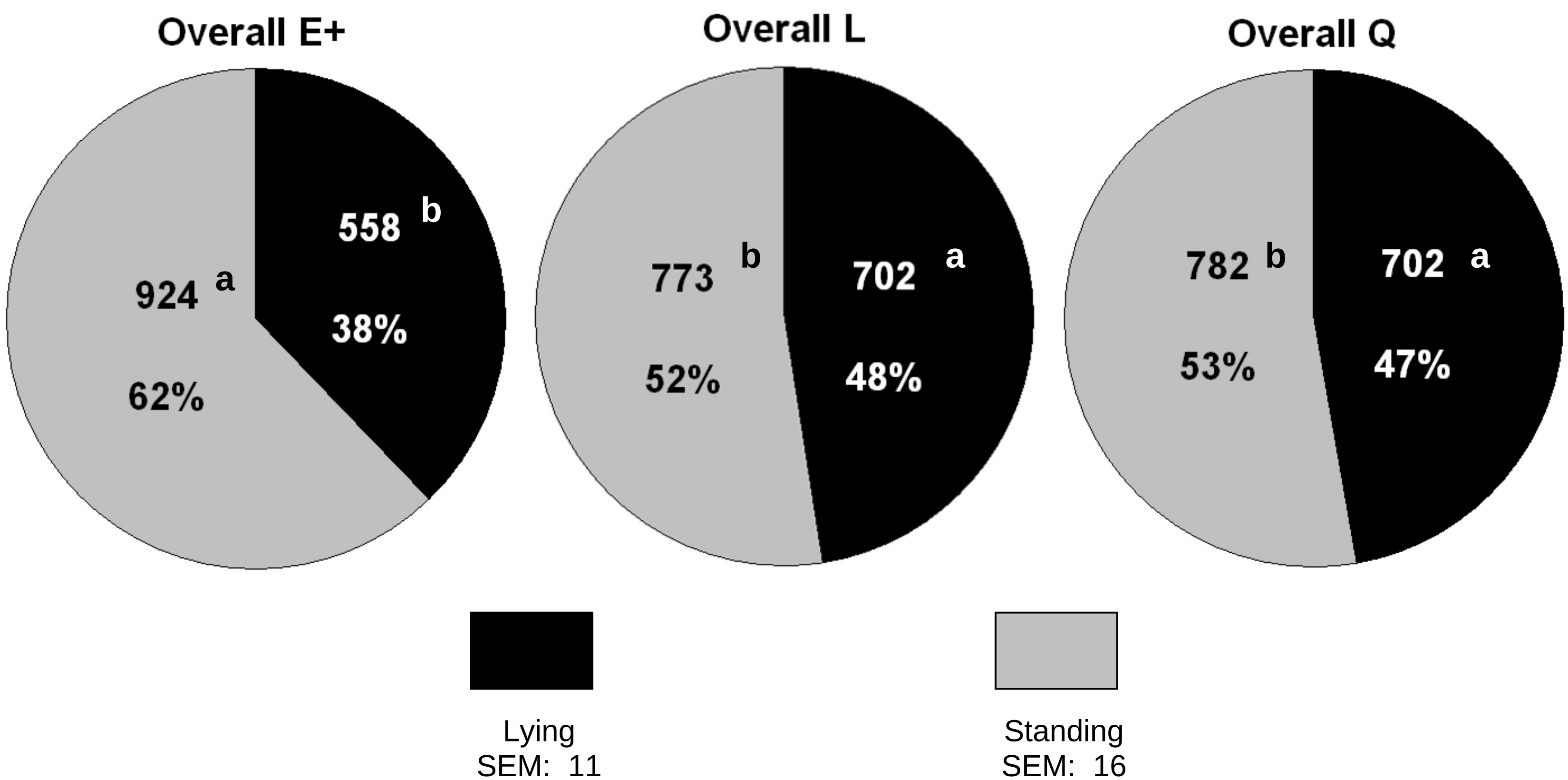


Figure 6. Overall least squares means of leg sensor data (time spent standing or lying) during data recorder phase in minutes and as a percentage of a 24 h period. (SEM reported in minutes) Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).



[ab] Different superscripts within activity are significantly different (P <0.05)

Table 12. Least squares means of number of prehensions, grazing mastications, and ruminating mastications during data recorder phase for a 24 h period for Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Q4508-AR542 novel endophyte tall fescue (Q).

		Activity			
Period	Forage	Prehensions, bites · d^{-1}	Biting rate, bites · min $grazing^{-1}$	Grazing mastications · d^{-1}	Ruminating mastications · d^{-1}
June	E+	39630	63	4721	34016
	L	45750	72	4229	41355
	Q	36802	70	3526	44102
July	E+	37064	56	5761	39238
	L	43033	67	4691	45285
	Q	41056	68	3206	46991
August	E+	30178	54	8769	35426
	L	44041	68	7000	43648
	Q	38578	64	6701	46567
September	E+	32799	54	5201	26413
	L	44580	69	2969	39329
	Q	37764	63	5669	38694
All months	SEM	3373	3	1333	2410
Overall	E+	34918 [b]	57 [b]	6113	33773 [b]
	L	44351 [a]	69 [a]	4723	42404 [a]
	Q	38550 [ab]	66 [a]	4776	44088 [a]
	SEM	2013	2	580	1293

[ab] Different superscripts within column within period are significantly different (*P* <0.05)

different between treatments within periods, but overall was less (*P*<0.05) for steers grazing E+ (57 bites·min grazing^{-1}) compared to steers grazing L (69 bites·min grazing^{-1}) or Q (66 bites·min grazing^{-1}) (Table 12). Biting rates during the month of June were numerically higher than other months across treatments, which may have been due to the mature stage of the forage that the steers were grazing. Stobbs (1974) reported that biting rate is increased when swards are mature because animals must select through dead material to reach leaves. Parish et al. (2003) reported lower biting rates for all treatments observed (E+, E-, and novel endophyte) than in the present study. However they correspond with the lower number of overall prehensions they observed as compared with the present study. They reported that steers grazing E+ had lower (*P*<0.10) biting rate (48.4 bites·min grazing^{-1}) than steers grazing novel endophyte infected tall fescue (59.4 bites·min grazing^{-1}) or steers grazing E- (56.3 bites·min grazing^{-1}) which was the same pattern observed in the present study.

Bite mass during July for steers grazing L (0.15 g DM·bite^{-1}) was numerically the highest followed by steers grazing E+ (0.14 g DM·bite^{-1}), with steers grazing Q (0.12 g DM·bite^{-1}) being the lowest (Table 3). Values were slightly lower than results from previous studies reporting bite mass of 0.16 g DM·bite^{-1} for E+, 0.19 g DM·bite^{-1} for novel endophyte, and 0.20 g DM·bite^{-1} for E- (Parish et al., 2003). The low bite mass in combination with a lower number of prehensions for steers grazing Q in the present study was probably restricting DMI. Stobbs (1973) suggested that bite mass below 0.2 g OM·bite^{-1} would restrict intake due to the number of bites necessary (36,000 bites·d^{-1}) to achieve intake at 2.0% BW for a 400 kg animal. Intake rate for Q was numerically lowest at 1.67 % BW.

Table 13. Average daily gain of cattle grazing Kentucky 31 endophyte infected tall fescue (E+), Kentucky 31 endophyte free tall fescue (E-), Lakota prairie grass (L), and Q4508-AR542 novel endophyte tall fescue (Q).

	Average daily gain (kg · d $^{-1}$)					
Forage	May	June	July	August	September	Overall
E+	0.31	0.15	0.19	0.13	0.21	0.20 ^{c}
E-	0.64	0.30	0.42	0.34	0.47	0.45 ^{ab}
L	0.64	0.37	0.48	0.42	0.53	0.50 ^{a}
Q	0.63	0.28	0.36	0.29	0.39	0.39 ^{bc}

^{abc} Different superscripts within overall column are significantly different (P <0.05)

Trends observed for ADG (Table 13) over the course of the study are probably explained by the amount of time grazing, biting rate, bite mass, and DMI. The low values of these parameters correlates with the low ADG of steers consuming E+ or Q, just as the higher ADG of steers consuming L correlates with the higher values for these parameters. However all values were low. Parish et al. (2003) reported ADG in Hereford steers from February to July for novel endophtye treatments (Jesup AR542- Kentucky 31 AR542, Georgia 5 AR542, and Jesup AR502-Kentucky 31 AR502) (0.78, 0.95, 0.96 kg, respectively) being similar to E- (0.97 kg) and greater (P<0.05) than E+ (0.31 kg).

Number of steps taken are presented in Table 14. There were no treatment effects and no interaction of treatment by month. Although not significant, overall, steers grazing Q took the least number of steps (2043, 2467, and 2643 steps$\cdot$d^{-1} for Q, E+, and L, respectively). In July steers grazing E+ (2424 steps$\cdot$d^{-1}) took a lower number of steps than steers grazing Q (2551 steps$\cdot$d^{-1}) or L (3,202 steps$\cdot$d^{-1}). Parish et al. (2003) reported steers grazing E- took a greater number of steps (3,151 steps$\cdot$d^{-1}) than steers grazing novel endophyte tall fescue (2,489 steps$\cdot$d^{-1}) or E+ (2,074 steps$\cdot$d^{-1}) similar to the present study. In the present study, the high number of steps taken by steers consuming E+ during the month of August should not be associated with the amount of time spent walking or grazing. It was observed that while steers in the E+ treatment were standing in the mud holes they had formed to cool off (Figure 1), they would raise and lower their forelegs to splash water on their bodies. This movement of the leg could not be distinguished by the data loggers as being any different from a normal step. Thus, the data appeared as though the animals were spending more time walking than they actually were. It was concluded that in this case what the data logger was

Table 14. Least squares means of number of steps during data recorder phase for a 24 h period for Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Q4508-AR542 novel endophyte tall fescue (Q).

Period	Forage	Number of steps
June	E+	2392
	L	2613
	Q	1888
July	E+	2424
	L	3202
	Q	2551
August	E+	2885
	L	2618
	Q	1767
September	E+	2049
	L	2138
	Q	1965
All months	SEM	190
Overall	E+	2437
	L	2643
	Q	2043
	SEM	148

recording as steps should not always be considered as walking. This could be true for steers in the E+ treatment in other months as well. However, in August during the week that recorder observations were made the highest temperatures of the entire experiment occurred. Due to this, the splashing activity of these steers was probably most pronounced during that time. If the month of August is removed from the overall statistical analysis of steps $\cdot$ d^{-1} the least squares means are as follows: 2135, 2291, 2651 steps$\cdot d^{-1}$; for Q, E+, and L, respectively, (data not presented in Table 14) similar to overall values calculated including the month of August.

For the data recorder period there were periods of time where data was missing due to malfunctions of the recorder equipment. During September there are only 4 d used of the 5 d that the recorders were worn. A hurricane system was in the area during this time and many of the recorders malfunctioned due to water damage. In the future, this is a problem that should be considered when using these types of devices. An issue that was encountered with one E+ replicate was that steers in this group chewed up the cables of their leg movement sensors. This damage to the cable resulted in no data for lying and standing time or number of steps being recorded. In August and September there was no leg sensor data from this replicate due to this problem.

Correlations between behaviors within treatments are presented by month in Tables 15-18 and overall in Table 19. Standing time for steers in E+ was negatively correlated with grazing in July and August, while standing time was positively correlated with grazing for L and Q in most months. Steers in the E+ treatment were observed spending a large amount of time standing near the waterers. This probably accounted for a large proportion of their time spent standing.

Table 15. June correlation (r) of time spent grazing (G), ruminating (R), idling (I), lying (LY), and standing (S); number of steps (STP), prehensions (P), grazing mastication (GM), and ruminating mastications (RM) during data recorder phase for steers grazing Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Q4508-AR542 novel endophyte tall fescue (Q).

			Activity							
Forage	Activity	n	G	R	I	LY	S	STP	P	GM
E+	G	14								
	R	14	0.21							
	I	14	-0.68	-0.82						
	LY	15	-0.13	0.71	-0.50					
	S	15	0.32	-0.66	0.36	-0.97				
	STP	15	0.11	0.36	-0.34	0.21	-0.12			
	P	13	0.85	0.73	-0.94	0.33	-0.14	0.33		
	GM	13	0.07	-0.67	0.41	-0.72	0.69	-0.21	-0.34	
	RM	14	0.25	0.98	-0.84	0.76	-0.70	0.32	0.73	-0.70
L	G	18								
	R	18	-0.42							
	I	18	-0.24	-0.22						
	LY	14	-0.47	-0.05	0.35					
	S	14	0.48	0.29	-0.48	-0.86				
	STP	14	0.03	0.57	-0.49	0.01	0.17			
	P	18	0.95	-0.58	-0.29	-0.35	0.25	-0.05		
	GM	18	-0.27	0.69	-0.07	0.04	0.25	0.02	-0.45	
	RM	18	-0.40	0.98	-0.32	-0.02	0.24	0.60	-0.54	0.61
Q	G	12								
	R	12	0.13							
	I	12	0.17	0.01						
	LY	10	-0.66	0.68	-0.24					
	S	10	-0.25	-0.36	0.64	-0.31				
	STP	10	-0.30	-0.04	0.24	-0.05	0.72			
	P	12	-0.02	-0.07	0.22	-0.24	0.98	0.81		
	GM	12	0.34	0.12	-0.18	0.08	-0.96	-0.80	-0.94	
	RM	12	0.04	0.99	0.04	0.63	-0.32	0.04	-0.06	0.09

Table 16. July correlation (r) of time spent grazing (G), ruminating (R), idling (I), lying (LY), and standing (S); number of steps (STP), prehensions (P), grazing mastication (GM), and ruminating mastications (RM) during data recorder phase for steers grazing Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Q4508-AR542 novel endophyte tall fescue (Q).

			Activity							
Forage	Activity	n	G	R	I	LY	S	STP	P	GM
E+	G	17								
	R	17	0.25							
	I	17	-0.81	-0.47						
	LY	8	0.48	-0.07	-0.23					
	S	8	-0.40	0.31	0.31	-0.93				
	STP	8	-0.13	0.26	0.09	0.74	-0.65			
	P	17	0.89	0.48	-0.92	0.45	-0.42	0.47		
	GM	17	-0.18	-0.03	0.57	-0.31	0.51	-0.44	-0.46	
	RM	17	0.46	0.91	-0.58	-0.20	0.44	-0.25	0.50	0.05
L	G	19								
	R	19	-0.48							
	I	19	-0.42	-0.25						
	LY	15	0.06	-0.28	0.40					
	S	15	0.42	0.24	-0.40	-0.85				
	STP	17	0.07	0.05	0.07	-0.18	0.12			
	P	19	0.94	-0.38	-0.46	0.14	0.39	-0.19		
	GM	19	-0.11	0.34	0.06	-0.37	0.37	0.52	-0.26	
	RM	19	-0.42	0.97	0.29	0.17	0.18	-0.07	-0.27	0.19
Q	G	11								
	R	11	-0.17							
	I	11	-0.55	-0.14						
	LY	11	0.23	0.21	0.24					
	S	11	0.52	-0.22	0.03	-0.32				
	STP	11	0.40	-0.75	-0.08	0.13	-0.39			
	P	11	0.88	-0.01	-0.68	0.10	0.33	0.55		
	GM	11	-0.23	-0.09	0.46	0.18	0.29	-0.69	-0.62	
	RM	11	-0.24	0.97	-0.17	0.16	-0.35	-0.67	-0.03	-0.14

Table 17. Aug correlation (r) of time spent grazing (G), ruminating (R), idling (I), lying (LY), and standing (S); number of steps (STP), prehensions (P), grazing mastication (GM), and ruminating mastications (RM) during data recorder phase for steers grazing Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Q4508-AR542 novel endophyte tall fescue (Q).

			Activity							
Forage	Activity	n	G	R	I	LY	S	STP	P	GM
E+	G	18								
	R	18	0.44							
	I	18	-0.77	-0.72						
	LY	8	0.58	0.84	-0.74					
	S	8	-0.47	-0.81	0.77	-0.96				
	STP	8	-0.74	-0.61	0.57	-0.12	0.07			
	P	17	0.76	0.56	-0.67	0.73	-0.66	-0.61		
	GM	17	-0.09	-0.26	0.19	-0.75	0.72	0.11	-0.65	
	RM	17	0.37	0.93	-0.71	0.83	-0.86	-0.47	0.45	-0.13
L	G	16								
	R	16	-0.46							
	I	16	-0.36	-0.42						
	LY	14	-0.05	-0.38	0.26					
	S	14	0.44	-0.16	0.15	-0.74				
	STP	14	0.24	0.00	0.06	-0.60	0.47			
	P	16	0.81	-0.56	-0.15	0.46	0.10	-0.18		
	GM	16	-0.02	0.41	-0.35	-0.72	0.28	0.41	-0.56	
	RM	16	-0.42	0.88	-0.40	0.06	-0.50	-0.39	-0.28	0.02
Q	G	12								
	R	12	-0.37							
	I	12	-0.13	-0.45						
	LY	15	-0.16	-0.15	0.35					
	S	14	0.17	0.25	-0.40	-0.89				
	STP	13	-0.01	0.30	-0.25	-0.09	0.37			
	P	11	0.30	0.14	-0.01	-0.78	0.93	0.59		
	GM	11	0.01	-0.27	-0.10	0.72	-0.89	-0.65	-0.94	
	RM	11	-0.47	0.98	-0.38	-0.31	0.27	-0.42	0.11	-0.20

Table 18. September correlation (r) of time spent grazing (G), ruminating (R), idling (I), lying (LY), and standing (S); number of steps (STP), prehensions (P), grazing mastication (GM), and ruminating mastications (RM) during data recorder phase for steers grazing Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Q4508-AR542 novel endophyte tall fescue (Q).

			Activity							
Forage	Activity	n	G	R	I	LY	S	STP	P	GM
E+	G	12								
	R	12	-0.28							
	I	12	-0.54	-0.42						
	LY	8	-0.04	0.36	-0.36					
	S	8	0.09	0.03	0.22	-0.88				
	STP	8	-0.27	0.40	-0.16	0.64	-0.57			
	P	12	0.62	0.20	-0.72	-0.47	0.56	-0.77		
	GM	12	0.37	-0.47	0.18	-0.95	0.46	0.95	-0.15	
	RM	12	-0.32	0.97	-0.43	0.48	-0.09	0.47	0.16	-0.41
L	G	10								
	R	10	-0.15							
	I	10	-0.52	-0.43						
	LY	10	-0.42	0.69	-0.01					
	S	10	0.73	-0.28	-0.11	-0.74				
	STP	10	-0.08	0.58	-0.19	0.38	-0.13			
	P	10	0.82	0.31	-0.56	-0.04	0.61	0.29		
	GM	7	0.53	-0.22	-0.27	-0.25	0.22	-0.64	0.12	
	RM	10	-0.01	0.93	-0.64	0.58	-0.23	0.60	0.39	-0.14
Q	G	10								
	R	10	-0.01							
	I	10	-0.51	-0.75						
	LY	10	-0.18	-0.06	0.42					
	S	10	0.43	0.13	-0.34	-0.83				
	STP	10	0.26	-0.47	0.01	-0.47	0.26			
	P	10	0.72	0.38	-0.68	-0.34	0.57	0.08		
	GM	8	-0.03	-0.10	0.17	0.68	-0.65	-0.35	-0.42	
	RM	10	-0.24	0.78	-0.45	-0.27	0.27	-0.21	0.14	-0.12

Table 19. Overall correlation (r) of time spent grazing (G), ruminating (R), idling (I), lying (LY), and standing (S); number of steps (STP), prehensions (P), grazing mastication (GM), and ruminating mastications (RM) during data recorder phase for steers grazing Kentucky 31 endophyte infected tall fescue (E+), Lakota prairie grass (L), Q4508-AR542 novel endophyte tall fescue (Q).

			Activity							
Forage	Activity	n	G	R	I	LY	S	STP	P	GM
E+	G	61								
	R	61	-0.02							
	I	61	-0.63	-0.59						
	LY	39	0.18	0.32	-0.41					
	S	39	-0.11	-0.15	0.40	-0.93				
	STP	39	-0.22	0.31	-0.02	0.34	-0.22			
	P	56	0.74	0.36	-0.75	0.22	-0.20	-0.14		
	GM	54	-0.22	-0.07	0.30	-0.36	0.45	0.33	-0.59	
	RM	60	0.00	0.96	-0.59	0.28	-0.14	0.25	0.33	0.00
L	G	63								
	R	63	-0.34							
	I	63	-0.37	-0.39						
	LY	53	0.00	-0.21	0.25					
	S	53	0.37	0.25	-0.26	-0.83				
	STP	53	-0.05	0.44	-0.26	-0.36	0.39			
	P	63	0.86	-0.44	-0.25	0.22	0.13	-0.26		
	GM	60	0.07	0.37	-0.33	-0.19	0.22	0.14	-0.28	
	RM	63	-0.28	0.96	-0.46	-0.15	0.21	0.47	-0.33	0.24
Q	G	45								
	R	45	-0.08							
	I	45	-0.23	-0.34						
	LY	46	-0.07	0.03	0.20					
	S	45	0.15	0.07	-0.12	-0.74				
	STP	44	0.00	0.07	-0.08	-0.28	0.46			
	P	44	0.30	0.06	-0.12	-0.55	0.88	0.46		
	GM	42	0.16	-0.09	-0.02	0.53	-0.85	-0.68	-0.87	
	RM	44	-0.18	0.96	-0.26	-0.08	0.09	-0.04	0.04	-0.08

Relationship between grazing behavior and forage chemical composition

Correlations of behavior and forage nutritive values are presented in Table 20. Grazing time was positively correlated to % CP in all months of the study. Time spent ruminating was positively correlated to % cellulose and negatively correlated to IVDMD. Although not consistent across months, overall time spent ruminating was negatively correlated with % CP, similar to results reported by Arnold (1961) in a study on grazing behavior of sheep where observations of grazing behavior were recorded for 24 h periods.

Correlations of behavior and forage mineral composition are presented in Table 21. Time spent grazing was positively correlated with both Cu and Zn content of forage in all months except June. Considering both of these minerals were at deficient levels in the tall fescue treatments, cattle could have been trying to compensate for that deficiency. This could also explain the positive correlation between grazing time and Ca as well, which was at a low, but not deficient level in the tall fescue treatments. Previous studies have shown that cattle will consume forages selectively to regulate intake of certain chemicals/minerals (Owen-Smith and Novellie, 1982; McNaughton, 1988). Arthington (2002) reported that cattle selectively grazed forages with higher CP (30 % more), Ca (52.6% more), and P (36.8% more) when compared to hand clipped forage samples.

Regression analysis of the data was performed and the variables Zn, Ca, and K explain over 53% of the variability (R^2=0.53) for time spent grazing. Percent DM, CP, and IVDMD explain 50% of the variability (R^2=0.57) for number of grazing mastications. Percent lignin, IVDMD, and Ca explain 48 % of the variability (R^2=0.48) for the amount

Table 20. Correlation (r) of behavior during data recorder phase to forage nutritive values for steers grazing Kentucky 31 endophyte infected tall fescue, Lakota prairie grass, and Q4508-AR542 novel endophyte tall fescue.

			Nutritive value parameters							
Period	Behavior	n	DM	Ash	CP	NDF	ADF	Cellulose	Lignin	IVDMD
June	Grazing	12	-0.48	0.02	0.60	0.12	0.12	0.07	0.16	0.49
	Ruminating	12	0.36	-0.78	-0.75	0.76	0.7	0.45	0.52	-0.82
	Idling	12	0.25	0.52	0.05	-0.71	-0.69	-0.07	-0.76	0.28
	Lying	12	-0.05	-0.63	-0.69	0.75	0.74	0.08	0.75	-0.72
	Standing	12	0.05	0.63	0.69	-0.75	-0.74	-0.08	-0.75	0.72
July	Grazing	12	0.66	0.08	0.47	0.16	-0.06	0.29	-0.12	-0.36
	Ruminating	12	-0.37	-0.59	-0.15	0.76	0.58	0.60	0.50	-0.81
	Idling	12	-0.68	0.38	-0.30	-0.64	-0.40	-0.63	-0.31	0.79
	Lying	12	0.18	0.19	-0.47	0.57	0.29	-0.07	0.33	-0.71
	Standing	12	-0.18	-0.19	0.47	-0.57	-0.29	0.07	-0.33	0.71
Aug	Grazing	12	-0.33	-0.08	0.90	-0.16	0.08	0.45	-0.15	0.06
	Ruminating	12	0.49	-0.12	0.57	0.05	0.05	0.70	-0.42	-0.14
	Idling	12	-0.28	-0.04	-0.91	0.29	0.02	-0.57	0.33	-0.15
	Lying	12	-0.44	-0.35	0.86	0.55	0.91	0.64	0.76	-0.50
	Standing	12	0.44	0.35	-0.86	-0.55	-0.91	-0.64	-0.76	0.50
Sept	Grazing	12	0.00	0.29	0.66	-0.43	0.14	0.30	0.02	0.15
	Ruminating	12	-0.03	0.53	-0.12	0.03	0.59	0.08	0.11	-0.70
	Idling	12	0.01	-0.59	-0.14	0.20	-0.49	-0.18	-0.05	0.57
	Lying	12	-0.41	0.09	-0.12	0.43	0.94	-0.20	0.67	-0.56
	Standing	12	0.41	-0.09	0.12	-0.43	-0.94	0.20	-0.67	0.56
Overall	Grazing	48	0.10	0.04	0.40	-0.19	-0.18	0.00	-0.18	0.27
	Ruminating	48	0.13	-0.26	-0.48	0.35	0.37	0.54	0.21	-0.48
	Idling	48	-0.17	0.13	0.06	-0.17	-0.24	-0.36	-0.15	0.23
	Lying	48	-0.15	-0.16	0.00	0.32	0.23	-0.03	0.33	-0.32
	Standing	48	0.15	0.16	0.00	-0.32	-0.23	0.03	-0.33	0.32

Table 21. Correlation (r) of behavior during data recorder phase to forage mineral values for steers grazing Kentucky 31 endophyte infected tall fescue, Lakota prairie grass, and Q4508-AR542 novel endophyte tall fescue.

			Minerals					
Period	Behavior	n	Ca	Mg	K	P	Cu	Zn
June	Grazing	12	0.50	-0.12	0.18	0.10	0.00	-0.70
	Ruminating	12	0.44	-0.16	-0.83	-0.25	0.88	0.42
	Idling	12	-0.78	0.50	0.36	0.22	-0.78	-0.03
	Lying	12	0.44	-0.45	-0.48	-0.46	0.86	0.49
	Standing	12	-0.44	0.45	-0.48	0.46	-0.86	-0.49
July	Grazing	12	0.55	-0.86	0.38	-0.66	0.40	0.63
	Ruminating	12	0.07	-0.47	-0.50	-0.23	0.60	0.09
	Idling	12	-0.50	0.98	0.06	0.65	-0.72	-0.62
	Lying	12	-0.04	-0.59	0.51	0.10	-0.07	0.18
	Standing	12	0.04	0.59	-0.51	-0.10	0.07	-0.18
Aug	Grazing	12	0.54	-0.40	0.36	-0.15	0.74	0.80
	Ruminating	12	0.23	-0.61	-0.01	-0.50	0.32	0.51
	Idling	12	-0.57	0.66	-0.34	0.60	-0.77	-0.86
	Lying	12	0.36	-0.61	-0.22	0.38	0.31	0.50
	Standing	12	-0.36	0.61	0.22	-0.38	-0.32	-0.50
Sept	Grazing	12	0.73	-0.30	0.70	0.15	0.71	0.76
	Ruminating	12	0.08	-0.61	-0.12	-0.74	-0.14	0.30
	Idling	12	-0.33	0.74	-0.17	0.70	-0.18	-0.56
	Lying	12	0.25	-0.24	0.01	0.30	-0.14	0.42
	Standing	12	-0.25	0.24	-0.01	-0.30	0.14	-0.42
Overall	Grazing	48	0.56	-0.15	0.33	-0.08	0.33	0.08
	Ruminating	48	0.19	-0.37	-0.30	-0.09	-0.27	-0.22
	Idling	48	-0.51	0.59	0.00	0.33	-0.02	-0.09
	Lying	48	0.28	-0.34	0.01	-0.11	0.18	0.36
	Standing	48	-0.29	0.34	-0.01	0.11	-0.18	-0.36

of time spent ruminating. Percent ADF, IVDMD, and Ca explain 48% of the variability (R^2=0.48) for number of mastications while ruminating. The variables % ash content, IVDMD, and Ca explain 57% of the variability (R^2=0.57) for time spent idling. Percent CP, IVDMD, and Cu explain 49% of the variability (R^2=0.49) for time spent lying and time spent standing.

Comparison of visual phase and behavior data recorder phase data

As with the analysis of the visual data alone, due to the occurrence of “unidentified” behavior periods of time and their relationship to the calculated values for time spent ruminating and idling, these activities were not used individually to compare the visual data phase to the data recorder phase. Only, grazing time could be used for this comparison. To compare the visual data to the behavior data recorder data, the computer output from the data recorders had to be converted to a 0600 to 2000 format from the original 24 h format. Only L and E+ were used in the comparison due to a lack of consecutive 0600 to 2000 periods of time available from the data recorders for steers grazing in Q. Correlation coefficient (r) of visual data to behavior data recorder for grazing time was 0.91. The high positive correlation indicates that grazing time of cattle was not negatively affected by wearing the data recorders. Even though it was not possible from the results of this study to analyze a correlation of ruminating time or idling time between the two phases, there may have been a high positive correlation for these activities as well. A drawback to utilization of the data recorders is that the report generated by the GRAZE software does not combine the information of the leg movement sensor and the jaw activity sensor, meaning that if the report states the animal was ruminating at 0900 it does not state if the animal was standing or lying during this time. It only reports a sum of time spent lying for the entire period recorded. Time spent lying or standing could not be converted to the necessary 0600 to 2000 format from the original 24 h format for comparison to the visual phase data. It could be assumed that because grazing time was not affected by wearing the data recorders that lying and standing time would not be affected either.

CONCLUSIONS

Results presented from this experiment show that steers grazing E+ exhibit the deleterious effects of consuming this forage regardless of additional environmental stress from temperature or humidity.

Data gathered from both the visual appraisal phase and the data recorder phase indicated that steers grazing L exhibited behavior supporting performance superior to that of steers grazing E+. Visual phase results also support the use of E- and Q as possible alternatives to use of E+ for grazing cattle. Even though data for Q is not always significantly different from E+, the cattle grazing Q did not exhibit the signs of fescue toxicosis which makes it a superior forage for grazing cattle than E+.

The high correlation for grazing time between data from the visual appraisal phase and the data recorder phase in this study indicated that the data recorders could be utilized without the concern of affecting normal grazing behavior of animals.

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APPENDICES

Appendix 1. Hourly environmental conditions data.

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
5/24/2004	0000	17.84	113.5	0	0	18.55	0	19.4	64.5
5/24/2004	0100	17.5	113.8	0	0	18.51	0	18.9	63.9
5/24/2004	0200	16.94	113.9	0	0	18.47	0	18.0	62.8
5/24/2004	0300	16.51	114	0	0	18.43	0	17.3	61.9
5/24/2004	0400	16.6	114	0	0.1332	18.38	0	17.4	62.1
5/24/2004	0500	16.26	114.1	0	0.0396	18.34	0	16.9	61.5
5/24/2004	0600	15.85	114.1	0	0	18.29	0	16.2	60.7
5/24/2004	0700	15.38	114.2	0.025	0	18.24	0	15.4	59.8
5/24/2004	0800	16.67	114.2	0.153	0	18.18	0	17.5	62.3
5/24/2004	0900	18.83	114	0.287	3.3912	18.13	0	21.1	66.4
5/24/2004	1000	21.12	103	0.402	8.082	18.1	0	24.4	70.2
5/24/2004	1100	24.12	83.6	0.576	9.5292	18.11	0	28.0	73.9
5/24/2004	1200	25.59	74.3	0.778	14.328	18.15	0	29.6	75.3
5/24/2004	1300	26.5	71.4	0.834	14.526	18.23	0	30.7	76.4
5/24/2004	1400	26.79	68.74	0.836	15.498	18.36	0	30.9	76.5
5/24/2004	1500	26.57	68.08	0.456	13.496	18.51	0	30.6	76.1
5/24/2004	1600	27	68.64	0.606	14.404	18.64	0	31.2	76.8
5/24/2004	1700	27.48	69.22	0.523	10.019	18.74	0	31.9	77.6
5/24/2004	1800	26.93	71.2	0.36	9.4968	18.84	0	31.3	77.0
5/24/2004	1900	26.43	74	0.207	7.0236	18.92	0	30.8	76.6
5/24/2004	2000	23.72	93.7	0.04	0.216	18.98	0	28.0	74.1
5/24/2004	2100	22.75	96.6	0.005	2.1276	19.01	0	26.6	72.7
5/24/2004	2200	21.59	97.2	0	5.8284	19.02	0	24.9	70.7
5/24/2004	2300	20.82	98.9	0	5.7744	19	0	23.8	69.4
5/25/2004	0000	20.26	102.3	0	0.27	18.97	0	23.0	68.6
5/25/2004	0100	19.43	106.5	0	0	18.94	0	21.8	67.3
5/25/2004	0200	19.39	107.4	0	2.8584	18.89	1.778	21.8	67.2
5/25/2004	0300	19.13	110.3	0	1.3464	18.85	2.794	21.4	66.9
5/25/2004	0400	18.49	109.5	0	3.402	18.8	3.302	20.4	65.6
5/25/2004	0500	18.02	111.4	0	2.9484	18.77	0	19.7	64.8
5/25/2004	0600	17.45	112.1	0	0.0036	18.72	0	18.8	63.7
5/25/2004	0700	16.43	112.8	0.031	0	18.67	0	17.1	61.8
5/25/2004	0800	17.8	110.7	0.182	0	18.61	0	19.3	64.3
5/25/2004	0900	19.44	101.9	0.339	2.7612	18.54	0	21.7	67.1
5/25/2004	1000	21.94	94.3	0.547	8.8812	18.5	0	25.3	71.1
5/25/2004	1100	24.35	84.8	0.739	11.675	18.49	0	28.4	74.4
5/25/2004	1200	25.64	77	0.895	15.037	18.53	0	29.9	75.7
5/25/2004	1300	26.67	71.3	0.895	13.406	18.62	0	30.9	76.7
5/25/2004	1400	26.77	72.1	0.725	11.25	18.76	0	31.1	76.9
5/25/2004	1500	27.04	73.9	0.735	11.732	18.91	0	31.6	77.5
5/25/2004	1600	27.73	71.3	0.715	11.383	19.04	0	32.4	78.3
5/25/2004	1700	28.41	65.26	0.665	12.676	19.18	0	32.9	78.5
5/25/2004	1800	26.91	74.1	0.188	4.878	19.32	0	31.5	77.4
5/25/2004	1900	23.63	89.7	0.059	4.3272	19.43	.254	27.6	73.6
5/25/2004	2000	20.64	102.7	0.013	1.2132	19.49	.254	23.6	69.3
5/25/2004	2100	20.07	108	0.001	0.9216	19.49	.254	22.9	68.5
5/25/2004	2200	19.67	110	0	0.0144	19.47	0	22.3	67.9

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
5/25/2004	2300	18.87	111.1	0	0.4644	19.43	0	21.1	66.4
5/26/2004	0000	18.28	112.6	0	0.288	19.38	0	20.1	65.3
5/26/2004	0100	17.91	113	0	0	19.31	0	19.5	64.6
5/26/2004	0200	19.15	106.3	0	4.014	19.24	0	21.4	66.7
5/26/2004	0300	19.02	105.4	0	0.5472	19.17	0	21.1	66.5
5/26/2004	0400	18.15	110.4	0	2.7396	19.11	.254	19.9	65.0
5/26/2004	0500	18.04	111.3	0	2.1996	19.05	0	19.7	64.8
5/26/2004	0600	17.67	111.6	0	0.2232	19	0	19.1	64.1
5/26/2004	0700	18.41	107.5	0.007	4.0356	18.94	0	20.2	65.4
5/26/2004	0800	19.4	99.7	0.144	7.8624	18.89	0	21.6	66.9
5/26/2004	0900	21.25	87.7	0.272	7.83	18.84	0	24.0	69.5
5/26/2004	1000	22.71	81.2	0.346	10.152	18.81	0	25.9	71.4
5/26/2004	1100	22.4	84.6	0.415	11.732	18.8	0	25.6	71.2
5/26/2004	1200	23.97	83	0.595	10.537	18.83	0	27.8	73.6
5/26/2004	1300	24.12	84	0.518	10.033	18.87	0	28.1	74.0
5/26/2004	1400	24.27	88.6	0.41	9.5652	18.95	1.016	28.5	74.6
5/26/2004	1500	23.2	97.8	0.413	5.3784	19.05	.508	27.4	73.6
5/26/2004	1600	24.92	93	0.565	3.1428	19.15	.762	29.8	76.2
5/26/2004	1700	25.73	83.2	0.305	9.954	19.23	0	30.4	76.5
5/26/2004	1800	23.69	92	0.018	7.0236	19.33	1.524	27.8	73.9
5/26/2004	1900	19.42	106.1	0.007	4.1796	19.4	2.794	21.8	67.2
5/26/2004	2000	18.08	107.5	0.007	6.1632	19.44	8.128	19.7	64.8
5/26/2004	2100	17.54	110.7	0.004	0.9648	19.44	0	18.9	63.9
5/26/2004	2200	17.09	112.2	0	0.3492	19.37	0	18.2	63.0
5/26/2004	2300	17.31	110	0	3.5928	19.3	0	18.5	63.4
5/27/2004	0000	17.22	108.1	0	6.5196	19.22	0	18.3	63.2
5/27/2004	0100	16.87	106.8	0	5.5692	19.14	0	17.8	62.5
5/27/2004	0200	16.49	108.2	0	3.708	19.06	0	17.2	61.8
5/27/2004	0300	16.03	110.7	0	0.594	18.98	0	16.5	61.0
5/27/2004	0400	16.87	108.5	0	6.1632	18.9	.762	17.8	62.5
5/27/2004	0500	17.62	101.7	0	12.316	18.83	1.524	18.9	63.8
5/27/2004	0600	16.7	101.5	0	7.758	18.75	2.54	17.4	62.1
5/27/2004	0700	15.59	109.2	0.017	0.972	18.68	0	15.8	60.1
5/27/2004	0800	16.05	107.4	0.103	6.2136	18.6	0	16.5	61.0
5/27/2004	0900	17.66	99.2	0.211	7.9524	18.52	0	18.9	63.8
5/27/2004	1000	19.18	90.7	0.433	9.5976	18.47	0	21.0	66.1
5/27/2004	1100	20.66	86.3	0.671	13.554	18.44	0	23.1	68.4
5/27/2004	1200	22.04	84.3	0.752	12.254	18.44	0	25.0	70.6
5/27/2004	1300	23.68	77.7	0.906	12.809	18.5	0	27.1	72.7
5/27/2004	1400	25.43	71.5	0.944	15.66	18.62	0	29.2	74.8
5/27/2004	1500	25.88	71.2	0.694	17.777	18.78	0	29.8	75.5
5/27/2004	1600	25.73	72	0.551	16.294	18.95	0	29.7	75.3
5/27/2004	1700	26.32	69.37	0.613	17.302	19.09	0	30.3	75.9
5/27/2004	1800	26.23	71.2	0.476	17.449	19.19	0	30.3	76.0
5/27/2004	1900	25.68	72.1	0.29	12.496	19.27	0	29.6	75.2
5/27/2004	2000	24.29	77.4	0.073	4.5576	19.33	0	28.0	73.6
5/27/2004	2100	21.54	93.4	0.008	0.7776	19.36	0	24.7	70.3
5/27/2004	2200	18.58	107.7	0	0.1368	19.36	0	20.5	65.7
5/27/2004	2300	18.86	108.4	0	0.6984	19.33	0	21.0	66.3
6/21/2004	0000	12.9	108.5	0	0.36	20.06	0	11.5	55.1
6/21/2004	0100	12.11	111.8	0	0.0972	19.92	0	10.2	53.5
6/21/2004	0200	11.86	112	0	0.2952	19.77	0	9.7	53.0

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
6/21/2004	0300	12.38	112.7	0	0	19.61	0	10.6	54.0
6/21/2004	0400	13.08	111.5	0	0.7452	19.47	0	11.7	55.3
6/21/2004	0500	13.37	111.9	0	0	19.34	0	12.2	55.9
6/21/2004	0600	13.54	112.2	0	0	19.24	0	12.5	56.2
6/21/2004	0700	13.39	112.4	0.021	0.054	19.15	0	12.2	55.9
6/21/2004	0800	14.44	110.9	0.058	0	19.06	0	13.9	57.9
6/21/2004	0900	15.36	107.9	0.066	0	18.99	0	15.4	59.7
6/21/2004	1000	17.19	102.3	0.185	0.018	18.94	0	18.2	63.0
6/21/2004	1100	19.92	91.4	0.396	0.5328	18.91	0	22.1	67.4
6/21/2004	1200	21.58	86.2	0.545	2.8692	18.92	0	24.4	69.9
6/21/2004	1300	21.73	88.1	0.35	5.148	18.97	0	24.7	70.3
6/21/2004	1400	22.5	88.2	0.218	1.3536	19.04	0	25.9	71.6
6/21/2004	1500	22.08	92.1	0.188	3.978	19.12	0	25.4	71.2
6/21/2004	1600	21.76	92.9	0.216	3.9852	19.19	0	25.0	70.7
6/21/2004	1700	22.33	91.7	0.198	0.3888	19.25	0	25.8	71.6
6/21/2004	1800	22.52	90.5	0.186	3.6792	19.3	0	26.0	71.8
6/21/2004	1900	22.21	90.5	0.202	3.4092	19.35	0	25.5	71.3
6/21/2004	2000	21.5	92.5	0.062	5.0004	19.4	0	24.6	70.2
6/21/2004	2100	20.93	94.9	0.006	3.1572	19.44	0	23.8	69.4
6/21/2004	2200	20.55	96.7	0	4.7016	19.46	0	23.3	68.8
6/21/2004	2300	19.79	100.3	0	5.1984	19.47	0	22.2	67.6
6/22/2004	0000	19.6	102.9	0	0.702	19.46	0	22.0	67.4
6/22/2004	0100	19.43	105.4	0	0.936	19.45	0	21.8	67.2
6/22/2004	0200	19.82	101.8	0	3.2688	19.44	0	22.3	67.8
6/22/2004	0300	18.83	106.1	0	0.414	19.43	0	20.9	66.1
6/22/2004	0400	18.45	108.1	0	0.4032	19.4	0	20.3	65.5
6/22/2004	0500	17.99	110.7	0	0.2844	19.37	0	19.6	64.7
6/22/2004	0600	18.44	109	0	0.846	19.34	0	20.3	65.5
6/22/2004	0700	17.89	111.6	0.016	0.1404	19.31	0	19.5	64.5
6/22/2004	0800	18.76	110	0.116	0.0036	19.29	0	20.8	66.2
6/22/2004	0900	20.84	100.5	0.272	0.414	19.27	0	23.8	69.5
6/22/2004	1000	23.13	93.8	0.375	0.8136	19.26	0	27.1	73.1
6/22/2004	1100	24.4	87.6	0.498	7.4556	19.29	0	28.7	74.8
6/22/2004	1200	25.77	81.5	0.751	9.2448	19.35	0	30.3	76.4
6/22/2004	1300	26.64	73.7	0.732	12.899	19.44	0	31.1	76.9
6/22/2004	1400	26.41	76.2	0.613	9.8388	19.55	0	30.9	76.8
6/22/2004	1500	26.88	74.9	0.734	8.6148	19.67	0	31.5	77.4
6/22/2004	1600	27.75	70.7	0.706	8.6364	19.79	0	32.4	78.2
6/22/2004	1700	27.79	68.68	0.615	10.181	19.91	0	32.3	78.0
6/22/2004	1800	27.83	65.36	0.517	9.522	20.03	0	32.1	77.7
6/22/2004	1900	27.45	70	0.317	7.6104	20.12	0	31.9	77.7
6/22/2004	2000	26.06	79.5	0.155	4.482	20.19	0	30.6	76.6
6/22/2004	2100	23.74	94.4	0.027	0.0072	20.24	0	28.0	74.2
6/22/2004	2200	21.94	104.9	0	0.9	20.26	0	25.7	71.8
6/22/2004	2300	21.47	107.1	0	2.9016	20.26	4.572	25.1	71.1
6/23/2004	0000	19.39	109.1	0	1.7028	20.25	.508	21.8	67.3
6/23/2004	0100	17.98	112.6	0	1.0692	20.22	0	19.6	64.7
6/23/2004	0200	17.76	113.3	0	0.4464	20.18	0	19.3	64.3
6/23/2004	0300	17.64	113.6	0	0.7092	20.11	0	19.1	64.1
6/23/2004	0400	17.69	113.7	0	0.126	20.04	0	19.2	64.2
6/23/2004	0500	17.44	113.8	0	0.054	19.97	0	18.8	63.7
6/23/2004	0600	17.33	113.9	0	0.3672	19.91	0	18.6	63.5

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
6/23/2004	0700	17.51	114	0.017	0.3852	19.84	0	18.9	63.9
6/23/2004	0800	18.59	113.7	0.116	0.0072	19.78	0	20.7	66.0
6/23/2004	0900	20.2	109.9	0.182	0.0144	19.73	0	23.2	68.9
6/23/2004	1000	21.19	103.4	0.171	0.144	19.71	0	24.5	70.4
6/23/2004	1100	21.54	101.2	0.168	0.2592	19.72	.508	25.0	70.9
6/23/2004	1200	21	103.7	0.139	0.6408	19.73	4.318	24.2	70.0
6/23/2004	1300	20.34	108.6	0.158	0.8028	19.76	4.318	23.3	69.1
6/23/2004	1400	22.08	101.7	0.4	1.5228	19.8	.254	25.8	71.9
6/23/2004	1500	22.14	100.9	0.245	2.6208	19.84	.254	25.9	71.9
6/23/2004	1600	21.66	104.5	0.183	2.79	19.88	1.778	25.3	71.3
6/23/2004	1700	21.18	103.4	0.243	3.1212	19.93	1.016	24.5	70.3
6/23/2004	1800	21.82	102.9	0.174	0.7308	19.97	0	25.5	71.5
6/23/2004	1900	22.28	101.7	0.165	1.5156	20.01	0	26.1	72.2
6/23/2004	2000	21.52	102.6	0.048	0.342	20.04	0	25.0	70.9
6/23/2004	2100	20.4	109.2	0.007	0	20.06	0	23.5	69.2
6/23/2004	2200	19.5	111.8	0	0.3132	20.08	0	22.1	67.6
6/23/2004	2300	19.36	112.6	0	0.0252	20.07	0	21.9	67.4
6/24/2004	0000	19.16	112.9	0	0	20.05	0	21.6	67.0
6/24/2004	0100	18.95	113	0	0	20.03	0	21.2	66.6
6/24/2004	0200	18.76	113.3	0	0	20.01	0	20.9	66.3
6/24/2004	0300	18.63	113.4	0	0	19.98	0	20.7	66.0
6/24/2004	0400	18.55	113.3	0	0	19.94	0	20.6	65.9
6/24/2004	0500	18.41	113.4	0	0	19.92	0	20.4	65.6
6/24/2004	0600	17.98	113.4	0	0	19.89	0	19.7	64.8
6/24/2004	0700	17.46	113.8	0.018	0	19.85	0	18.8	63.8
6/24/2004	0800	18.76	112.8	0.099	0	19.81	0	20.9	66.3
6/24/2004	0900	19.87	105.7	0.219	2.1348	19.77	0	22.5	68.0
6/24/2004	1000	21.56	93.5	0.428	6.336	19.74	0	24.7	70.4
6/24/2004	1100	22.59	84.4	0.686	6.5736	19.74	0	25.8	71.5
6/24/2004	1200	23.59	77.3	0.784	3.6216	19.77	0	26.9	72.5
6/24/2004	1300	24.77	71.8	0.926	5.3316	19.82	0	28.3	73.8
6/24/2004	1400	25.3	65.79	0.811	4.4964	19.9	0	28.7	74.0
6/24/2004	1500	26.23	62	0.926	3.78	20	0	29.7	74.9
6/24/2004	1600	26.67	59.96	0.761	2.5236	20.11	0	30.2	75.3
6/24/2004	1700	26.29	65.19	0.48	2.0772	20.23	0	30.0	75.4
6/24/2004	1800	26.51	64.92	0.42	3.2976	20.33	0	30.3	75.7
6/24/2004	1900	25.98	71.1	0.248	0.7668	20.39	0	30.0	75.6
6/24/2004	2000	24.05	90.3	0.091	0.1296	20.45	0	28.3	74.4
6/24/2004	2100	21.29	104.4	0.015	0	20.48	0	24.7	70.6
6/24/2004	2200	19.29	110.5	0	0	20.49	0	21.7	67.2
6/24/2004	2300	18.12	112.1	0	0.2412	20.47	0	19.9	65.0
6/27/2004	0000	13.74	109.7	0	1.7352	19.68	0	12.8	56.6
6/27/2004	0100	13.57	109.9	0	3.1968	19.56	0	12.5	56.3
6/27/2004	0200	13.15	110.6	0	0.7632	19.45	0	11.8	55.5
6/27/2004	0300	12.56	111.8	0	0.4356	19.34	0	10.9	54.3
6/27/2004	0400	11.62	112.8	0	0.0288	19.22	0	9.3	52.5
6/27/2004	0500	11.05	113.4	0	0.1836	19.1	0	8.4	51.4
6/27/2004	0600	10.63	113.7	0	0.5256	18.97	0	7.7	50.6
6/27/2004	0700	11	113.8	0.022	0.072	18.83	0	8.3	51.3
6/27/2004	0800	12.21	113.3	0.151	0.198	18.7	0	10.3	53.6
6/27/2004	0900	14.81	105.7	0.235	0.0072	18.59	0	14.5	58.7
6/27/2004	1000	17.07	93.9	0.308	0.6912	18.52	0	17.9	62.6

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation kW·m$^{2-1}$	Wind speed km·hr^{-1}	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
6/27/2004	1100	18.78	86.4	0.431	1.1664	18.5	0	20.3	65.3
6/27/2004	1200	20.28	68.9	0.401	0.4212	18.51	0	22.0	66.8
6/27/2004	1300	20.94	69.05	0.558	1.998	18.54	0	22.9	67.8
6/27/2004	1400	21.06	65.36	0.546	3.5784	18.6	0	22.9	67.8
6/27/2004	1500	22.35	64.32	0.748	2.4552	18.66	0	24.6	69.6
6/27/2004	1600	22.48	66	0.556	2.4516	18.74	0	24.9	69.9
6/27/2004	1700	22.63	68.99	0.518	3.1608	18.83	0	25.2	70.4
6/27/2004	1800	22.52	71.4	0.38	3.0528	18.92	0	25.2	70.4
6/27/2004	1900	22.01	77.1	0.185	1.512	18.99	0	24.7	70.0
6/27/2004	2000	20.97	90	0.087	0.09	19.06	0	23.7	69.1
6/27/2004	2100	18.19	103.8	0.019	0.0612	19.1	0	19.8	64.9
6/27/2004	2200	15.62	111	0	0	19.11	0	15.8	60.2
6/27/2004	2300	14.92	112.6	0	0.0288	19.08	0	14.7	58.9
6/28/2004	0000	13.94	113.2	0	0	19.02	0	13.1	57.0
6/28/2004	0100	13.34	113.7	0	0.0144	18.93	0	12.1	55.8
6/28/2004	0200	13.88	113.9	0	0.3996	18.83	0	13.0	56.8
6/28/2004	0300	13.83	114.1	0	0.09	18.73	0	12.9	56.7
6/28/2004	0400	13.94	114.2	0	0.9792	18.65	0	13.1	57.0
6/28/2004	0500	13.56	114.4	0	0.5184	18.59	0	12.5	56.2
6/28/2004	0600	13.68	114.4	0	0.5436	18.54	0	12.7	56.5
6/28/2004	0700	13.92	114.5	0.015	0	18.49	0	13.1	56.9
6/28/2004	0800	14.39	114.4	0.061	0.4968	18.45	0	13.8	57.8
6/28/2004	0900	14.9	114.3	0.112	1.4184	18.42	0	14.7	58.8
6/28/2004	1000	16.41	113.2	0.34	1.4004	18.4	0	17.1	61.7
6/28/2004	1100	19.13	100	0.598	2.106	18.4	0	21.2	66.4
6/28/2004	1200	22.1	87.2	0.714	1.8648	18.42	0	25.2	70.9
6/28/2004	1300	23.08	84.3	0.649	5.0652	18.49	0	26.6	72.3
6/28/2004	1400	23.77	76.2	0.608	6.0804	18.6	0	27.1	72.7
6/28/2004	1500	23.72	78.1	0.517	4.5504	18.72	0	27.2	72.8
6/28/2004	1600	23.42	81.3	0.342	3.8016	18.82	0	26.9	72.6
6/28/2004	1700	23.08	80.1	0.231	5.3856	18.93	0	26.4	71.9
6/28/2004	1800	21.93	80.8	0.148	5.2488	19.01	0	24.7	70.1
6/28/2004	1900	21.91	76.6	0.228	6.2388	19.06	0	24.5	69.8
6/28/2004	2000	22.64	75.4	0.167	2.9304	19.09	0	25.5	70.9
6/28/2004	2100	20.85	84.6	0.04	0.5148	19.11	0	23.3	68.6
6/28/2004	2200	17.81	93.2	0	1.0872	19.12	0	19.0	63.9
6/28/2004	2300	15.73	104.1	0	0.3348	19.1	0	15.9	60.3
6/29/2004	0000	14.62	108.6	0	0.1332	19.04	0	14.2	58.3
6/29/2004	0100	13.79	111.7	0	0.2916	18.96	0	12.9	56.7
6/29/2004	0200	12.79	112.9	0	0	18.86	0	11.2	54.8
6/29/2004	0300	12.37	113.6	0	0	18.74	0	10.6	53.9
6/29/2004	0400	12.04	113.9	0	0.3816	18.62	0	10.0	53.3
6/29/2004	0500	12.24	114.1	0	0	18.49	0	10.3	53.7
6/29/2004	0600	13.02	114.2	0	0	18.37	0	11.6	55.2
6/29/2004	0700	12.95	114.2	0.015	0	18.27	0	11.5	55.0
6/29/2004	0800	13.38	114.3	0.087	0	18.2	0	12.2	55.9
6/29/2004	0900	15.25	114	0.269	0	18.14	0	15.2	59.5
6/29/2004	1000	19.3	101.4	0.472	1.4652	18.12	0	21.5	66.8
6/29/2004	1100	22.05	82.4	0.685	2.52	18.12	0	25.0	70.4
6/29/2004	1200	23.33	78.4	0.842	4.1976	18.18	0	26.6	72.2
6/29/2004	1300	24.67	72.9	0.879	3.6792	18.28	0	28.2	73.8
6/29/2004	1400	25.17	69.91	0.72	3.5028	18.41	0	28.8	74.2

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
6/29/2004	1500	25.77	64.9	0.802	6.4908	18.58	0	29.3	74.6
6/29/2004	1600	26.33	60.03	0.746	8.352	18.74	0	29.7	74.9
6/29/2004	1700	25.88	61.63	0.489	7.4844	18.89	0	29.2	74.4
6/29/2004	1800	26.32	58.15	0.482	6.8112	19.01	0	29.6	74.6
6/29/2004	1900	25.92	60.06	0.287	3.8484	19.1	0	29.2	74.3
6/29/2004	2000	24.5	69.33	0.119	0.8388	19.18	0	27.8	73.2
6/29/2004	2100	20.87	86	0.024	1.1664	19.23	0	23.4	68.7
6/29/2004	2200	17.63	104.1	0	0	19.26	0	18.9	63.8
6/29/2004	2300	15.62	109.8	0	0	19.23	0	15.8	60.2
6/30/2004	0000	14.67	112.3	0	0.0144	19.16	0	14.3	58.4
6/30/2004	0100	14.16	113.1	0	0	19.06	0	13.5	57.4
6/30/2004	0200	14.13	113.5	0	0.3276	18.95	0	13.4	57.3
6/30/2004	0300	13.97	113.5	0	0.27	18.83	0	13.2	57.0
6/30/2004	0400	13.99	113.5	0	0.036	18.73	0	13.2	57.1
6/30/2004	0500	13.89	113.6	0	0	18.63	0	13.0	56.9
6/30/2004	0600	14.08	113.6	0	0.1224	18.54	0	13.3	57.2
6/30/2004	0700	14.14	113.4	0.022	0.5652	18.46	0	13.4	57.4
6/30/2004	0800	15.44	111.2	0.135	0.3096	18.4	0	15.5	59.9
6/30/2004	0900	17.94	103.1	0.29	0.018	18.35	0	19.4	64.4
6/30/2004	1000	20.83	90.7	0.475	1.1124	18.34	0	23.5	68.9
6/30/2004	1100	23.35	79.3	0.687	1.5876	18.36	0	26.7	72.3
6/30/2004	1200	25.23	65.98	0.822	1.7028	18.42	0	28.6	73.9
6/30/2004	1300	26.46	60.74	0.913	0.2376	18.53	0	29.9	75.1
6/30/2004	1400	27.01	58.42	0.856	2.4372	18.67	0	30.5	75.6
6/30/2004	1500	27.42	55.73	0.757	3.7584	18.83	0	30.9	75.9
6/30/2004	1600	27.68	55.07	0.506	2.484	19	0	31.2	76.1
6/30/2004	1700	26.52	66.03	0.45	3.7224	19.15	0	30.4	75.8
6/30/2004	1800	25.61	72.2	0.306	5.2596	19.25	0	29.5	75.1
6/30/2004	1900	22.5	86.4	0.141	2.8944	19.34	0	25.8	71.5
6/30/2004	2000	22.24	89.4	0.076	0.3636	19.4	0	25.5	71.3
6/30/2004	2100	21.49	95.4	0.025	0.3312	19.44	0	24.7	70.4
6/30/2004	2200	18.62	108.3	0	0	19.45	0	20.6	65.8
6/30/2004	2300	17.8	112	0	0	19.42	0	19.3	64.4
7/1/2004	0000	18.12	112.1	0	0.0468	19.37	0	19.9	65.0
7/1/2004	0100	17.36	112.6	0	0.0792	19.31	0	18.6	63.6
7/1/2004	0200	16.77	113.3	0	0.5148	19.26	0	17.7	62.4
7/1/2004	0300	16.42	113.6	0	1.3284	19.19	0	17.1	61.8
7/1/2004	0400	15.44	113.7	0	0.0684	19.12	0	15.5	59.9
7/1/2004	0500	15.47	114	0	0.6768	19.05	0	15.6	59.9
7/1/2004	0600	16.08	114.1	0	0.7776	18.96	0	16.6	61.1
7/1/2004	0700	16.59	114.2	0.01	0	18.9	0	17.4	62.1
7/1/2004	0800	17.11	114.2	0.038	0.0144	18.85	0	18.3	63.1
7/1/2004	0900	17.84	114	0.116	0.5112	18.83	0	19.4	64.5
7/1/2004	1000	19.05	109.5	0.183	2.8656	18.82	0	21.3	66.7
7/1/2004	1100	20.56	101.5	0.391	5.4504	18.83	0	23.4	69.1
7/1/2004	1200	23.17	90.6	0.675	3.96	18.86	0	27.0	72.9
7/1/2004	1300	25.33	81.3	0.929	3.9348	18.92	0	29.7	75.7
7/1/2004	1400	26.91	72.9	0.833	3.3588	19.04	0	31.4	77.2
7/1/2004	1500	27.7	61.39	0.761	3.258	19.19	0	31.6	77.0
7/1/2004	1600	27.49	64.22	0.566	3.5892	19.36	0	31.6	77.0
7/1/2004	1700	27.99	63.77	0.502	2.0196	19.52	0	32.2	77.7
7/1/2004	1800	27.93	65.6	0.369	1.1664	19.65	0	32.3	77.8

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation kW·m$^{2-1}$	Wind speed km·hr^{-1}	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
7/1/2004	1900	27.41	72.4	0.207	0.468	19.75	0	32.0	77.9
7/1/2004	2000	25.75	82	0.107	1.2312	19.83	0	30.3	76.4
7/1/2004	2100	23.44	92.3	0.017	0.8316	19.88	0	27.5	73.5
7/1/2004	2200	20.85	105	0	0.1908	19.91	0	24.0	69.8
7/1/2004	2300	20.29	109.2	0	1.8216	19.9	0	23.3	69.0
7/2/2004	0000	19.65	110.5	0	0.972	19.87	0	22.3	67.9
7/2/2004	0100	18.76	112.1	0	0.3816	19.83	0	20.9	66.2
7/2/2004	0200	18.35	112.8	0	0.1656	19.78	0	20.3	65.5
7/2/2004	0300	17.82	113.3	0	0.2088	19.73	0	19.4	64.5
7/2/2004	0400	17.64	113.7	0	0.0792	19.66	0	19.1	64.1
7/2/2004	0500	17.83	113.9	0	0.0684	19.59	0	19.4	64.5
7/2/2004	0600	17.7	114.1	0	0.0216	19.53	0	19.2	64.3
7/2/2004	0700	17.88	114.2	0.016	0.162	19.48	0	19.5	64.6
7/2/2004	0800	18.7	114.2	0.09	1.5588	19.45	0	20.9	66.2
7/2/2004	0900	19.72	113.7	0.261	1.1988	19.42	0	22.5	68.2
7/2/2004	1000	22.11	102	0.447	2.9232	19.42	0	25.9	71.9
7/2/2004	1100	24.56	91.8	0.557	2.8332	19.45	0	29.1	75.4
7/2/2004	1200	26.3	82.5	0.748	3.2652	19.51	0	31.1	77.4
7/2/2004	1300	27.41	73.8	0.879	3.4056	19.6	0	32.1	78.1
7/2/2004	1400	28.5	68.27	0.891	3.6432	19.73	0	33.2	79.0
7/2/2004	1500	28.79	68.33	0.775	6.426	19.89	0	33.6	79.5
7/2/2004	1600	28.8	70.4	0.683	5.1336	20.06	0	33.8	79.8
7/2/2004	1700	27.69	74.7	0.376	3.9024	20.21	0	32.6	78.6
7/2/2004	1800	28.37	70.2	0.349	1.9008	20.32	0	33.2	79.1
7/2/2004	1900	23.66	98.5	0.057	5.8392	20.4	.508	28.1	74.5
7/2/2004	2000	22.22	107	0.046	0.4032	20.45	.254	26.3	72.5
7/2/2004	2100	21.69	109.8	0.009	0	20.46	0	25.5	71.7
7/2/2004	2200	21.16	112.2	0	0.0216	20.46	0	24.8	70.8
7/2/2004	2300	20.39	112.9	0	0	20.44	0	23.6	69.4
7/19/2004	0000	19.17	104	0	0.6984	19.81	0	21.3	66.7
7/19/2004	0100	18.59	103.2	0	0.9612	19.78	0	20.4	65.6
7/19/2004	0200	17.48	108.8	0	1.2456	19.74	0	18.8	63.7
7/19/2004	0300	16.24	109.4	0	0.2124	19.68	0	16.8	61.4
7/19/2004	0400	15.51	111.6	0	0.774	19.62	0	15.6	60.0
7/19/2004	0500	14.66	112.4	0	0	19.53	0	14.3	58.4
7/19/2004	0600	13.81	113.4	0	0	19.42	0	12.9	56.7
7/19/2004	0700	14.05	113.9	0.011	0	19.3	0	13.3	57.2
7/19/2004	0800	15.02	114.1	0.078	0	19.18	0	14.9	59.1
7/19/2004	0900	17.68	109	0.305	1.0152	19.08	0	19.1	64.1
7/19/2004	1000	19.7	95.8	0.393	5.6088	19.03	0	21.9	67.3
7/19/2004	1100	21.51	86.8	0.533	3.8484	19.02	0	24.4	69.9
7/19/2004	1200	22.77	79.8	0.733	5.0472	19.04	0	25.9	71.4
7/19/2004	1300	23.96	75.1	0.879	5.2524	19.1	0	27.4	72.9
7/19/2004	1400	25.22	69.17	0.824	2.466	19.19	0	28.8	74.2
7/19/2004	1500	25.52	68.1	0.638	3.7944	19.32	0	29.1	74.6
7/19/2004	1600	26.08	67.48	0.761	5.0508	19.46	0	29.9	75.3
7/19/2004	1700	25.76	68.49	0.634	7.0092	19.59	0	29.5	75.0
7/19/2004	1800	25.73	68.49	0.492	6.4152	19.7	0	29.4	74.9
7/19/2004	1900	25.18	69.61	0.293	4.9284	19.79	0	28.8	74.2
7/19/2004	2000	24.16	72.7	0.122	2.6208	19.86	0	27.5	73.0
7/19/2004	2100	21.17	83.5	0.01	1.2564	19.9	0	23.7	69.1
7/19/2004	2200	20.11	88.6	0	2.2608	19.9	0	22.3	67.6

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
7/19/2004	2300	17.99	100.5	0	0.126	19.86	0	19.4	64.4
7/20/2004	0000	16.28	109.3	0	0.6372	19.78	0	16.9	61.4
7/20/2004	0100	15.6	111.8	0	0.7344	19.69	0	15.8	60.2
7/20/2004	0200	14.69	112.7	0	0.2592	19.59	0	14.3	58.4
7/20/2004	0300	13.92	113.4	0	0	19.47	0	13.1	56.9
7/20/2004	0400	13.27	113.8	0	0	19.35	0	12.0	55.7
7/20/2004	0500	12.99	114.1	0	0.0612	19.21	0	11.6	55.1
7/20/2004	0600	12.68	114.2	0	0.6588	19.07	0	11.0	54.5
7/20/2004	0700	13.02	114.4	0.011	0.3852	18.93	0	11.6	55.2
7/20/2004	0800	14.07	114.3	0.075	0	18.81	0	13.3	57.2
7/20/2004	0900	16.36	113.1	0.281	0.9612	18.72	0	17.0	61.6
7/20/2004	1000	19.64	97.5	0.466	1.026	18.68	0	21.9	67.2
7/20/2004	1100	22.49	86.3	0.667	3.7296	18.69	0	25.8	71.5
7/20/2004	1200	23.91	78.9	0.804	6.9876	18.74	0	27.5	73.2
7/20/2004	1300	25.07	71.2	0.845	5.9256	18.84	0	28.7	74.2
7/20/2004	1400	25.92	63.36	0.906	5.688	18.97	0	29.4	74.7
7/20/2004	1500	26.49	54.97	0.895	5.436	19.14	0	29.6	74.5
7/20/2004	1600	26.99	50.34	0.808	4.7052	19.31	0	29.9	74.6
7/20/2004	1700	27.35	50	0.692	4.788	19.47	0	30.4	75.1
7/20/2004	1800	27.38	51.38	0.501	3.7476	19.61	0	30.5	75.3
7/20/2004	1900	26.77	58.36	0.299	3.1824	19.71	0	30.2	75.3
7/20/2004	2000	25.6	70.8	0.119	0.4608	19.79	0	29.4	75.0
7/20/2004	2100	20.74	97.7	0.015	0.0972	19.84	0	23.6	69.2
7/20/2004	2200	17.2	107.7	0	0.0396	19.85	0	18.3	63.1
7/20/2004	2300	16.2	111	0	0.27	19.8	0	16.7	61.3
7/21/2004	0000	15.49	112	0	0	19.71	0	15.6	60.0
7/21/2004	0100	15.06	113.2	0	0.3744	19.6	0	14.9	59.1
7/21/2004	0200	14.36	113.5	0	0.288	19.47	0	13.8	57.8
7/21/2004	0300	13.97	113.8	0	0.162	19.35	0	13.2	57.0
7/21/2004	0400	13.8	114.1	0	0.1224	19.22	0	12.9	56.7
7/21/2004	0500	13.82	114.3	0	0.3168	19.1	0	12.9	56.7
7/21/2004	0600	13.08	114.4	0	0	18.99	0	11.7	55.3
7/21/2004	0700	12.91	114.5	0.012	0	18.88	0	11.4	55.0
7/21/2004	0800	14.42	114.4	0.128	0	18.78	0	13.9	57.9
7/21/2004	0900	16.72	110	0.297	0.918	18.69	0	17.6	62.3
7/21/2004	1000	19.97	94.3	0.485	1.548	18.65	0	22.3	67.7
7/21/2004	1100	22.92	83	0.684	2.0988	18.65	0	26.3	71.9
7/21/2004	1200	25.44	69.8	0.828	2.0592	18.71	0	29.1	74.6
7/21/2004	1300	26.8	60.1	0.912	3.1788	18.81	0	30.3	75.5
7/21/2004	1400	27.87	53.59	0.927	3.9492	18.94	0	31.3	76.2
7/21/2004	1500	28.71	47.86	0.917	3.3372	19.12	0	31.9	76.5
7/21/2004	1600	29.02	51.86	0.823	4.4604	19.32	0	32.6	77.5
7/21/2004	1700	29.27	53.12	0.692	3.5388	19.51	0	33.1	78.0
7/21/2004	1800	29.72	52.79	0.504	2.1888	19.68	0	33.6	78.6
7/21/2004	1900	29.62	54.76	0.302	0.8208	19.82	0	33.7	78.7
7/21/2004	2000	27	75.8	0.081	0	19.92	0	31.7	77.7
7/21/2004	2100	22.69	97.5	0.01	0.2196	20	0	26.6	72.6
7/21/2004	2200	21.27	103.7	0	0.0972	20.03	0	24.6	70.5
7/21/2004	2300	20.21	107	0	0.0936	20.03	0	23.1	68.7
7/22/2004	0000	18.46	109.7	0	0.0648	20	0	20.4	65.6
7/22/2004	0100	17.31	111.3	0	0.0684	19.95	0	18.5	63.4
7/22/2004	0200	16.72	112.6	0	0.1044	19.86	0	17.6	62.3

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
7/22/2004	0300	16.41	113.3	0	0.0864	19.76	0	17.1	61.7
7/22/2004	0400	15.99	113.7	0	0.2736	19.66	0	16.4	60.9
7/22/2004	0500	15.67	113.9	0	0.1044	19.55	0	15.9	60.3
7/22/2004	0600	16.08	114.1	0	0.306	19.45	0	16.6	61.1
7/22/2004	0700	16.47	114.2	0.014	0.0108	19.36	0	17.2	61.9
7/22/2004	0800	16.83	114.3	0.056	0.1116	19.29	0	17.8	62.6
7/22/2004	0900	18.46	113.5	0.246	0.018	19.26	0	20.4	65.7
7/22/2004	1000	22.1	97.1	0.442	1.368	19.24	0	25.7	71.6
7/22/2004	1100	24.19	90.2	0.269	2.7324	19.26	0	28.5	74.6
7/22/2004	1200	25.27	86.6	0.3	3.7728	19.31	0	29.9	76.1
7/22/2004	1300	25.36	85.7	0.279	9.0828	19.39	0	30.0	76.2
7/22/2004	1400	24.35	86.4	0.326	9.1008	19.47	0	28.5	74.6
7/22/2004	1500	23.24	94.6	0.134	5.2308	19.55	1.016	27.3	73.4
7/22/2004	1600	21.91	106.5	0.07	2.7864	19.62	2.286	25.8	71.9
7/22/2004	1700	21.48	109.1	0.101	2.8404	19.67	3.556	25.2	71.3
7/22/2004	1800	21.5	107.5	0.083	4.8492	19.71	.508	25.1	71.2
7/22/2004	1900	21.34	108.5	0.094	4.068	19.76	.254	24.9	71.0
7/22/2004	2000	22	107	0.094	2.9376	19.79	0	25.9	72.1
7/22/2004	2100	21.69	109.8	0.005	0.5472	19.82	0	25.5	71.7
7/22/2004	2200	21.2	112.4	0	1.6092	19.85	5.334	24.9	70.9
7/22/2004	2300	20.98	113.3	0	0.0036	19.88	0	24.5	70.6
7/24/2004	0000	20.92	110	0	0.7092	20.67	0	24.3	70.3
7/24/2004	0100	19.91	111.8	0	0.2628	20.64	0	22.7	68.4
7/24/2004	0200	18.81	112.7	0	0.1332	20.59	0	21.0	66.4
7/24/2004	0300	18.54	113.4	0	0	20.54	0	20.6	65.9
7/24/2004	0400	17.65	113.7	0	0	20.47	0	19.1	64.1
7/24/2004	0500	17.89	114.1	0	0.288	20.38	0	19.5	64.6
7/24/2004	0600	17.91	113.7	0	1.5912	20.29	0	19.6	64.6
7/24/2004	0700	17.37	113.7	0.013	3.1068	20.2	0	18.7	63.6
7/24/2004	0800	18.55	112.6	0.099	0.4644	20.12	0	20.6	65.8
7/24/2004	0900	20.71	104.2	0.253	0.72	20.06	0	23.8	69.5
7/24/2004	1000	22.7	92.7	0.403	4.158	20.02	0	26.4	72.3
7/24/2004	1100	23.18	89.8	0.31	2.4408	20.02	0	27.0	72.9
7/24/2004	1200	25.56	80.3	0.754	2.196	20.05	0	29.9	75.9
7/24/2004	1300	26.06	75.1	0.757	3.2472	20.1	0	30.3	76.2
7/24/2004	1400	26.88	73.7	0.957	5.148	20.18	0	31.4	77.3
7/24/2004	1500	27.59	69.95	0.832	4.4928	20.3	0	32.1	77.9
7/24/2004	1600	27.57	70.5	0.567	3.0996	20.44	0	32.1	77.9
7/24/2004	1700	28.15	66.85	0.631	2.664	20.58	0	32.7	78.3
7/24/2004	1800	27.93	65.65	0.44	3.4956	20.69	0	32.3	77.8
7/24/2004	1900	26.99	73	0.277	4.05	20.77	0	31.5	77.3
7/24/2004	2000	24.89	82	0.073	7.3116	20.83	0	29.1	75.0
7/24/2004	2100	23.46	87.5	0.011	5.7708	20.85	0	27.3	73.2
7/24/2004	2200	21.67	96.8	0	2.3328	20.84	0	25.0	70.8
7/24/2004	2300	20.49	104.8	0	1.8972	20.82	0	23.5	69.1
7/25/2004	0000	19.3	110	0	0.0972	20.77	0	21.7	67.2
7/25/2004	0100	18.94	111.4	0	0.5796	20.72	0	21.2	66.5
7/25/2004	0200	18.8	111.9	0	1.5372	20.66	0	21.0	66.3
7/25/2004	0300	18.97	111.8	0	0.6552	20.6	0	21.2	66.6
7/25/2004	0400	19.18	111.5	0	0.036	20.54	0	21.6	67.0
7/25/2004	0500	19.12	111.4	0	0	20.5	0	21.5	66.9
7/25/2004	0600	18.89	109.2	0	0.36	20.46	0	21.0	66.4

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
7/25/2004	0700	18.94	110	0.002	0.1476	20.42	0	21.1	66.5
7/25/2004	0800	19.13	106.9	0.042	0.6984	20.37	0	21.4	66.7
7/25/2004	0900	20.25	99.9	0.2	2.1924	20.34	0	22.9	68.4
7/25/2004	1000	21.95	90.7	0.466	3.8556	20.31	0	25.2	70.9
7/25/2004	1100	23.33	85.4	0.548	3.6288	20.3	0	27.0	72.8
7/25/2004	1200	23.83	84.4	0.495	3.3588	20.33	0	27.7	73.5
7/25/2004	1300	24.64	83	0.796	6.7824	20.39	0	28.8	74.7
7/25/2004	1400	25.29	79.6	0.736	4.842	20.45	0	29.5	75.4
7/25/2004	1500	25.67	79.6	0.659	6.876	20.54	0	30.1	76.0
7/25/2004	1600	26.72	75.8	0.708	4.9464	20.64	0	31.3	77.3
7/25/2004	1700	26.69	75.2	0.636	10.148	20.73	0	31.2	77.1
7/25/2004	1800	26.39	74.2	0.414	9.6552	20.81	0	30.7	76.6
7/25/2004	1900	25.35	80.3	0.185	6.0012	20.87	0	29.6	75.6
7/25/2004	2000	24.51	86.3	0.099	9.4392	20.91	0	28.8	74.8
7/25/2004	2100	22.73	94.5	0.004	8.5932	20.92	0	26.5	72.5
7/25/2004	2200	21.94	97.8	0	6.9336	20.9	0	25.4	71.3
7/25/2004	2300	21.56	100.5	0	6.8328	20.87	0	25.0	70.8
7/26/2004	0000	21	104.8	0	7.2396	20.84	0	24.3	70.1
7/26/2004	0100	20.37	109.8	0	5.6124	20.8	0	23.4	69.2
7/26/2004	0200	20.25	110.4	0	6.0912	20.77	0	23.3	69.0
7/26/2004	0300	20.3	108.9	0	6.516	20.73	0	23.3	69.0
7/26/2004	0400	20.26	107.9	0	5.2452	20.7	0	23.2	68.9
7/26/2004	0500	20.26	107.7	0	2.7612	20.66	0	23.2	68.9
7/26/2004	0600	20.06	109.9	0	5.4972	20.63	0	22.9	68.6
7/26/2004	0700	19.83	110.9	0.012	2.5272	20.59	0	22.6	68.2
7/26/2004	0800	20.25	109.3	0.072	2.16	20.56	0	23.2	68.9
7/26/2004	0900	21.24	104.1	0.203	3.3948	20.54	0	24.6	70.5
7/26/2004	1000	22.35	98.1	0.225	1.584	20.52	0	26.1	72.1
7/26/2004	1100	23.63	91.5	0.327	0.8316	20.53	0	27.7	73.8
7/26/2004	1200	24.57	88.1	0.508	3.1284	20.55	0	28.9	75.1
7/26/2004	1300	25.79	84.9	0.669	2.1924	20.59	0	30.6	76.8
7/26/2004	1400	26.93	81.3	0.909	5.094	20.66	0	32.0	78.2
7/26/2004	1500	27.6	77.8	0.589	4.3812	20.77	0	32.7	78.9
7/26/2004	1600	25.09	90.6	0.084	6.966	20.9	0	29.9	76.2
7/26/2004	1700	22.93	104.2	0.075	3.8232	20.99	2.286	27.3	73.6
7/26/2004	1800	22.33	110.4	0.109	1.3032	21.04	7.366	26.6	73.0
7/26/2004	1900	21.83	108.4	0.123	2.538	21.06	.254	25.7	71.9
7/26/2004	2000	21.76	107.3	0.081	0.0468	21.08	0	25.6	71.7
7/26/2004	2100	21.05	109.8	0.005	0	21.09	0	24.5	70.5
7/26/2004	2200	20.31	112.5	0	0.0216	21.08	0	23.4	69.2
7/26/2004	2300	20.62	113.2	0	0.5112	21.06	0	23.9	69.9
7/27/2004	0000	20.71	113.3	0	0.2916	21.03	0	24.1	70.0
7/27/2004	0100	20.59	113.5	0	0	21	.254	23.9	69.8
7/27/2004	0200	20.61	113.7	0	0	20.97	.508	23.9	69.9
7/27/2004	0300	20.55	113.7	0	0.4716	20.94	.508	23.8	69.8
7/27/2004	0400	19.8	113	0	0	20.92	0	22.6	68.3
7/27/2004	0500	18.6	113.5	0	0.0216	20.89	0	20.7	66.0
7/27/2004	0600	18.65	113.9	0	0	20.84	0	20.8	66.1
7/27/2004	0700	18.95	113.9	0.004	0	20.79	.254	21.3	66.7
7/27/2004	0800	19.37	113.9	0.061	0	20.74	0	21.9	67.5
7/27/2004	0900	20.2	111.2	0.145	0	20.69	0	23.2	68.9
7/27/2004	1000	21.68	104.9	0.263	0	20.67	0	25.3	71.4

Appendix 1. Hourly environmental conditions

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
7/27/2004	1100	22.9	98.5	0.277	0	20.66	0	27.0	73.1
7/27/2004	1200	22.88	98.6	0.212	3.8772	20.68	0	26.9	73.1
7/27/2004	1300	23.2	96.7	0.24	5.886	20.7	0	27.3	73.5
7/27/2004	1400	23.13	96.2	0.278	8.298	20.73	0	27.2	73.3
7/27/2004	1500	23.07	99.8	0.399	6.912	20.75	.254	27.3	73.5
7/27/2004	1600	23.2	97.1	0.372	4.9284	20.78	0	27.3	73.5
7/27/2004	1700	23.92	93.4	0.299	0.81	20.81	0	28.3	74.5
7/27/2004	1800	23.79	93.9	0.205	0.1584	20.85	0	28.1	74.3
7/27/2004	1900	23.44	96.9	0.137	0.0072	20.89	0	27.7	73.9
7/27/2004	2000	23.52	96.5	0.082	0.0252	20.92	0	27.8	74.0
7/27/2004	2100	22.18	105.2	0.01	0	20.94	0	26.1	72.3
7/27/2004	2200	21.12	109.9	0	0.5652	20.96	4.572	24.6	70.6
7/27/2004	2300	20.46	112.5	0	0.054	20.95	2.032	23.7	69.5
7/28/2004	0000	20.48	112.8	0	1.4076	20.94	.508	23.7	69.6
7/28/2004	0100	20.18	112.3	0	1.0476	20.93	.254	23.2	69.0
7/28/2004	0200	20.09	113	0	0.09	20.91	.254	23.1	68.8
7/28/2004	0300	20.01	113.3	0	0.1764	20.88	0	23.0	68.7
7/28/2004	0400	19.79	113.6	0	0.3132	20.86	0	22.6	68.3
7/28/2004	0500	19.1	113.4	0	0.2556	20.83	0	21.5	66.9
7/28/2004	0600	19.07	111.9	0	0.3096	20.8	0	21.4	66.8
7/28/2004	0700	18.84	106.9	0.005	3.492	20.76	0	20.9	66.2
7/28/2004	0800	19	102.5	0.057	3.9708	20.72	0	21.0	66.3
7/28/2004	0900	19.95	96	0.235	5.5368	20.67	0	22.3	67.7
7/28/2004	1000	20.94	88.9	0.536	7.3008	20.63	0	23.6	69.0
7/28/2004	1100	21.47	83.8	0.703	7.5168	20.6	0	24.2	69.6
7/28/2004	1200	22.14	77	0.576	4.9752	20.58	0	24.9	70.2
7/28/2004	1300	23.39	71.1	0.825	4.9644	20.59	0	26.4	71.7
7/28/2004	1400	24.44	65.76	0.922	3.636	20.64	0	27.5	72.8
7/28/2004	1500	25.19	62.51	0.793	2.7144	20.74	0	28.3	73.5
7/28/2004	1600	25.96	62.52	0.745	2.9232	20.86	0	29.4	74.6
7/28/2004	1700	25.83	63.82	0.666	4.338	21	0	29.3	74.6
7/28/2004	1800	25.36	63.91	0.516	6.0588	21.13	0	28.7	73.9
7/28/2004	1900	25.04	65.77	0.319	4.6224	21.23	0	28.3	73.6
7/28/2004	2000	23.72	72.7	0.128	3.4056	21.28	0	26.9	72.3
7/28/2004	2100	20.32	87	0.011	1.2996	21.29	0	22.6	67.9
7/28/2004	2200	17.79	101.3	0	1.2456	21.25	0	19.1	64.1
7/28/2004	2300	16.11	109.6	0	0.4788	21.16	0	16.6	61.1
7/29/2004	0000	15.4	111.7	0	0.7272	21.03	0	15.5	59.8
7/29/2004	0100	14.53	112.8	0	0.054	20.88	0	14.1	58.1
7/29/2004	0200	14	113.4	0	0.162	20.72	0	13.2	57.1
7/29/2004	0300	13.39	113.8	0	0.1404	20.55	0	12.2	55.9
7/29/2004	0400	13.49	114.1	0	0.7272	20.38	0	12.4	56.1
7/29/2004	0500	14.08	114.2	0	0	20.22	0	13.3	57.2
7/29/2004	0600	14.08	114.2	0	0	20.07	0	13.3	57.2
7/29/2004	0700	13.68	114.1	0.012	0	19.95	0	12.7	56.5
7/29/2004	0800	14.48	114	0.08	0	19.84	0	14.0	58.0
7/29/2004	0900	16.45	110.6	0.212	0	19.74	0	17.1	61.8
7/29/2004	1000	19.92	94.1	0.41	0	19.68	0	22.2	67.6
7/29/2004	1100	22.18	87.3	0.515	3.2976	19.67	0	25.4	71.0
7/29/2004	1200	23.42	85	0.655	7.4772	19.71	0	27.1	72.9
7/29/2004	1300	24.34	83.2	0.603	5.85	19.82	0	28.3	74.2
7/29/2004	1400	24.66	85.4	0.603	6.9948	19.97	0	28.9	75.0

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
7/29/2004	1500	26.08	82.3	0.674	5.0292	20.12	0	30.8	77.0
7/29/2004	1600	26.35	82.3	0.515	6.1776	20.31	0	31.2	77.4
7/29/2004	1700	26.91	80.6	0.613	6.678	20.49	0	31.9	78.1
7/29/2004	1800	26.45	83.7	0.359	7.4196	20.66	0	31.4	77.7
7/29/2004	1900	26.04	85.7	0.239	8.154	20.81	0	31.0	77.3
7/29/2004	2000	24.61	92	0.055	7.6788	20.92	0	29.2	75.5
7/29/2004	2100	23.46	97.2	0.003	7.1604	20.98	0	27.8	74.0
7/29/2004	2200	22.8	98.4	0	6.4044	21.01	0	26.8	72.9
7/29/2004	2300	22.19	101	0	0.3276	21.01	0	26.0	72.0
8/16/2004	0000	16.53	112.9	0	0.2232	19.1	0	17.3	62.0
8/16/2004	0100	16.61	113.3	0	0	19.04	0	17.4	62.1
8/16/2004	0200	16.63	113.2	0	1.044	18.98	0	17.5	62.2
8/16/2004	0300	16.75	112.8	0	0	18.93	0	17.7	62.4
8/16/2004	0400	16.38	113.2	0	0	18.89	0	17.1	61.7
8/16/2004	0500	14.71	113.7	0	0	18.84	0	14.4	58.5
8/16/2004	0600	14.7	114.2	0	0.0504	18.77	0	14.3	58.4
8/16/2004	0700	15.54	114.3	0.001	0.7848	18.68	0	15.7	60.1
8/16/2004	0800	15.48	114.4	0.036	0.8064	18.61	0	15.6	59.9
8/16/2004	0900	16.15	114.3	0.116	0.5724	18.57	0	16.7	61.2
8/16/2004	1000	17.4	108.2	0.163	0.1332	18.55	0	18.6	63.5
8/16/2004	1100	18.51	100.6	0.256	3.7728	18.56	0	20.2	65.3
8/16/2004	1200	20.58	92.8	0.673	4.6296	18.59	0	23.2	68.6
8/16/2004	1300	22.13	85.8	0.774	5.2128	18.67	0	25.2	70.8
8/16/2004	1400	22.95	83.4	0.925	8.0028	18.82	0	26.3	72.0
8/16/2004	1500	23.58	78.5	0.857	7.5276	19.05	0	27.0	72.6
8/16/2004	1600	24.49	67.13	0.769	7.3044	19.3	0	27.7	73.0
8/16/2004	1700	24.29	66.06	0.462	5.0508	19.53	0	27.3	72.6
8/16/2004	1800	23.83	67.1	0.283	3.6432	19.72	0	26.8	72.0
8/16/2004	1900	24.02	66.8	0.237	2.4228	19.84	0	27.0	72.2
8/16/2004	2000	21.86	78.6	0.08	1.0476	19.91	0	24.5	69.9
8/16/2004	2100	17.34	101.6	0.002	0.0216	19.93	0	18.4	63.3
8/16/2004	2200	15.49	110.2	0	0.072	19.88	0	15.6	59.9
8/16/2004	2300	14.37	112.2	0	0.1008	19.77	0	13.8	57.8
8/17/2004	0000	13.62	113.3	0	0	19.62	0	12.6	56.3
8/17/2004	0100	13.98	113.8	0	0	19.46	0	13.2	57.0
8/17/2004	0200	14.35	113.8	0	0.0108	19.32	0	13.8	57.8
8/17/2004	0300	14.38	113.8	0	0	19.19	0	13.8	57.8
8/17/2004	0400	13.59	113.8	0	0	19.09	0	12.5	56.3
8/17/2004	0500	13.23	114.2	0	0	18.98	0	11.9	55.6
8/17/2004	0600	13.41	114.3	0	0.054	18.86	0	12.2	55.9
8/17/2004	0700	13.42	114.4	0.002	0	18.75	0	12.3	55.9
8/17/2004	0800	14.19	114.3	0.034	0.108	18.65	0	13.5	57.4
8/17/2004	0900	15.68	111.2	0.182	0.9	18.57	0	15.9	60.3
8/17/2004	1000	18.58	94.6	0.442	2.3904	18.53	0	20.2	65.2
8/17/2004	1100	21.46	82.6	0.645	2.2212	18.53	0	24.1	69.5
8/17/2004	1200	23.12	79	0.79	1.8648	18.58	0	26.4	71.9
8/17/2004	1300	24.77	72.7	0.885	3.0924	18.72	0	28.4	73.9
8/17/2004	1400	26.18	64.23	0.929	2.9268	18.94	0	29.8	75.1
8/17/2004	1500	26.53	62.26	0.879	4.2516	19.21	0	30.1	75.4
8/17/2004	1600	26.7	61.73	0.781	4.3272	19.5	0	30.3	75.6
8/17/2004	1700	27.15	60.86	0.522	1.9296	19.76	0	30.9	76.1
8/17/2004	1800	25.84	67.54	0.253	2.2968	19.98	0	29.5	75.0

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
8/17/2004	1900	25.08	73.6	0.192	0.6084	20.14	0	28.9	74.5
8/17/2004	2000	22.95	86.4	0.048	2.9376	20.24	0	26.5	72.2
8/17/2004	2100	20.39	100.1	0.001	2.9052	20.29	0	23.1	68.7
8/17/2004	2200	17.83	109.4	0	0	20.28	0	19.3	64.4
8/17/2004	2300	16.95	112.6	0	0	20.21	0	18.0	62.8
8/18/2004	0000	16.09	113.3	0	0	20.1	0	16.6	61.1
8/18/2004	0100	15.33	113.8	0	0	19.97	0	15.4	59.7
8/18/2004	0200	15.6	114.2	0	0	19.83	0	15.8	60.2
8/18/2004	0300	16.59	114.2	0	0	19.69	0	17.4	62.1
8/18/2004	0400	17.02	114.1	0	0.0036	19.6	0	18.1	62.9
8/18/2004	0500	17.17	114.1	0	0.0072	19.53	0	18.4	63.2
8/18/2004	0600	17.28	114.1	0	0	19.48	0	18.5	63.4
8/18/2004	0700	17.48	114.2	0.001	0	19.43	0	18.9	63.8
8/18/2004	0800	17.85	114	0.02	0	19.39	0	19.5	64.5
8/18/2004	0900	18.68	111.4	0.132	1.1484	19.36	0	20.8	66.1
8/18/2004	1000	20.14	102	0.266	4.5288	19.35	0	22.8	68.4
8/18/2004	1100	21.73	95.6	0.523	1.98	19.37	0	25.0	70.8
8/18/2004	1200	24.29	85	0.821	2.4048	19.43	0	28.4	74.3
8/18/2004	1300	25.67	76.7	0.802	1.9728	19.55	0	29.9	75.7
8/18/2004	1400	26.94	68.31	0.942	3.5784	19.76	0	31.1	76.7
8/18/2004	1500	27.22	63.77	0.617	4.2948	20.01	0	31.2	76.6
8/18/2004	1600	27.83	58.22	0.628	5.868	20.27	0	31.6	76.7
8/18/2004	1700	27.34	60.58	0.367	1.5408	20.5	0	31.1	76.4
8/18/2004	1800	26.82	66.45	0.269	1.6416	20.68	0	30.8	76.3
8/18/2004	1900	27.05	68.25	0.2	1.1952	20.8	0	31.2	76.9
8/18/2004	2000	24.84	88.1	0.076	0	20.89	0	29.3	75.5
8/18/2004	2100	19.6	105.4	0.001	0	20.93	0	22.1	67.5
8/18/2004	2200	17.25	111.1	0	0	20.89	0	18.4	63.3
8/18/2004	2300	16.09	113	0	0	20.77	0	16.6	61.1
8/19/2004	0000	15.3	113.6	0	0	20.61	0	15.3	59.6
8/19/2004	0100	14.74	114	0	0	20.44	0	14.4	58.5
8/19/2004	0200	14.81	114.2	0	0	20.26	0	14.5	58.6
8/19/2004	0300	15.33	114.4	0	0	20.09	0	15.4	59.7
8/19/2004	0400	14.94	114.4	0	0	19.95	0	14.7	58.9
8/19/2004	0500	14.42	114.6	0	0	19.82	0	13.9	57.9
8/19/2004	0600	14.36	114.7	0	0	19.69	0	13.8	57.8
8/19/2004	0700	15.14	114.7	0.002	0	19.56	0	15.1	59.3
8/19/2004	0800	15.16	114.7	0.047	0	19.45	0	15.1	59.3
8/19/2004	0900	16.61	114.5	0.19	0.0144	19.37	0	17.5	62.1
8/19/2004	1000	20.09	104.7	0.413	0.072	19.32	0	22.8	68.4
8/19/2004	1100	24.17	89.8	0.619	1.62	19.32	0	28.4	74.6
8/19/2004	1200	27.06	78.9	0.624	4.6116	19.4	0	32.0	78.2
8/19/2004	1300	27.85	72.5	0.694	7.7472	19.57	0	32.7	78.6
8/19/2004	1400	29.12	66.6	0.882	8.4888	19.8	0	34.0	79.7
8/19/2004	1500	29.61	63.82	0.763	6.4152	20.08	0	34.4	80.0
8/19/2004	1600	30.14	61.16	0.688	4.914	20.4	0	34.9	80.4
8/19/2004	1700	30.14	60.14	0.573	5.1948	20.7	0	34.8	80.2
8/19/2004	1800	30.22	57.61	0.44	3.9528	20.95	0	34.7	80.0
8/19/2004	1900	27.71	68.74	0.112	5.814	21.16	0	32.2	77.9
8/19/2004	2000	25.08	83.6	0.033	0.6804	21.29	0	29.4	75.5
8/19/2004	2100	21.83	102.6	0.001	0.2124	21.33	0	25.5	71.5
8/19/2004	2200	19.36	110	0	0.018	21.31	0	21.8	67.3

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
8/19/2004	2300	18.3	112.5	0	0	21.22	0	20.2	65.4
8/22/2004	0000	16.3	104.1	0	0.6516	20.73	0	16.8	61.4
8/22/2004	0100	15.4	107.3	0	0.6408	20.6	0	15.4	59.8
8/22/2004	0200	13.78	111.4	0	0.0864	20.46	0	12.9	56.7
8/22/2004	0300	12.97	113.6	0	0.7704	20.29	0	11.5	55.1
8/22/2004	0400	12.37	114.1	0	0.6012	20.11	0	10.5	53.9
8/22/2004	0500	11.83	114.4	0	0	19.92	0	9.7	52.9
8/22/2004	0600	11.98	114.6	0	0	19.74	0	9.9	53.1
8/22/2004	0700	12.49	114.7	0.001	0	19.57	0	10.7	54.1
8/22/2004	0800	12.61	114.7	0.041	0	19.44	0	10.9	54.4
8/22/2004	0900	13.91	114.6	0.181	1.0296	19.33	0	13.1	56.9
8/22/2004	1000	15.8	110.4	0.364	1.6344	19.26	0	16.1	60.5
8/22/2004	1100	18.81	94.6	0.639	1.2132	19.23	0	20.6	65.6
8/22/2004	1200	20.7	86.2	0.736	3.9672	19.25	0	23.1	68.5
8/22/2004	1300	22.29	78	0.847	2.8224	19.32	0	25.1	70.5
8/22/2004	1400	22.89	76.5	0.492	2.574	19.47	0	25.9	71.3
8/22/2004	1500	23.19	76.5	0.583	3.4704	19.66	0	26.3	71.8
8/22/2004	1600	23.91	76.1	0.555	2.6748	19.84	0	27.3	72.9
8/22/2004	1700	23.96	77.1	0.375	2.142	20.02	0	27.5	73.1
8/22/2004	1800	23.12	82.4	0.215	3.1248	20.19	0	26.5	72.2
8/22/2004	1900	22.5	85.6	0.188	1.512	20.32	0	25.8	71.4
8/22/2004	2000	21.19	91.9	0.052	0.0648	20.41	0	24.1	69.6
8/22/2004	2100	17.74	107.8	0.001	0	20.45	0	19.2	64.2
8/22/2004	2200	15.61	112.6	0	0	20.41	0	15.8	60.2
8/22/2004	2300	14.69	113.7	0	0	20.31	0	14.3	58.4
8/23/2004	0000	14.89	114.2	0	0	20.17	0	14.6	58.8
8/23/2004	0100	15.72	114.4	0	0.2556	20.03	0	16.0	60.4
8/23/2004	0200	15.23	114.5	0	2.268	19.92	0	15.2	59.5
8/23/2004	0300	14.76	114.6	0	2.9556	19.83	0	14.4	58.5
8/23/2004	0400	14.6	114.8	0	2.34	19.75	0	14.2	58.2
8/23/2004	0500	14.6	114.8	0	1.3464	19.68	0	14.2	58.2
8/23/2004	0600	14.94	114.9	0	0.4608	19.6	0	14.7	58.9
8/23/2004	0700	14.81	114.9	0.001	3.8736	19.53	0	14.5	58.6
8/23/2004	0800	14.96	114.9	0.025	1.5768	19.47	0	14.8	58.9
8/23/2004	0900	15.32	114.9	0.09	2.3508	19.41	0	15.4	59.6
8/23/2004	1000	16.17	114.8	0.18	2.2968	19.36	0	16.7	61.3
8/23/2004	1100	16.95	114.7	0.359	4.086	19.34	0	18.0	62.8
8/23/2004	1200	19.37	107.3	0.697	2.7504	19.35	0	21.8	67.2
8/23/2004	1300	23.62	90.3	0.879	3.0852	19.43	0	27.6	73.7
8/23/2004	1400	26.64	76	0.876	2.916	19.62	0	31.2	77.2
8/23/2004	1500	27.73	68.97	0.887	3.1896	19.92	0	32.2	78.0
8/23/2004	1600	28.49	62.13	0.78	2.4948	20.25	0	32.8	78.2
8/23/2004	1700	28.78	58.7	0.629	3.06	20.58	0	32.9	78.1
8/23/2004	1800	29.41	58.35	0.446	1.098	20.85	0	33.7	79.0
8/23/2004	1900	26.01	76.7	0.134	6.4152	21.07	0	30.4	76.3
8/23/2004	2000	24.37	86.3	0.035	2.0304	21.21	0	28.6	74.6
8/23/2004	2100	23.09	92.9	0	1.0908	21.27	0	27.0	73.0
8/23/2004	2200	21.11	106.7	0	1.1556	21.27	0	24.5	70.4
8/23/2004	2300	20	110.8	0	0.9864	21.23	0	22.9	68.5
8/24/2004	0000	19.3	111.9	0	0	21.17	0	21.8	67.3
8/24/2004	0100	18.39	113.3	0	0.036	21.08	0	20.3	65.6
8/24/2004	0200	17.47	113.7	0	0.0108	20.97	0	18.8	63.8

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
8/24/2004	0300	16.74	114.1	0	0.0108	20.84	0	17.7	62.4
8/24/2004	0400	16.04	114.4	0	0.0936	20.7	0	16.5	61.0
8/24/2004	0500	15.5	114.5	0	0.0144	20.56	0	15.6	60.0
8/24/2004	0600	15.96	114.6	0	0.0324	20.4	0	16.4	60.9
8/24/2004	0700	16.09	114.7	0.002	0.0684	20.27	0	16.6	61.1
8/24/2004	0800	16.73	114.7	0.037	0.2232	20.16	0	17.6	62.4
8/24/2004	0900	17.73	114.6	0.114	0.234	20.08	0	19.3	64.3
8/24/2004	1000	19.09	113.5	0.218	1.26	20.03	0	21.5	66.9
8/24/2004	1100	21.29	103.1	0.311	0.9252	20.02	0	24.6	70.5
8/24/2004	1200	23.68	91.5	0.353	1.4616	20.05	0	27.8	73.9
8/24/2004	1300	25.2	86.6	0.713	4.1868	20.14	0	29.8	76.0
8/24/2004	1400	26.55	77.9	0.587	2.1816	20.3	0	31.2	77.2
8/24/2004	1500	26.76	77.5	0.679	7.4196	20.52	0	31.5	77.5
8/24/2004	1600	27.28	70.6	0.512	4.7988	20.75	0	31.7	77.5
8/24/2004	1700	25.8	76.1	0.211	2.718	20.98	0	30.0	75.9
8/24/2004	1800	24.16	92.5	0.09	0.0072	21.15	0	28.6	74.8
8/24/2004	1900	23.53	96	0.05	2.9124	21.24	0	27.8	74.0
8/24/2004	2000	21.36	102.7	0.014	0.414	21.29	0	24.7	70.6
8/24/2004	2100	20.15	109.5	0	0	21.28	0	23.1	68.8
8/24/2004	2200	20.14	111.3	0	0.144	21.24	0	23.1	68.8
8/24/2004	2300	20.29	111	0	1.1016	21.18	0	23.3	69.1
8/25/2004	0000	20.14	110.6	0	0.558	21.13	0	23.1	68.8
8/25/2004	0100	19.76	111.7	0	1.1628	21.07	0	22.5	68.1
8/25/2004	0200	19.63	110.9	0	0.2268	21.01	0	22.3	67.8
8/25/2004	0300	19.14	110.3	0	0.3672	20.95	0	21.5	66.9
8/25/2004	0400	18.45	111.2	0	0.8244	20.88	0	20.4	65.6
8/25/2004	0500	18.25	111.3	0	0.5184	20.81	0	20.1	65.2
8/25/2004	0600	17.46	111.5	0	1.5624	20.73	0	18.8	63.7
8/25/2004	0700	17.34	112	0.001	0.6228	20.64	0	18.6	63.5
8/25/2004	0800	17.47	111.3	0.036	0.1296	20.55	0	18.8	63.7
8/25/2004	0900	18.56	107.3	0.11	1.656	20.47	0	20.5	65.7
8/25/2004	1000	21.44	95.5	0.277	0.2808	20.42	0	24.6	70.3
8/25/2004	1100	22.8	89.7	0.398	1.1772	20.4	0	26.4	72.2
8/25/2004	1200	23.22	87.8	0.321	2.2536	20.44	0	26.9	72.8
8/25/2004	1300	24	86	0.47	2.9268	20.52	0	28.0	73.9
8/25/2004	1400	24.68	81.1	0.571	4.6476	20.63	0	28.7	74.6
8/25/2004	1500	25.72	76.2	0.695	4.3164	20.77	0	29.9	75.7
8/25/2004	1600	26.08	72.4	0.657	6.786	20.95	0	30.2	75.9
8/25/2004	1700	27.12	64.47	0.607	3.8052	21.15	0	31.1	76.5
8/25/2004	1800	25.98	69.35	0.393	8.2872	21.34	0	29.8	75.4
8/25/2004	1900	24.59	77.3	0.193	8.118	21.48	0	28.4	74.1
8/25/2004	2000	22.47	84.2	0.03	5.0724	21.55	0	25.7	71.3
8/25/2004	2100	20.57	93	0	1.7532	21.55	0	23.2	68.6
8/25/2004	2200	17.52	107.9	0	0.7128	21.48	0	18.8	63.7
8/25/2004	2300	15.67	111.8	0	0.2484	21.36	0	15.9	60.3
8/26/2004	0000	14.56	113.5	0	0.0432	21.19	0	14.1	58.2
8/26/2004	0100	13.79	114.1	0	0	21	0	12.9	56.7
8/26/2004	0200	13.25	114.4	0	0.1008	20.79	0	12.0	55.6
8/26/2004	0300	13.53	114.5	0	0.378	20.57	0	12.4	56.2
8/26/2004	0400	13.05	114.5	0	0	20.38	0	11.6	55.2
8/26/2004	0500	12.33	114.7	0	0.3096	20.2	0	10.5	53.8
8/26/2004	0600	13.07	114.7	0	0.4032	20.03	0	11.7	55.3

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
8/26/2004	0700	13.01	114.7	0.001	0.0324	19.88	0	11.6	55.1
8/26/2004	0800	13.88	114.8	0.032	1.1196	19.75	0	13.0	56.8
8/26/2004	0900	15.1	114.6	0.13	0.0576	19.64	0	15.0	59.2
8/26/2004	1000	17.51	109.7	0.343	0.702	19.57	0	18.8	63.8
8/26/2004	1100	21.2	94.3	0.6	1.8072	19.55	0	24.2	69.8
8/26/2004	1200	23.22	86.9	0.617	2.1708	19.61	0	26.9	72.7
8/26/2004	1300	24.08	83.4	0.605	3.1068	19.74	0	28.0	73.8
8/26/2004	1400	25.95	75.3	0.776	2.376	19.93	0	30.2	76.0
8/26/2004	1500	26.52	71.4	0.886	4.0824	20.17	0	30.7	76.4
8/26/2004	1600	27.19	66.02	0.584	2.3796	20.45	0	31.3	76.8
8/26/2004	1700	26.9	66.5	0.419	2.9628	20.73	0	30.9	76.4
8/26/2004	1800	26.77	67.42	0.323	1.8288	20.96	0	30.8	76.4
8/26/2004	1900	26.96	69.72	0.208	0.7704	21.12	0	31.2	76.9
8/26/2004	2000	23.61	88.8	0.037	2.79	21.23	0	27.6	73.5
8/26/2004	2100	21.67	94.9	0	2.52	21.29	0	24.9	70.7
8/26/2004	2200	19.91	101.4	0	1.4112	21.27	0	22.4	67.9
8/26/2004	2300	18.06	109.3	0	0	21.2	0	19.7	64.8
8/27/2004	0000	17.88	112.1	0	0	21.09	0	19.5	64.5
8/27/2004	0100	18.37	112.3	0	0	20.97	0	20.3	65.5
8/27/2004	0200	17.62	112.6	0	0.0684	20.87	0	19.1	64.1
8/27/2004	0300	16.89	113.3	0	0	20.78	0	17.9	62.7
8/27/2004	0400	15.94	113.8	0	0.018	20.66	0	16.4	60.8
8/27/2004	0500	15.09	114.1	0	0	20.54	0	15.0	59.2
8/27/2004	0600	15.34	114.4	0	0	20.4	0	15.4	59.7
8/27/2004	0700	15.78	114.5	0.001	0.126	20.26	0	16.1	60.5
8/27/2004	0800	16.23	114.6	0.029	0.6408	20.15	0	16.8	61.4
8/27/2004	0900	16.66	114.7	0.065	0.1764	20.07	0	17.5	62.2
8/27/2004	1000	17.95	114.1	0.293	0.4176	20.02	0	19.6	64.7
8/27/2004	1100	21.84	96.2	0.59	1.0296	20	0	25.2	71.1
8/27/2004	1200	24.36	85	0.746	2.8764	20.04	0	28.5	74.4
8/27/2004	1300	26.49	80.7	0.832	3.366	20.18	0	31.3	77.5
8/27/2004	1400	28.05	74.7	0.887	6.2676	20.41	0	33.1	79.2
8/27/2004	1500	29.06	68.15	0.863	6.7932	20.72	0	34.0	79.8
8/27/2004	1600	29.6	68.13	0.772	6.9372	21.05	0	34.7	80.6
8/27/2004	1700	28.39	75.8	0.523	8.7012	21.37	0	33.7	79.9
8/27/2004	1800	26.49	87.7	0.202	4.6332	21.64	0	31.8	78.3
8/27/2004	1900	26.54	87.8	0.097	1.3032	21.82	0	31.9	78.4
8/27/2004	2000	23.98	100.6	0.011	0.0324	21.92	0	28.7	75.2
8/27/2004	2100	23.24	103.5	0	1.5696	21.96	0	27.7	74.1
8/27/2004	2200	22.37	106.4	0	0.828	21.94	0	26.5	72.7
8/27/2004	2300	21.14	110.2	0	0.342	21.9	0	24.7	70.7
9/18/2004	0000	16.75	97	0	21.838	20.14	0	17.5	62.1
9/18/2004	0100	16.18	97.9	0	21.744	19.97	0	16.6	61.1
9/18/2004	0200	15.72	99.9	0	17.989	19.8	0	15.9	60.3
9/18/2004	0300	15.47	99.7	0	17.878	19.63	0	15.5	59.8
9/18/2004	0400	15.06	99	0	19.199	19.47	0	14.9	59.1
9/18/2004	0500	14.64	101.1	0	15.599	19.31	0	14.2	58.3
9/18/2004	0600	14.57	100.6	0	13.385	19.16	.254	14.1	58.2
9/18/2004	0700	14.29	101.1	0	16.009	19.02	0	13.7	57.7
9/18/2004	0800	13.91	102.2	0.006	15.278	18.89	0	13.1	57.0
9/18/2004	0900	13.95	100.2	0.038	14.645	18.76	0	13.2	57.1
9/18/2004	1000	14.13	98.8	0.065	10.152	18.64	0	13.4	57.4

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
9/18/2004	1100	14.37	97	0.088	13.46	18.53	0	13.8	57.9
9/18/2004	1200	15.13	92.3	0.165	13.702	18.44	0	15.0	59.2
9/18/2004	1300	16.34	86.6	0.41	17.428	18.36	0	16.7	61.2
9/18/2004	1400	16.77	82.4	0.414	14.504	18.3	0	17.3	61.9
9/18/2004	1500	16.54	81	0.446	13.129	18.29	0	16.9	61.5
9/18/2004	1600	17.28	77.4	0.473	9.09	18.3	0	18.0	62.6
9/18/2004	1700	18	72.6	0.584	14.36	18.33	0	18.9	63.6
9/18/2004	1800	17.87	73.6	0.324	16.394	18.38	0	18.7	63.4
9/18/2004	1900	17.56	73.9	0.14	7.65	18.42	0	18.3	62.9
9/18/2004	2000	16.09	80.1	0.007	7.488	18.41	0	16.3	60.7
9/18/2004	2100	15.55	82.9	0	6.1056	18.38	0	15.5	59.9
9/18/2004	2200	13.41	93.3	0	1.0188	18.3	0	12.4	56.2
9/18/2004	2300	13.26	93	0	3.078	18.2	0	12.1	56.0
9/19/2004	0000	11.29	100.8	0	0.7632	18.08	0	9.0	52.3
9/19/2004	0100	10.68	103.4	0	3.8232	17.94	0	8.0	51.1
9/19/2004	0200	12.1	95.9	0	4.0788	17.79	0	10.3	53.9
9/19/2004	0300	9.76	108.2	0	0.9576	17.64	0	6.4	49.2
9/19/2004	0400	8.1	112.1	0	0.9612	17.5	0	3.7	45.8
9/19/2004	0500	7.05	113.4	0	0.4896	17.35	0	1.9	43.7
9/19/2004	0600	6.712	113.9	0	1.0044	17.19	0	1.3	43.0
9/19/2004	0700	6.241	114.3	0	0.414	17.01	0	0.6	42.0
9/19/2004	0800	6.116	114.7	0.024	0.3312	16.85	0	0.3	41.7
9/19/2004	0900	9.05	113.9	0.228	0.0432	16.69	0	5.1	47.5
9/19/2004	1000	13.33	86.5	0.442	4.6044	16.57	0	12.3	56.2
9/19/2004	1100	16.14	71.3	0.62	2.7432	16.51	0	16.3	60.7
9/19/2004	1200	17.87	62.61	0.755	4.0068	16.52	0	18.5	63.1
9/19/2004	1300	19.82	51.76	0.833	3.9564	16.63	0	20.8	65.3
9/19/2004	1400	21.81	42.02	0.855	5.2164	16.84	0	23.0	67.3
9/19/2004	1500	22.4	44.21	0.806	8.9784	17.12	0	23.8	68.2
9/19/2004	1600	23.09	48.56	0.695	6.7428	17.43	0	24.9	69.4
9/19/2004	1700	23.14	48.21	0.536	7.0776	17.73	0	24.9	69.4
9/19/2004	1800	23.04	49.53	0.343	5.9112	17.99	0	24.8	69.4
9/19/2004	1900	22.39	59.64	0.143	1.4112	18.18	0	24.5	69.3
9/19/2004	2000	15.55	93.7	0.007	0.0216	18.31	0	15.6	59.9
9/19/2004	2100	11.17	108.3	0	0	18.33	0	8.7	51.8
9/19/2004	2200	8.9	111.6	0	0	18.25	0	5.0	47.3
9/19/2004	2300	8.36	113.5	0	0.0396	18.09	0	4.0	46.2
9/20/2004	0000	7.21	112.7	0	0.1152	17.88	0	2.2	44.0
9/20/2004	0100	6.246	112.9	0	0.0396	17.66	0	0.6	42.1
9/20/2004	0200	5.032	113.7	0	0	17.44	0	-1.4	39.7
9/20/2004	0300	4.337	114.9	0	0	17.2	0	-2.6	38.3
9/20/2004	0400	3.851	115.4	0	0	16.97	0	-3.4	37.2
9/20/2004	0500	4.557	115.5	0	0	16.74	0	-2.2	38.6
9/20/2004	0600	4.42	115.4	0	0	16.53	0	-2.5	38.4
9/20/2004	0700	4.536	115.6	0	0.1368	16.36	0	-2.3	38.6
9/20/2004	0800	4.594	115.6	0.026	0.0144	16.21	0	-2.2	38.7
9/20/2004	0900	5.508	115.3	0.119	0	16.08	0	-0.7	40.5
9/20/2004	1000	8.36	114.7	0.346	0.2052	15.97	0	4.0	46.1
9/20/2004	1100	13.13	88.4	0.605	6.2316	15.9	0	12.0	55.8
9/20/2004	1200	15.4	71.3	0.742	8.0136	15.91	0	15.2	59.6
9/20/2004	1300	16.65	65.1	0.822	10.663	16.01	0	16.9	61.4
9/20/2004	1400	18.19	62.02	0.837	8.0712	16.2	0	18.9	63.5

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
9/20/2004	1500	19.26	60.18	0.79	9.27	16.46	0	20.3	64.9
9/20/2004	1600	19.94	57.83	0.683	8.7156	16.75	0	21.2	65.8
9/20/2004	1700	19.96	59.27	0.525	9.8136	17.03	0	21.2	65.9
9/20/2004	1800	19.49	60.34	0.333	8.9856	17.25	0	20.6	65.3
9/20/2004	1900	18.56	64.84	0.136	5.2128	17.41	0	19.5	64.1
9/20/2004	2000	13.57	92.9	0.005	0.504	17.49	0	12.6	56.5
9/20/2004	2100	10.23	108.1	0	0.0252	17.48	0	7.2	50.0
9/20/2004	2200	8.34	112.2	0	0	17.37	0	4.1	46.2
9/20/2004	2300	7.35	113.7	0	0	17.21	0	2.4	44.2
9/21/2004	0000	6.849	114.2	0	0	17.02	0	1.6	43.2
9/21/2004	0100	6.038	114.7	0	0	16.81	0	0.2	41.6
9/21/2004	0200	7.08	114.8	0	0	16.61	0	1.9	43.6
9/21/2004	0300	7.3	114.8	0	0.0612	16.43	0	2.3	44.0
9/21/2004	0400	6.981	115	0	0	16.3	0	1.7	43.4
9/21/2004	0500	7.08	115.1	0	0	16.19	0	1.9	43.6
9/21/2004	0600	7.09	115.1	0	0	16.09	0	1.9	43.6
9/21/2004	0700	7.11	115.2	0	0.1008	16	.254	1.9	43.6
9/21/2004	0800	7.03	115.2	0.014	2.574	15.92	0	1.8	43.5
9/21/2004	0900	7.17	115.2	0.119	1.6776	15.84	0	2.0	43.7
9/21/2004	1000	8.19	115.1	0.246	2.1276	15.77	0	3.7	45.7
9/21/2004	1100	10.73	114.6	0.532	1.5732	15.72	0	7.9	50.7
9/21/2004	1200	15.38	92.8	0.73	2.7252	15.73	0	15.3	59.6
9/21/2004	1300	19.59	64.36	0.811	2.5272	15.84	0	20.9	65.6
9/21/2004	1400	22.23	49.93	0.827	2.7	16.05	.762	23.8	68.4
9/21/2004	1500	23.99	45.63	0.768	2.232	16.35	0	25.8	70.3
9/21/2004	1600	24.93	44.06	0.595	1.836	16.69	0	26.9	71.3
9/21/2004	1700	25.34	34.3	0.518	3.7872	17.02	0	26.9	70.8
9/21/2004	1800	25.07	35.54	0.331	3.4956	17.31	0	26.6	70.6
9/21/2004	1900	24.01	52.71	0.132	0.0324	17.54	0	26.2	70.9
9/21/2004	2000	15.76	96.1	0.006	0.1836	17.68	0	15.9	60.3
9/21/2004	2100	12.17	106.9	0	0	17.72	0	10.3	53.7
9/21/2004	2200	10.7	112.2	0	0	17.65	0	7.9	50.8
9/21/2004	2300	9.82	113.4	0	0	17.52	0	6.4	49.0
9/25/2004	0000	14	114.6	0	0	18.55	0	13.2	57.1
9/25/2004	0100	15.01	114.7	0	0	18.41	0	14.8	59.0
9/25/2004	0200	15.03	114.7	0	0	18.29	0	14.9	59.1
9/25/2004	0300	14.7	114.8	0	0	18.21	0	14.3	58.4
9/25/2004	0400	13.95	114.9	0	0	18.12	0	13.1	57.0
9/25/2004	0500	14.61	115	0	0.2448	18.03	0	14.2	58.3
9/25/2004	0600	14.56	115.1	0	0.3132	17.95	0	14.1	58.2
9/25/2004	0700	14.62	115.2	0	0.18	17.89	0	14.2	58.3
9/25/2004	0800	14.69	115.2	0.009	0	17.84	0	14.3	58.4
9/25/2004	0900	14.76	115.2	0.055	0.4608	17.8	0	14.4	58.5
9/25/2004	1000	15.01	115.2	0.141	0.6552	17.77	0	14.8	59.0
9/25/2004	1100	15.91	114.9	0.208	0.3168	17.76	0	16.3	60.8
9/25/2004	1200	18.26	102.5	0.434	1.44	17.77	0	19.9	65.0
9/25/2004	1300	21.77	83	0.7	2.4444	17.84	0	24.6	70.0
9/25/2004	1400	23.36	78.9	0.662	2.9268	17.99	0	26.7	72.3
9/25/2004	1500	24.69	76.2	0.661	2.934	18.23	0	28.5	74.1
9/25/2004	1600	25.4	72.8	0.629	3.4308	18.5	0	29.3	74.9
9/25/2004	1700	25.58	71.2	0.392	1.9332	18.77	0	29.4	75.0
9/25/2004	1800	24.15	79.4	0.129	0.7236	19.01	0	27.9	73.6

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW \cdot m^{2-1}$	Wind speed $km \cdot hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
9/25/2004	1900	22.56	88	0.068	0.4212	19.19	0	26.0	71.7
9/25/2004	2000	19.24	103.8	0.002	1.8396	19.29	0	21.5	66.8
9/25/2004	2100	16.29	110.7	0	0.306	19.3	0	16.9	61.5
9/25/2004	2200	15.51	113.5	0	0.0756	19.22	0	15.7	60.0
9/25/2004	2300	14.47	114.2	0	0.0108	19.09	0	14.0	58.0
9/26/2004	0000	13.71	114.7	0	0	18.94	0	12.7	56.5
9/26/2004	0100	13.9	114.9	0	0	18.78	0	13.0	56.9
9/26/2004	0200	13.62	114.9	0	0.198	18.63	0	12.6	56.3
9/26/2004	0300	13.87	115.1	0	0.3096	18.51	0	13.0	56.8
9/26/2004	0400	14.16	115.2	0	0	18.41	0	13.5	57.4
9/26/2004	0500	14.05	115.2	0	0.2232	18.33	0	13.3	57.2
9/26/2004	0600	14.01	115.2	0	0.3852	18.26	0	13.2	57.1
9/26/2004	0700	14.05	115.3	0	0.3744	18.19	0	13.3	57.2
9/26/2004	0800	14.01	115.3	0.009	0.5616	18.13	0	13.2	57.1
9/26/2004	0900	14.39	115.3	0.068	0.0684	18.07	0	13.8	57.8
9/26/2004	1000	15.29	115.2	0.125	0.9468	18.03	0	15.3	59.6
9/26/2004	1100	16.17	115	0.232	0.306	18.01	0	16.7	61.3
9/26/2004	1200	18.72	105.7	0.668	2.2068	18.03	0	20.7	65.9
9/26/2004	1300	22.86	83.9	0.785	7.2072	18.1	0	26.2	71.9
9/26/2004	1400	24.08	74.7	0.784	10.469	18.29	0	27.5	73.0
9/26/2004	1500	24.15	69.73	0.607	9.1368	18.57	0	27.3	72.7
9/26/2004	1600	24.57	67.34	0.61	9.8496	18.85	0	27.8	73.1
9/26/2004	1700	24.79	64.19	0.473	8.28	19.08	0	27.9	73.1
9/26/2004	1800	23.71	70.9	0.214	5.3244	19.27	0	26.8	72.1
9/26/2004	1900	21.81	85.6	0.076	4.5828	19.4	0	24.7	70.3
9/26/2004	2000	18.27	102.2	0.004	0.1512	19.46	0	19.9	65.0
9/26/2004	2100	16.09	110.4	0	0.0468	19.43	0	16.6	61.1
9/26/2004	2200	14.72	112.7	0	0	19.32	0	14.4	58.5
9/26/2004	2300	13.67	113.8	0	0	19.16	0	12.7	56.4
9/27/2004	0000	13.52	114.4	0	0	18.99	0	12.4	56.1
9/27/2004	0100	13.61	114.7	0	0	18.83	0	12.6	56.3
9/27/2004	0200	13.54	114.9	0	0.2232	18.67	0	12.4	56.2
9/27/2004	0300	13.23	115.1	0	0.108	18.54	0	11.9	55.6
9/27/2004	0400	13.34	115.2	0	0	18.44	.254	12.1	55.8
9/27/2004	0500	13.9	115.2	0	0	18.34	0	13.0	56.9
9/27/2004	0600	14.56	115.2	0	0	18.26	0	14.1	58.2
9/27/2004	0700	14.99	115.2	0	1.4364	18.19	0	14.8	59.0
9/27/2004	0800	15.35	111.2	0.012	2.754	18.13	0	15.4	59.7
9/27/2004	0900	16.46	104	0.09	6.3432	18.07	0	17.1	61.7
9/27/2004	1000	17.31	98.9	0.097	8.4744	18.03	0	18.3	63.1
9/27/2004	1100	17.13	102.4	0.068	10.505	18.01	0	18.1	62.9
9/27/2004	1200	17.54	102.6	0.101	7.5456	18	0	18.8	63.6
9/27/2004	1300	17.67	105.1	0.105	7.4592	18.01	0	19.0	63.9
9/27/2004	1400	17.62	107.8	0.137	6.9192	18.03	0	19.0	63.9
9/27/2004	1500	18.25	103.6	0.164	11.07	18.05	0	19.9	65.0
9/27/2004	1600	18.24	103.5	0.074	10.282	18.08	0	19.9	64.9
9/27/2004	1700	17.95	104.7	0.052	8.928	18.12	0	19.4	64.5
9/27/2004	1800	17.73	106.4	0.028	7.0308	18.14	0	19.1	64.1
9/27/2004	1900	17.75	106.6	0.01	7.5456	18.14	0	19.2	64.1
9/27/2004	2000	17.59	106.9	0	7.5996	18.14	0	18.9	63.8
9/27/2004	2100	17.56	107.5	0	7.1964	18.13	0	18.9	63.8
9/27/2004	2200	17.57	109.3	0	8.2188	18.11	.508	18.9	63.9

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
9/27/2004	2300	17.6	110.7	0	7.5204	18.1	.254	19.0	64.0
9/28/2004	0000	17.77	111.4	0	5.508	18.08	1.778	19.3	64.3
9/28/2004	0100	17.81	113.2	0	3.4596	18.07	6.096	19.4	64.4
9/28/2004	0200	17.7	114.2	0	1.44	18.06	10.16	19.2	64.3
9/28/2004	0300	18.04	114.3	0	4.3164	18.04	9.652	19.8	64.9
9/28/2004	0400	18.06	114.1	0	3.15	18.04	14.22	19.8	65.0
9/28/2004	0500	18.28	114.5	0	3.2328	18.04	9.652	20.2	65.4
9/28/2004	0600	18.44	114.3	0	4.0032	18.05	2.032	20.4	65.7
9/28/2004	0700	18.45	114.1	0	1.0872	18.07	.508	20.4	65.7
9/28/2004	0800	18.45	113.4	0.001	6.4512	18.08	4.318	20.4	65.7
9/28/2004	0900	18.54	112.7	0.01	9.2376	18.1	15.24	20.6	65.8
9/28/2004	1000	18.61	113.3	0.035	4.1652	18.14	6.858	20.7	66.0
9/28/2004	1100	18.83	113	0.061	3.0672	18.22	2.794	21.0	66.4
9/28/2004	1200	19.14	111.3	0.132	6.3432	18.33	1.524	21.5	66.9
9/28/2004	1300	19.65	107.2	0.192	10.915	18.46	.508	22.2	67.7
9/28/2004	1400	19.59	104	0.265	15.052	18.66	.254	22.0	67.4
9/28/2004	1500	19.92	101	0.266	14.429	18.89	.254	22.4	67.9
9/28/2004	1600	21.57	93.6	0.49	15.57	18.99	0	24.7	70.4
9/28/2004	1700	21.23	91.4	0.239	15.124	19.01	0	24.1	69.7
9/28/2004	1800	20.1	94.8	0.047	8.136	19.04	0	22.5	67.9
9/28/2004	1900	19.62	96.4	0.026	11.635	19.04	0	21.8	67.1
9/28/2004	2000	19.39	94.9	0.001	15.052	19.02	0	21.4	66.7
9/28/2004	2100	18.92	95.3	0	11.578	18.97	0	20.7	65.9
9/28/2004	2200	18.59	94.1	0	9.9684	18.91	0	20.2	65.2
9/28/2004	2300	18.48	92.7	0	9.1116	18.83	0	20.0	65.0
9/29/2004	0000	17.76	93.5	0	5.85	18.76	0	18.9	63.8
9/29/2004	0100	16.65	97.7	0	4.1724	18.68	0	17.3	61.9
9/29/2004	0200	15.29	101.9	0	0.7452	18.59	0	15.2	59.5
9/29/2004	0300	13.49	110.1	0	0.288	18.48	0	12.4	56.1
9/29/2004	0400	14.36	106.9	0	1.3896	18.35	0	13.8	57.8
9/29/2004	0500	14	107.9	0	1.872	18.2	0	13.2	57.1
9/29/2004	0600	13.66	107.6	0	0.9864	18.06	0	12.7	56.5
9/29/2004	0700	12.57	111.2	0	1.134	17.93	0	10.9	54.4
9/29/2004	0800	14.15	106.5	0.021	6.3288	17.79	0	13.5	57.4
9/29/2004	0900	16.13	98.1	0.164	8.3844	17.66	0	16.5	61.0
9/29/2004	1000	17.99	89	0.349	2.5956	17.57	0	19.2	64.0
9/29/2004	1100	18.65	86.2	0.5	6.228	17.52	0	20.1	65.1
9/29/2004	1200	19.96	81.1	0.66	7.6428	17.55	0	21.9	67.0
9/29/2004	1300	21.1	73.9	0.755	9.6588	17.66	0	23.3	68.4
9/29/2004	1400	21.67	71.3	0.768	8.4924	17.83	0	24.0	69.1
9/29/2004	1500	22.33	63.74	0.698	6.5268	18.06	0	24.6	69.5
9/29/2004	1600	22.9	59.62	0.622	7.416	18.31	0	25.1	70.0
9/29/2004	1700	22.23	64.16	0.371	6.4368	18.54	0	24.4	69.4
9/29/2004	1800	20.7	73.6	0.148	4.5252	18.73	0	22.7	67.7
9/29/2004	1900	19.28	82.1	0.068	4.6404	18.85	0	20.9	65.9
9/29/2004	2000	17.14	91.3	0.001	5.3676	18.89	0	18.0	62.7
9/29/2004	2100	16.31	95.2	0	1.0656	18.86	0	16.8	61.3
9/29/2004	2200	16.03	93.6	0	1.6848	18.79	0	16.3	60.8
9/29/2004	2300	15.21	96.3	0	0.324	18.7	0	15.1	59.4
9/30/2004	0000	14.23	101.7	0	0.1656	18.6	0	13.6	57.6
9/30/2004	0100	13.43	106.6	0	0.2664	18.48	0	12.3	56.1
9/30/2004	0200	13.19	109.3	0	0.846	18.36	0	11.9	55.6

Appendix 1. Hourly environmental conditions data (cont'd).

Date	Time	Air temperature ºC	Relative Humidity %	Solar radiation $kW{\cdot}m^{2-1}$	Wind speed $km{\cdot}hr^{-1}$	Soil temperature ºC	Rainfall mm	THI ºC	THI ºF
9/30/2004	0300	12.39	111.9	0	0	18.24	0	10.6	54.0
9/30/2004	0400	12.92	113.1	0	0	18.12	0	11.4	55.0
9/30/2004	0500	12.76	113.5	0	0.0792	18.01	0	11.2	54.7
9/30/2004	0600	12.28	113.6	0	0.7668	17.91	0	10.4	53.8
9/30/2004	0700	11.93	113.7	0	0.1764	17.8	0	9.8	53.1
9/30/2004	0800	11.55	114.1	0.018	0	17.7	0	9.2	52.3
9/30/2004	0900	12.52	113.8	0.068	0.5364	17.59	0	10.8	54.2
9/30/2004	1000	14.66	105.3	0.198	1.1376	17.5	0	14.3	58.4
9/30/2004	1100	16.33	93.8	0.326	7.3116	17.46	0	16.8	61.3
9/30/2004	1200	18.29	85.9	0.513	3.0672	17.48	0	19.6	64.4
9/30/2004	1300	20.5	76.6	0.705	3.1932	17.54	0	22.5	67.6
9/30/2004	1400	22.09	71	0.761	2.9412	17.7	0	24.5	69.7
9/30/2004	1500	22.59	70.1	0.593	3.9852	17.95	0	25.2	70.4
9/30/2004	1600	22.88	69.15	0.535	3.5316	18.22	0	25.6	70.7
9/30/2004	1700	23.29	67.41	0.439	5.1336	18.46	0	26.0	71.2
9/30/2004	1800	22.5	72.9	0.245	4.4748	18.67	0	25.2	70.5
9/30/2004	1900	20.58	86.3	0.067	0.5076	18.82	0	23.0	68.3
9/30/2004	2000	17.51	102.6	0.001	0	18.9	0	18.7	63.6
9/30/2004	2100	15.84	109.4	0	0	18.9	0	16.2	60.6
9/30/2004	2200	15.14	111.6	0	0	18.84	0	15.0	59.3
9/30/2004	2300	15.41	112.9	0	0.0612	18.75	0	15.5	59.8

Appendix 2. Temperature Humidity Index (THI) for cattle [ab]

DEG F	RELATIVE HUMIDITY 0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
75														72	72	73	73	74	74	75	75
80							72	72	73	73	74	74	75	76	76	77	78	78	79	79	80
85			72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
90	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
95	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
100	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	
105	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97						
110	81	83	84	86	87	89	90	91	93	94	96	97									
115	84	85	87	88	90	91	93	95	96	87											
120	86	88	89	91	93	94	96	98													

NO STRESS

MILD STRESS

MEDIUM STRESS

SEVERE STRESS

[a] THI= Air Temperature °F-(0.55 - (0.55 * RH % / 100)) * (Air Temp°F - 58.8)
[b]Modified from Dr. Frank Wierama (1990), Department of Agricultural Engineering, The University of Arizona, Tucson, Arizona.

VITA

Holly Terry Boland was born June 6, 1978 to Rodney Anthony Terry and Estelle King Terry, in Winston-Salem, NC. She grew up in Ararat, VA, attended Patrick Co. High School and graduated in 1996. She attended Surry Community College from 1996 to 1997 and then transferred to Virginia Polytechnic Institute and State University. She graduated with a Bachelor of Science degree in Biology in 1999. She entered the workforce as a Minerals Analyst for Olver Laboratories, Inc. in Blacksburg, VA in 1999. In 2000 she became a Laboratory Technician at Virginia Polytechnic Institute and State University. In January 2003 she started on a Master of Science degree in the Animal and Poultry Sciences Department in Ruminant Nutrition also at Virginia Polytechnic Institute and State University.