

RUMINAL TEMPERATURE FOR IDENTIFICATION AND
PREDICTION OF ESTRUS IN BEEF COWS

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CHAPTER I

INTRODUCTION

Production efficiency of a cow-calf operation can be enhanced by increasing the number and weight of calves. Artificially inseminating cows to genetically superior bulls enhances the genetic merit of offspring and provides producers with an opportunity to increase the production efficiency of the cowherd. Estrous synchronization in combination with AI can shorten the calving interval, decrease labor, and result in greater cow productivity (Lauderdale, 2009). Although AI is utilized in 78% of U.S. dairy herds (USDA, 2009), estrous synchronization and AI are only used in 8% of U.S. beef herds (USDA, 2011). Time and labor expenditures are the primary deterrents for the utilization of reproductive technologies. Estrous detection is critical for efficient use of AI. Visual observation of estrous cows is the most commonly used method of estrous detection in beef and dairy herds. The ideal estrous detection system would include constant surveillance of cows, accurate and automatic estrous detection, and minimal labor expense (Senger, 1994). Recent advances in technology have led to the development of accurate estrous detection systems which utilize either estrous behavior or physiological changes occurring at estrus. Ruminal boluses have been developed for noninvasive, frequent measurement of ruminal temperature (RuT) and have been used to detect estrus in beef cows (Cooper-Prado et al., 2011).

Body temperature increases during estrus. Piccione et al. (2003) demonstrated that rectal temperature increased 1.3°C on the day of estrus. Similarly, vaginal temperature (Redden et al., 1993; Kyle et al., 1998; Fisher et al., 2008) and RuT (Bailey et al., 2009; Cooper-Prado et al., 2011) increase between 0.5 and 1.0°C at estrus. Use of RuT to predict estrus has potential to enhance reproductive efficiency in beef and dairy cows.

The effect of ambient temperature (T_{amb}) on RuT at estrus is not well established. Cows produce heat as a result of metabolic processes, which helps them to maintain body temperature. During exposure to elevated T_{amb} , thermoregulatory mechanisms of cows may be inadequate which may result in increases in body temperature. Heat stress of cattle limits metabolic efficiency, growth, lactation, and reproduction, and accounts for annual average economic losses of \$897 and \$369 million in the dairy and beef industries, respectively (St-Pierre et al., 2003). Exposure of cows to elevated T_{amb} alters estrous behavior, follicular development, and endocrine profile. Increases in core body temperature may influence the usefulness of RuT for estrous detection. The current research evaluated the use of RuT to identify and predict estrus and determine effects that ambient temperature may have on the application of RuT for predicting the time of insemination of beef cows.

CHAPTER II

REVIEW OF LITERATURE

ESTRUS IN COWS

Endocrine Regulation of Estrus

Estrus is the period of sexual receptivity in the bovine female. Beginning at puberty, the estrous cycle averages 21 d in duration and occurs throughout the life of a female, unless pregnancy, suckling, malnutrition, or environmental stress occurs. Phases of the estrous cycle are identified by the primary structures present on the ovary. The luteal phase of the estrous cycle occurs with the development and growth of the corpus luteum (CL) and continues until regression of the CL occurs. Progesterone production from the CL decreases to a nadir approximately 2 d prior to estrus (Swanson et al., 1972; Wettemann et al., 1972; Hendricks, 1976). The follicular phase of the estrous cycle occurs when the dominant follicle is present on the ovary. Follicle stimulating hormone (FSH) and luteinizing hormone (LH) from the pituitary support follicular development until dominance occurs (Dobson, 1978; Silvia and Taylor, 1989; Flint et al., 1990). As reviewed by Ginther et al. (1996), 2 to 3 follicular waves occur throughout the estrous cycle and the dominant follicle develops from a 4 mm follicle cohort that arises after an FSH surge. Estradiol secretion by the dominant follicle increases during the 3 d prior to estrus (Dobson, 1978; Ireland et al., 1984) and maximum plasma concentrations of estradiol occurs just prior to estrus (Wettemann et al., 1972). Coinciding with maximum estradiol concentrations, the ovulatory surge of LH occurs and plasma LH is minimal in the 2 d following estrus

(Wettemann et al., 1972; Echternkamp and Hansel, 1973; Chenault et al., 1975; Lemon et al., 1975; De Silva et al., 1981). Estradiol, alone or following progesterone priming, stimulates estrous behavior in ovariectomized cows (Vailes et al., 1992). Differentiation of the theca and granulosa cells of the ruptured follicle occurs and results in development of the corpus luteum (CL). Progesterone secretion increases to maximum concentrations (Swanson et al., 1972; Wettemann et al., 1972) during the luteal phase. Progesterone exerts an inhibitory effect on GnRH neurons in the hypothalamus and limits LH, FSH, and estradiol secretion. Exogenous progesterone inhibits sexual behavior in ovariectomized cows (Davidge et al., 1987; Vailes et al., 1992). Progesterone concentrations in plasma are maximum until uterine prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) stimulates CL regression (Louis et al., 1973; Lauderdale, 1974).

Detection of Estrus

Detection of estrus is a major factor limiting reproductive efficiency. Senger (1994) outlined requirements of the ideal estrous detection system including continuous (24h/d) surveillance of cows, accurate and automatic identification of cows in estrus, an operational duration lasting the productive lifespan of the cow, minimal to no labor input, and high accuracy in identifying behavioral or physiological events that are highly correlated with ovulation. The most common method of estrous detection is twice daily observation of cows. Exploiting behavioral changes occurring at estrus, an observer must watch cows to determine which cows are mounted by other cows. The observation of cows for signs of estrous behavior generally occurs for 30 min intervals, 2 to 3 times daily. When observation time is increased the efficiency of estrous detection is increased (Hall et al., 1959). Cows not exhibiting estrous behavior during observation periods may be overlooked and may be considered anestrus (Foote, 1975). Technologies have been developed for estrous detection that utilize mounting behavior. Patches fitted with dye-containing vials, which are broken upon mounting, increase the number of estruses detected compared with visual observation, but patches are subject to loss and false

positive identification (Baker, 1965). The percentage of dairy cows correctly identified in estrus were > 81% when multiple estrous detection methods were used simultaneously (Cavalieri et al., 2003a). Advances in technology have incorporated pressure sensors and data logging. Such systems, including the HeatWatch system (CowChips LLC, Malapan, NJ) are able to record time of mount and duration. The use of radiotelemetric devices to record mounting activity detected a greater number of heifers in estrus compared with visual observation (Stevenson et al., 1996). The number of mounts received by cows determined by observation and HeatWatch were correlated (Floyd et al., 2009). Efficiency of these systems for estrous detection ranges from 48% to 100% (Dohi et al., 1993; Xu et al., 1998; Cavalieri et al., 2003b; Peralta et al., 2005; Floyd et al., 2009).

Pedometers or accelerometers have been developed to monitor cow activity associated with estrus and can be effective estrous detection tools (Liu and Spahr, 1993; Nebel et al., 2011). Kiddy (1977) observed an increase in activity in 93% of dairy cows in free stalls at the time of estrus and Yoshioka et al. (2010) observed a correlation between increased activity and ovulation in beef cattle. Increased activity at estrus was greater compared with periods before and after estrus (Løvendahl and Chagunda, 2010). An increase in activity correctly identified 80% of cows in estrus (Liu and Spahr, 1993; Redden et al., 1993). Estrous detection rates were similar when comparing mounting behavior and increased activity (At-Taras and Spahr, 2001). Nebel et al. (2011) observed optimal conception rates with AI between 13 to 16 h after maximal activity at estrus. Silent estrus, environment, lack of ambulatory movement, housing conditions, and accuracy of the identification model may be limiting factors in the usefulness of activity as an estrous detection method.

Development of estrous detection systems, which utilize physiological changes in cows, has occurred with recent advances in technology. Measures of vaginal conductivity (VC) have been studied to aid in the detection of estrus. Vaginal dwelling probes, that emit alternating

currents between electrodes, can be used to measure electrical resistance of cervical mucus. Patterns of VC during the estrous cycle have been quantified for beef cows (Meena et al., 2003) and water buffaloes (Gupta and Purohit, 2001), and the greatest decrease in VC (30 to 50%) occurs at estrus. There was a curvilinear relationship between VC and serum progesterone (Aboul-Ela et al., 1983) and changes in vaginal electrical resistance are associated with changes in progesterone during the 2 d before to 23 d after onset of estrus (Scipioni and Foote, 1999). Vaginal conductivity increases in concert with the LH surge, however, considerable animal variation prevented use of VC as a physiological indicator of estrus (Fisher et al., 2008). Incorrect identification of estrus by VC occurred in 36% of cows (Meena et al., 2003). Kitwood et al. (1993) observed minimal difference in estrous detection rate between VC and twice daily observation for estrous behavior. Insemination of cows when estrus was detected by VC resulted in pregnancy rates from 50 to 82% (Leidl and Stolla, 1976; Meena et al., 2003). Vaginal conductivity is highly variable, differs in individual animals during consecutive estruses (Gartland et al., 1976; Elving et al., 1983), and varies between animals on the same day relative to the onset of estrus (Gartland et al., 1976; Leidl and Stolla, 1976). Positioning of the probe (Aboul-Ela et al., 1983; Kitwood et al., 1993) and inflammation of the reproductive tract in response to the presence of the probe (Leidl and Stolla, 1976) can result in inconsistent measurement of VC. Rorie (2002) concluded that use of VC for estrous detection is greatly limited due to variation in VC, duration of probe use, and labor requirements.

Increases in core body temperature may be useful for the detection of estrus. Vaginal temperature (VT) can be measured by insertion of temperature cathodes into the vaginal lumen. Increases in VT at estrus range from 0.48 to 1.0°C and are 6.5 to 11 h in duration (Bobowiec et al., 1990; Mosher et al., 1990; Kyle et al., 1998; Fisher et al., 2008; Suthar et al., 2011). Duration of the interval from PGF_{2α} to ovulation and to maximum VT were correlated ($r = 0.74$; Rajamahendran et al., 1989). The intervals between maximum LH and estradiol at estrus and

maximum VT were 30 to 60 min, respectively (Mosher et al., 1990). Concentrations of progesterone in plasma at estrus were not correlated with VT (Suthar et al., 2011). A 0.3°C increase in mean VT for 3 h, compared with the mean VT for the previous 4 d, occurred in 81% of estrous dairy cows (Redden et al., 1993). Kyle et al. (1998) observed VT increases of at least 0.3 or 0.5 during a 3 h identification period, compared with the mean VT during the preceding 72 h, occurred in 56.9 and 89.2% of estrous cows, respectively. During a 4 h period, VT increases of at least 0.3 or 0.5°C occurred in 75.0 and 89.3%, respectively, of estrous cows (Kyle et al., 1998). Increases in VT of at least 0.3°C, compared with mean VT during the preceding 72 h, correctly identified 84% of estrus cows, whereas 53.2% of estrous cows were identified by visual observation (Kyle et al., 1998).

Increases in ruminal temperature (RuT) at estrus have been established (Bailey et al., 2009; Cooper-Prado et al., 2011). Measurement of RuT is achieved by administering a temperature bolus into the rumen of cows and information is sent to a computer via telemetry. Ruminal temperature increased 0.4 to 1.0°C at estrus, and RuT was not influenced by Tamb or season (Bailey et al., 2009; Cooper-Prado et al., 2011). An increase in RuT ≥ 0.3 °C and ≥ 0.7 °C during an 8 h evaluation period, compared with a mean pre-estrus RuT 12 to 84 h before the 8 h period, correctly identified 95% and 42%, respectively, of cows in estrus in December, and 100% of estrous cows were detected in May by either a ≥ 0.3 °C or ≥ 0.7 °C RuT increase (Bailey et al., 2009).

The utilization of physiological temperature changes for the determination of estrus is contingent on methods of data analyses. Estrous detection by body temperature monitoring is primarily limited by the ability of the data analyses procedures to separate estrus related temperature changes from other factors which influence body temperature (Firk et al., 2002).

Estrous Behavior

The duration of estrus in dairy cows ranges from 7.1 to 13.6 h (Walker et al., 1996; Xu et al., 1998; Cavalieri et al., 2003b) and 5.6 to 21.5 h in beef cows (Mathew et al., 1999; White et al., 2002; Ciccioli et al., 2003; Landaeta-Hernández et al., 2004; Lents et al., 2008). The interval from onset of estrus to ovulation was shorter in dairy cows (27.6 h; Walker et al., 1996) than beef cows (31.1 h; White et al., 2002).

Changes in cow behavior are associated with estrus. Increases in activity, nervousness, and mounting behavior are primary characteristics of estrus in cows as reviewed by Foote et al. (Foote, 1975). Typically, cows do not stand to be mounted during the luteal phase of the cycle because plasma progesterone inhibits estrous behavior. Mounting activity is influenced by day of the estrous cycle (Alexander et al., 1984; Helmer and Britt, 1985). When plasma concentrations of estradiol increase and plasma progesterone decreases at estrus, willingness to accept a mate is increased. Standing behavior is the best indicator of estrus in cows (Foote, 1975). Mounting behavior of cows is variable. The number of mounts received by estrous dairy cows ranged from 4.37 to 12.8 (Alexander et al., 1984; Dransfield et al., 1998; Xu et al., 1998) and 11.9 to 46.7 in beef cows (White et al., 2002; Ciccioli et al., 2003; Lents et al., 2008).

Not all cycling cows exhibit mounting behavior during estrus. “Silent estrus” is the lack of mounting behavior associated with ovulation and commonly occurs at the first postpartum ovulation (Morrow, 1971). Ovulation or luteinization of the dominant follicle without visual observation of estrus (Hansel et al., 1961; Anderson et al., 1962; Hansel et al., 1966) or estrus detection by HeatWatch (Floyd et al., 2009) occurs in 3 to 16% of beef cows. Similar results were observed in dairy cow (6% to 35%) when estrus was detected visually or by increased activity occurring at estrus (Trimberger and Hansel, 1955; Erb et al., 1971; Ranasinghe et al., 2010). Dairy cows are typically in a negative energy balance after parturition due to the increase

in milk production. At the first, second and third ovulation after parturition, the occurrence of standing estrus in dairy cows with ovulation was 16%, 43% and 57%, respectively (Ranasinghe et al., 2010).

Reception of mounts by other cows is definitively the best indicator of estrus, however, not all estrous cows receive mounting behavior. Foote (1975) indicated that secondary signs of estrus may include increases in vocalization, activity, social interaction, mucus discharge, swelling and pink coloration of the vulva, and decreased feed consumption and milk production. The amount of time cows spend standing and in ambulatory movement is increased while lying is decreased at estrus (Pollock and Hurnick, 1979; Hurnik and King, 1987). Similar to mounting behaviors, sniffing and chin resting activity, by other cows, were maximal at the onset of sexual receptivity (Hurnik and King, 1987), however a minority of the herd consistently expressed the secondary signs of estrus. Vulvar swelling increased (Anderson et al., 1962), vaginal mucus discharge increased (Trimberger and Hansel, 1955), and the amount, thickness and adhesiveness of cervical mucus increased at estrus (Alliston et al., 1958). A significant linear decrease in chin resting behavior occurred when increasing amounts of progesterone were given to ovariectomized Holstein cows treated with estradiol (Davidge et al., 1987). Vocalizations increased 84% from 2 d before onset compared with onset of estrus, however there was much variation in individual responses (Schon et al., 2007).

Factors Influencing Estrous Behavior

Estrous behavior can be influenced by breed, age, and parity. The interval from parturition to first ovulation was influenced by breed of dairy cow (Friggens and Labouriau, 2010). Hereford sired cows had a shorter interval between estruses than cows of the same age, and sired by Angus or MARC III bulls (Cushman et al., 2007). Duration of estrus was similar for Charolais and Charolais x Brahman cows, however, Brahman influenced cows received fewer

mounts at estrus than Charolais cows (Galina et al., 1982). In contrast, Brahman cows had more mounts in the first 12 h after the onset of estrus (HeatWatch) than Angus and Senepol cows and duration of estrus was greater in Angus and Brahman cows compared with Senepol cows (Landaeta-Hernández et al., 2004). Breed influences on estrous behavior may be altered by the social organization of cows.

Estrous behavior is influenced by stage of the estrous cycle. Mount attempts on estrous cows are more commonly made by other estrous cows, specifically those in proestrus and estrus (Helmer and Britt, 1985). Multiparous cows attempted more mounts than primiparous cows but other physiological states did not effect mounting behavior (Vailes et al., 1992). Mounting activity was greater when unfamiliar cows were comingled at estrus compared with familiar cows (Alexander et al., 1984).

Management Factors Effecting Estrous Behavior

Management of cattle at estrus, particularly housing facilities, stocking densities, and feeding times, can influence the expression of estrous behavior. When dairy cows were housed on dirt, mounting activity was increased four-fold compared with cows housed on concrete (Vailes and Britt, 1990). Beef cows managed in a drylot had a shorter interval to estrus after prostaglandin treatment than those on pasture (Floyd et al., 2009), but duration of estrus and number of mounts received were not influenced. Increased number of mounts received per estrous cow was greater when the number of cows simultaneously in estrus was increased (Floyd et al., 2009). Estrous behavior is enhanced when more than one dairy cow is in estrus and penned on a dirt surface (Hurnik et al., 1975; Vailes and Britt, 1990). A rapid decline in mounting behavior occurred immediately following feed delivery to confined beef cows (Hurnik and King, 1987).

Environmental and Diurnal Factors Effecting Estrous Behavior

The duration of estrus for beef cows was longer in summer compared with winter or spring and the number of mounts received were reduced in the spring and summer compared with winter (White et al., 2002). The number of standing events was greater in July compared with June, and August was intermediate (Peralta et al., 2005). Duration of estrus was similar in dairy cows in June, July and August (Peralta et al., 2005). Maximum temperature on the day of estrus did not effect the duration of estrus in dairy cows (Britt et al., 1986) and season did not influence the time of ovulation in beef cows (White et al., 2002). Monthly and seasonal effects are influenced by the environment. There was a curvilinear relationship between ambient temperature (T_{amb}) and intensity of estrous behavior (Gwazdauskas et al., 1983), and estrous behavior intensity increased as temperature increased to 25°C, and declined after 30°C.

Mounting frequency was greater in beef cows between 0600 to 1200 h compared with other times of the day (White et al., 2002). In contrast, Xu et al. (1998) and Peralta et al. (2005) observed mounting activity and time of onset of estrus in dairy cows was not affected by time of day, and physical activity increased between 0100 and 0600 (Peralta et al., 2005). Feeding, turnout periods, and other management effects may alter the daily expression of estrous behavior.

BODY TEMPERATURE IN COWS

Mammals maintain a constant body temperature over a wide range of environmental conditions. Homeotherms, including cows, are able to regulate internal body temperature, independent of T_{amb} , as a result of alterations in heat loss and metabolic rate or heat production. Thermogenesis ensures optimal body temperatures for biological processes; low temperatures limit enzymatic efficiency and high temperatures can denature enzymes. Homeotherms exchange heat with their external environment for core body temperature to remain between 33 and 40°C.

Thermoregulation occurs through chemical, behavioral, and physiological means that allow a thermal balance between the animal and the environment.

Heat Production

Cows produce heat by metabolic processes from either body tissues or microbial fermentation. Metabolizable energy of maintenance (ME_m) is utilized by an animal to achieve basal metabolism for sustaining vital body functions or voluntary activities, digesting, and metabolizing feed stuffs. In beef cows, maintenance functions account for nearly 70% of the ME that is consumed (Ferrell and Jenkins, 1987). A primary maintenance function is body temperature regulation (NRC, 1996) as energy that is not utilized by cows results in heat production. Heat production is affected by level of nutrition, age and stage of production (Freetly et al., 2006). Purwanto et al. (1990) described the diurnal pattern of heat production in dairy cows, with maximum heat production occurring in the late afternoon and the nadir occurring in the early morning. Heat production decreases when cows are exposed to a sudden thermal challenge and is correlated with thyroxine disappearance rates (Yousef et al., 1967).

Sensory Input

Animals first sense changes in environmental temperature through cutaneous warm and cold receptors. Temperature sensation from the core and periphery passes through the central nervous system to stimulate thermosensitive neurons in the brain which activate thermogenic, sympathetic, and efferent neurons (Morrison et al., 2008). The hypothalamus contains many of the loci involved in temperature regulation and is generally accepted as the integration site for thermosensory information for most mammals. The preoptic nucleus has been identified as the major locus for thermosensory innervation in rats (Banet and Brandt, 1990; Bratincsak and Palkovits, 2004; Nakamura and Morrison, 2008, 2010) and sheep (Kendrick et al., 1989). Although several tissues can affect localized thermoregulatory responses, regulation of internal

body temperature is dependent on the hypothalamus. Destruction of the preoptic area of goats limited the ability of the animals to respond to both heat and cold exposure (Andersson et al., 1965)

Thermoneutral Zone

Cows have a temperature range that is optimal for performance and health. The thermoneutral zone (TNZ) is defined as the range of T_{amb} within which heat production of a unstressed animal offsets the heat loss to the environment (NRC, 1891). The TNZ is influenced by species, breed, age, gender, degree of thermal acclimation, and time of day (Yousef, 1985). When cows are within the TNZ, production of heat is primarily based on feed consumption and is independent of T_{amb} (NRC, 1996). The lower critical temperature of an animal is the T_{amb} at which an animal must increase heat production to maintain a constant body temperature. The TNZ of cows is 0°C to 16°C (Bianca, 1970). The ambient temperature at which an animal must employ mechanisms to facilitate heat loss is the upper critical temperature. Animals are considered heat stressed when exposed to T_{amb} above the upper critical temperature and are unable to maintain body temperature. Cows can adapt to changes in T_{amb} . The TNZ of cattle can shift by as much as 15°C (NRC, 1891) with acclimation rates of 0.1 to 0.4°C of body temperature per day (Hahn et al., 1990).

Diurnal Factors Effecting Body Temperature

Similar to other animals, body temperature of cows fluctuates throughout the day. Maximum body temperature of cattle occurs in early morning hours and the lowest occurs between 0800 and 1300. The daily range in temperature of cattle is 38.6 to 41.4°C (AlZahal et al., 2008; Beatty et al., 2008; Vickers et al., 2010). Body temperature increases throughout the afternoon and decreases during early morning hours (Bitman et al., 1984; Hahn et al., 1990; Lefcourt and Adams, 1996; Beatty et al., 2006; Ipema et al., 2008). Diurnal variation in core

body temperature is independent of sleep-wake and rest-activity cycles (Aschoff, 1983). Hahn et al. (1990) observed that changes in the core body temperature of cattle mirrors changes in Tamb within 2 to 5 h. Cattle are able to dissipate the daytime heat load during the night time hours and maintain a body temperature similar to cattle exposed to a consistently lower temperature (Mader et al., 1999). Lefcourt and Adams (1996) suggested the lower than normal body temperatures during morning hours would allow animals the ability to tolerate increased thermal stress occurring during afternoon periods.

Endocrine Responses to Elevated Ambient Temperature

Thyroid hormones are important regulators of metabolic rate of cattle. When steers are exposed to elevated Tamb, plasma concentrations of triiodothyronine (T3) and thyroxine (T4) are decreased and the responsiveness to thyroid releasing hormone (TRH) is reduced (Pratt and Wettemann, 1986). Triiodothyronine concentrations decreased in heifers exposed to thermal stress (Pereira et al., 2008). Plasma concentrations of thyroxine in cows decreased significantly 60 h after sudden exposure to heat (Yousef et al., 1967). When cows were returned to thermoneutral conditions, plasma bound iodine concentrations returned to pre exposure concentrations within 84 h. Thyroxine disappearance rates were correlated with heat production and rectal temperature (Yousef et al., 1967). Cows with induced hyperthyroidism had a greater occurrence of anestrus and abnormal cycle length, however serum progesterone concentration, and ovarian function were not affected (De Moraes et al., 1998). Treatment with thyroxine increased metabolic rates in both thermoneutral and thermally challenged cows (Yousef and Johnson, 1966)

Despite a reduction in reproductive efficiency, the hormonal response to elevated Tamb is varied. Cortisol is a primary stress hormone. For conditioned cows, sudden exposure to thermal stress increased plasma cortisol concentrations (Christison and Johnson, 1972) and with

prolonged exposure cortisol concentrations were decreased (Christison and Johnson, 1972; Abilay et al., 1975).

The effect of thermal stress on adrenocorticotropin (ACTH) and progesterone secretion is not well defined as reviewed by Gwazdauskas (1985), however, ACTH stimulates adrenal production of progesterone (Gwazdauskas et al., 1972). Plasma concentrations of LH (Madan and Johnson, 1973; Dunlap et al., 1981) and estradiol (Wolfenson et al., 1995; Wilson et al., 1998) are suppressed in response to thermal stress. Thermal exposure of cows (Wolfenson et al., 1997), or dominant follicles in culture (Bridges et al., 2005), reduces estradiol production by the dominant follicle in vitro. Bridges et al., (2005) observed a decrease in androstenedione and an increase in progesterone secretion of dominant follicles cultured at elevated temperatures. Follicle stimulating hormone was increased and inhibin decreased in thermally stressed dairy cows (Roth et al., 2000). Treatment with estrogen increased the thermal conductance of the vagina, likely as a result of increased local blood flow.

Behavioral Response to Elevated Ambient Temperature

Cattle dissipate heat through conduction, convection, and radiation. When ambient temperature or thermal radiation increases to greater than skin temperatures, the ability of an animal to dissipate heat is limited. Evaporative heat loss is the primary thermoregulatory mechanism when T_{amb} is greater than body temperature and occurs through sweating and increased respiration. Respiration rates were increased in heat stressed beef (Robertshaw, 1985; Al-Haidary et al., 2001; Boehmer et al., 2011a) and dairy cows (Sanchez et al., 1994). Respiratory alkalosis, a result of thermoregulatory panting, increased in heat stressed sheep along with an increase in arterial pH and a decrease in pCO_2 (Andrianakis et al., 1989). Sweating is increased when cattle are exposed to thermal stress and the efficiency of heat dissipation is strongly influenced by humidity, wind velocity, and animal insulation (Gebremedhin et al., 2008).

Exposure to elevated Tamb increases cutaneous moisture loss of dairy cows which supports the theory that cutaneous blood flow is increased during heat stress (Alvarez et al., 1970) although heart rate remains consistent (Mundia and Yamamoto, 1997). Similarly, blood flow through the caudal artery of beef steers increased following thermal challenge while heart rate was not altered (Kirch et al., 2008). Increases in blood flow during thermal stress serves to transfer heat to the periphery, aiding in heat abatement.

Thermal stress has an inhibitory effect on reproductive traits. Exposure of cows to elevated Tamb during estrus reduces the length and intensity of estrous behavior when estrus was detected by visual observation and aided a teaser bull (Abilay et al., 1975). The longest interval between received mounts (HeatWatch) for estrous cows was greatest in the summer when maximal daily temperatures at estrus averaged 28 °C compared with spring and winter when maximal daily temperatures were less (White et al., 2002). Duration of non cyclic activity as determined by progesterone (< 1 ng/ml) is increased concurrent with a reduction in the length of the estrous cycle when cows are exposed to elevated Tamb (Torres-Júnior et al., 2008). Follicular growth and development is altered when cows are exposed to elevated Tamb (Torres-Júnior et al., 2008; Shehab-El-Deen et al., 2010). Growth of the dominant follicle is depressed in heat stressed cows and the number of medium sized follicles in the subsequent cohort is reduced (Roth et al., 2000).

External and Sub-Dermal Measures of Body Temperature

Infrared thermography (IR) can be used to measure surface body temperature in ruminants. Temperature measurements, of any surface, can be taken from a distance using IR. Variation in IR between measurement locations is not well defined; Kotrba et al. (2007) observed measurements of body temperature in the trunk and appendages of cattle were not different, while Montanholi et al. (2010) observed temperature differences of 7°C between peripheral and core

body locations. Measurement of IR temperature may be a predictor of heat production (Stewart et al., 2007; Montanholi et al., 2010). Infrared thermography is strongly affected by Tamb (Kotrba et al., 2007). Temperature transmitters can also be surgically implanted sub-dermally throughout the body. Gaughan et al., (2010) determined flank temperatures were greater than rectal temperatures. The magnitude of increase in body temperature was greater in beef steers without shade during elevated ambient temperatures compared with steers housed under shade (Gaughan et al., 2010). Tympanic temperatures are strongly correlated with body skin temperatures and are similar among various thermal environments (Berman, 1971). Tympanic temperature was greater than ear surface temperature and less influenced by seasonal environment (2006). Tympanic temperature is minimally influenced by water and food consumption compared with rectal and RuT (Davis et al., 2003). Sub-dermal measures of body temperature, including tympanic temperature, are greatly influenced by environment when compared with internal body temperature measures (Shiraki et al., 1986; Hahn et al., 1990).

Internal Measures of Body Temperature

Measurement of internal body temperature of cows can occur at several locations. Rectal temperature (RT) is the most common measure of core body temperature. While highly repeatable, technician variation, penetration depth, and thermometer type may influence the measurement of RT (Burfeind et al., 2010). Rectal temperature is correlated with vaginal temperature (Rajamahendran et al., 1989; Hillman et al., 2009; Vickers et al., 2010), RuT (Prendiville et al., 2002; Bewley et al., 2008a; Boehmer et al., 2011a) and reticular temperature (Burns et al., 2002; Bewley et al., 2008a) of cows. Although VT and RT were not different (Hillman et al., 2009), uterine temperatures were greater (0.2°C) than RT in dairy cows (Gwazdauskas et al., 1973). Elevated Tamb increased VT in dairy cows with the greatest increase in VT occurred during the day (Mundia and Yamamoto, 1997). Vaginal temperature of dairy cows was not correlated with temperature humidity index (Suthar et al., 2011).

Ruminal temperature is an effective measure of core body temperature and is correlated with rectal and tympanic temperature (Prendiville et al., 2002). Ruminal temperature is usually 0.2 to 0.6°C greater than RT (Burns et al., 2002; Prendiville et al., 2002; Bewley et al., 2008a) and changes in RT and RuT tended to be similar (Gengler et al., 1970). Temperature within the rumen is dependent on location, with a 0.5°C difference from the top of the rumen to the bottom (Dale et al., 1954). Localized, exogenous changes in RuT have minimal effect on temperature elsewhere in the body. Beatty et al., (2008) observed that a 2°C decrease in RuT (associated with drinking) resulted in a decrease of 0.1°C in core body temperature. Scharf et al., (2010) determined that core body temperature was more closely related to Tamb than other meteorological parameters.

Factors Effecting Ruminal Temperature

The rumen is the primary storage and fermentation chamber of the digestive tract and several factors influence RuT. Consumption of water decreases RuT of beef (Beatty et al., 2008; Boehmer et al., 2009) and dairy cows (Bewley et al., 2008b), and the magnitude of the RuT depression is affected by the temperature and amount of consumed water. Type and amount of consumed feed also effects RuT. Dale et al., (1954) observed an increase in RuT during fasting. Lactating dairy cows consuming soy hulls had greater RT compared with cows receiving wheat hay (Arieli et al., 2004). Heat is produced as a result of ruminal fermentation and metabolism of feed, and an increase in metabolic rate is associated with feeding (Conrad, 1985; NRC, 1996). Exposure of cows to elevated Tamb can affect feed and water consumption and ruminal function. Water intake was increased in dairy cows exposed to elevated Tamb (Sanchez et al., 1994). Feed intake was reduced in heat stressed dairy cows (Arieli et al., 2004) and the duration of eating events was reduced during acute and chronic heat stress (Hahn et al., 1990; Aoki et al., 2005). Amplitude of rumen contractions were decreased when cattle were exposed to elevated Tamb (Attebery and Johnson, 1969).

Body Temperature at Estrus

It is well accepted that core body temperature increases at estrus. Increases in RT occurred at estrus compared with other periods (Burns et al., 2002). Piccione et al. (2003) observed a RT increase of 1.3°C at estrus in dairy cows. The use of temperature transponders has allowed the reporting of VT and RuT. Vaginal temperature increased about 0.5 to 1.0°C in dairy and beef cows at estrus (Bobowiec et al., 1990; Mosher et al., 1990; Redden et al., 1993; Kyle et al., 1998; Fisher et al., 2008). Similarly, RuT increases 0.44 to 1.0°C in beef cows at estrus (Bailey et al., 2009; Boehmer et al., 2010; Boehmer et al., 2011b; Cooper-Prado et al., 2011). Vaginal temperature increases in the 12 h prior to ovulation (Suthar et al., 2011) and remains elevated for 6.5 to 11 h (Bobowiec et al., 1990; Mosher et al., 1990; Redden et al., 1993; Kyle et al., 1998). Maximum estrual VT occurs 1 h and 0.5 h after maximum serum concentrations of estradiol and LH, respectively (Mosher et al., 1990). The relationship between VT and progesterone is less clearly defined. Although serum progesterone and VT are not correlated (Suthar et al., 2011), Mosher et al. (1990) observed that the VT increase associated with estrus occurred after the decline in serum progesterone. Ruminal temperature is elevated at estrus compared with the day before and the day after estrus in beef cows (Bailey et al., 2009; Cooper-Prado et al., 2011) and RuT returned to basal levels within 16 h after the cows were first observed in estrus (Cooper-Prado et al., 2011). Vaginal temperature of dairy cows returned to basal values from 12 to 36 h after the onset of estrus (Bobowiec et al., 1990; Suthar et al., 2011).

SUMMARY

Increasing the genetic merit of calves by AI cows to genetically superior bulls can enhance the production efficiency of a cow-calf operation. Estrous synchronization and AI can provide producers an opportunity to increase cow productivity, but are not commonly utilized in beef herds because of the time and labor required. Estrous detection is critical for efficient use of

AI. Visual observation of estrous cows is the most commonly used method of estrous detection, but can be subjective and requires time and labor input. Radiotelemetric estrous detection systems have been developed to identify estrus. Body temperature of cows is greater at estrus and may be a useful tool for the identification of estrus. Ruminant temperature boluses have been developed for frequent, non invasive measurement of body temperature of cow in their natural environment. Changes in ruminal temperature at estrus in cows may be useful for the identification and prediction of estrus and the timing of AI. The usefulness of ruminal temperature as an estrous detection system may be limited by elevated ambient temperature and diurnal variation in ruminal temperature. Evaluating the efficacy of ruminal temperature models for estrus identification and prediction is necessary. Physiological based estrous detection systems could decrease the calving interval, reduce the time and labor required for estrous detection, and promote the use of AI. Therefore objectives of this thesis were: 1) to evaluate ruminal temperature during the estrous cycle of beef cows, 2) to develop ruminal temperature models for the identification and prediction of estrus 3) to determine the effect of elevated ambient temperature on ruminal temperature of beef cows, 4) to evaluate relationships between ruminal temperature, rectal temperature, and respiration rate of beef cows during thermal stress, and 5) to determine the effect of elevated ambient temperature on the efficacy of ruminal temperature to predict estrus.

CHAPTER III

IDENTIFICATION OF ESTRUS IN BEEF COWS WITH RUMINAL TEMPERATURE

Abstract: Postpartum, Angus cows (4 to 7 yr of age) were used to evaluate changes in ruminal temperature (RuT) associated with estrus. In Exp. 1, estrus of cows ($n = 20$) was synchronized with PGF_{2 α} at 79 ± 1 d postpartum and RuT was evaluated during the subsequent estrous cycle. In Exp. 2, estrus of cows ($n = 47$) was synchronized at 88 ± 1 d postpartum and RuT was evaluated from 96 h before to 96 h after the synchronized estrus. Ruminal temperature boluses (SmartStock, LLC) were programed to transmit RuT every hour. The onset of estrus was determined by HeatWatch (CowChips, LLC). Progesterone was quantified in plasma each day to verify stage of the estrous cycle. Ambient temperature was recorded each hour (www.mesonet.org) and mean daily maximum ambient temperature (Tmax) ranged from 11 to 40°C in Exp. 1. Mean RuT of cows was $38.47 \pm 0.07^\circ\text{C}$ and RuT was greater ($P < 0.001$) during 9 h after the onset ($39.10 \pm 0.10^\circ\text{C}$) compared with 16 to 24 h before ($38.21 \pm 0.11^\circ\text{C}$) and 24 to 32 h after ($38.10 \pm 0.10^\circ\text{C}$) the onset of the synchronized estrus. Mean RuT of cows during the natural estrus was $38.59 \pm 0.10^\circ\text{C}$ and was greater ($P < 0.01$) during 9 h after the onset ($39.25 \pm 0.14^\circ\text{C}$) compared with 16 to 24 h before ($38.53 \pm 0.14^\circ\text{C}$) and 24 to 32 h after ($38.69 \pm 0.14^\circ\text{C}$) onset of estrus. A RuT increase of $\geq 0.7^\circ\text{C}$ for any 9 h period, compared with the mean RuT that occurred 12 to 84 h prior to the 9 h mean, correctly identified 75% and 93% of estrous cows during the synchronized and natural estruses, respectively. A RuT increase of $\geq 0.7^\circ\text{C}$ occurred

in 38% and 50% of non estrus cows during the synchronized and natural estruses, respectively. In Exp. 2, mean daily Tmax ranged from 10.5 to 38.2°C and mean RuT was $38.20 \pm 0.02^\circ\text{C}$. Ruminal temperature was greater ($P < 0.001$) in the 9 h after the onset of estrus ($38.87 \pm 0.08^\circ\text{C}$) compared with 16 to 24 h before ($38.10 \pm 0.08^\circ\text{C}$) and 24 to 32 h after ($38.13 \pm 0.08^\circ\text{C}$) the onset of estrus. The onset of estrus determined by a RuT increase of $\geq 0.7^\circ\text{C}$, compared with mean RuT during the previous 12 to 84 h, correctly identified 84% of estrous cows. In the 72 h before to 72 h after the onset of estrus, a RuT increase of $\geq 0.7^\circ\text{C}$ occurred in 16% of non estrous cows. Ruminal temperature in beef cows increases at estrus and RuT has potential for identification of estrus.

INTRODUCTION

Use of AI in beef and dairy cows can enhance the genetic merit of progeny. Superior genetics available through use of AI can increase profitability of the cow herd. The use of AI can be enhanced when used with estrous synchronization. Whereas AI and estrous synchronization are only used in 8% of beef herds in the U.S. (USDA, 2011), these technologies can increase production efficiency in beef and dairy herds (Lauderdale, 2009). Major detractors from use of AI are time and labor (Thibier and Wagner, 2002). When timed AI programs are not utilized, estrous detection is critical. The most common estrous detection method is twice daily visual observation of cows. Visual observation is an effective estrous detection method but it is subjective and requires considerable time and labor inputs (At-Taras and Spahr, 2001).

Development of radio telemetric estrous detection systems provides producers with labor saving methods. The HeatWatch system records mounts received by cows and can effectively identify cows in estrus (Walker et al., 1996; Peralta et al., 2005; Floyd et al., 2009). Estrous detection systems have been developed which monitor changes in animal physiology at estrus. An increase in ambulatory activity at estrus (Kiddy, 1977) is an effective method (Liu and Spahr, 1993; Nebel et al., 2011). An increase in core body temperature of cows at estrus has been

utilized for the detection of estrus. Vaginal temperature increases (0.5 to 1.0°C for 6.5 to 11 h) in estrous cows (Mosher et al., 1990; Kyle et al., 1998; Suthar et al., 2011) and may be useful to determine the onset of estrus (Kyle et al., 1998). Body temperature is greater when cattle are exposed to elevated ambient temperature (Hahn et al., 1990) and body temperature varies throughout the day (Lefcourt et al., 1999; Beatty et al., 2006).

Temperature boluses (SmartStock, LLC, Pawnee, OK) have been developed for the frequent, non invasive measurement of ruminal temperature (Rose-Dye et al., 2011). Ruminal temperature increases 0.6 to 1.0°C at estrus in beef cows (Bailey et al., 2009; Cooper-Prado et al., 2011). Estrus was correctly identified in 42 to 100% of estrous cows (Bailey et al., 2009) when RuT was increased $\geq 0.7^{\circ}\text{C}$ compared with pre-estrus mean RuT. Estrous detection systems utilizing body temperature must precisely and effectively identify estrus through accurate and frequent monitoring of body temperature. Therefore, objectives of these studies were: 1) to evaluate RuT during the estrous cycle of beef cows, 2) to develop RuT models for the identification of estrus, and 3) to determine the effect of ambient temperature on RuT at estrus.

MATERIALS AND METHODS

Animals and Management

The Institutional Animal Care and Use Committee of Oklahoma State University approved all animal related procedures used in these experiments.

Exp. 1

Postpartum, lactating, Angus cows (4 to 7 yr of age, n = 20) were used to evaluate changes in RuT associated with the estrous cycle during May, June and July in Oklahoma. Cows and calves were managed in a drylot (0.25 ha) at the South Range Cow Research Center with *ad libitum* hay and water. Cows weighed 530 ± 8 kg, had a BCS of 4.5 ± 0.1 (Wagner et al., 1988)

and were administered PGF_{2α} (Lutalyse 25 mg, i.m.; Pfizer, Inc., New York, NY) at 88 ± 1 d postpartum to synchronize estrus. Cows that did not exhibit estrus after initial treatment with PGF_{2α} were administered PGF_{2α} 10 d after the first treatment. The synchronized and subsequent natural estrus were evaluated.

The HeatWatch system (CowChips, LLC, Manalapan, NJ) was used to monitor the onset of estrus. The onset of estrus can be accurately determined by HeatWatch (Walker et al., 1996; At-Taras and Spahr, 2001; Floyd et al., 2009). HeatWatch detected 100% of visually observed estruses and the number of mounts received per cow by the two detection methods were correlated (Floyd et al., 2009). Cows were fitted with pressure sensitive radio transmitters when treated with PGF_{2α}. Radio transmitters were placed in nylon patches and secured to the tail head with adhesive. Patches were monitored daily for proper attachment and secured with adhesive as needed. The onset of estrus was defined as the first of two or more mounts received within a 4 h period (White et al., 2002). Mounts were recorded if the mount duration was greater than 2 sec.

Cows were administered RuT boluses (8.25 cm x 3.17 cm; 114 g), 4 to 5 d prior to PGF_{2α} treatment with a balling gun. Bolus records were transmitted through 3 receiver/repeater antennas located in the drylot within 100 m of a base station receiver linked to a PC data recovery system (SmartStock, LLC, Pawnee, OK). Boluses were programmed to transmit bolus ID, RuT, date, and time. Each hourly record contained the temperature readings for the current hour and the preceding 11 h. Ruminal temperature was recorded from 4 d prior to the first PGF_{2α} treatment until 4 d after the natural (second) estrus. Identification of estrus by RuT was determined as a mean RuT increase $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, or $\geq 0.7^{\circ}\text{C}$ for 9 h compared with the mean RuT during 12 to 84 h before the start of the 9 h identification period (Figure 1). The pre-estrus mean RuT included ≥ 12 RuT values and the 9 h identification period included ≥ 4 RuT values. Individual cows were evaluated for RuT increases before, during and after estrus and for failure to increase when a cow was in estrus. When inadequate RuT data (less than 4 RuT values per day) were

recorded during the 24 h before to 24 h after the onset of estrus, the cow was excluded from estrous detection analyses, but was evaluated for RuT increases when cows were not in estrus. The 24 h period following the onset of estrus was excluded from the analysis for RuT increases when cows were identified as non estrus. Outliers associated with drinking events (Bewley et al., 2008b; Cooper-Prado et al., 2011) were identified as RuT values less than 2 x SD ($> 35.3^{\circ}\text{C}$) from the mean RuT. One bolus failed to transmit data and the cow was excluded from analyses. During the synchronized and subsequent natural estruses, onset of estrus by HeatWatch was not determined in 3 and 5 cows, respectively, and these cows were excluded from analyses.

Time of ovulation after the natural (second) estrus was determined by transrectal ultrasonography (Aloka 500-V ultrasound with a 7.5-MHz probe; Corometrics Medical Systems, Wallingford, CT). Size and position of dominant follicles were determined every 8 h commencing 16 h after the onset of estrus, as determined by HeatWatch, until the dominant follicle was not present on the ovary. Time of ovulation was recorded as 4 h before the dominant follicle was not present.

Blood was collected via caudal venipuncture once daily between 0700 and 1200 h. Samples were collected into vacutainer blood collection tubes containing EDTA (Monoject™, Covidien AG, Mansfield, MA). Samples were stored on ice after collection, centrifuged at 2500 x g (4°C) for 20 min within 3 h of collection, and plasma was stored at -20°C . Plasma concentrations of progesterone were quantified to determine luteal activity (Wettemann et al., 1972) by solid phase RIA (Vizcarra et al., 1997). Samples within a cow were analyzed in one assay. Samples below the assay sensitivity (0.1 ng/ml) were rounded up to the minimum concentration. Intra and interassay CV (n = 6 assays) were 1.9 and 14.1%, respectively.

Environmental data were collected (www.mesonet.org) from a weather station 3.6 km from the experimental site. Ambient temperature (T_{amb}) and relative humidity were recorded

every 5 min during 39 d and maximum, minimum and mean ambient temperatures were calculated for each hour. Daily maximum ambient temperature (Tmax) ranged from 11 to 34°C during the synchronized estrus and 18 to 40°C during the natural estrus. Temperature humidity index was calculated (Thom, 1959).

Exp. 2

Postpartum, lactating, Angus cows (4 to 7 yr of age, n = 47) were used to evaluate RuT associated with synchronized estrus. Cows weighed 512 ± 8 kg and had a BCS of 4.2 ± 0.1 . Cows were managed and estrus was synchronized at 79 ± 1 d postpartum as described for Exp. 1. Ruminal temperature was recorded from 4 d before PGF_{2α} treatment to 4 d after the synchronized estrus, as determined by HeatWatch. Onset of estrus was not recorded in 4 cows and the cows were excluded from analyses. All cows had ≥ 12 RuT values 12 to 84 h before the start of the 9 h identification period and ≥ 4 RuT during the identification period. Ambient temperature and relative humidity were recorded during 36 d. Daily Tmax ranged from 11 to 38°C. Intra and interassay CV for progesterone RIA (n = 4 assays) were 12.2 and 9.7%, respectively. Two boluses failed to transmit data and cows were excluded from analyses. Onset of estrus was not determined by HeatWatch in 2 cows, and cows were excluded from analyses.

Statistical Analyses

Mean RuT during the 9 h after the onset of estrus, as determined by HeatWatch, was compared with 16 to 24 h before and 24 to 32 h after the onset of estrus. Periods for comparison were selected based on information about estrous behavior, core body temperature at estrus, and RuT at estrus (Bailey et al., 2009; Cooper-Prado et al., 2011). Periods evaluated the same time of day for the day before, the day of, and the day after estrus to minimize the effect of diurnal variation in RuT (Cooper-Prado et al., 2011). Daily periods when the onset of estrus were evaluated (0100 to 0800, 0900 to 1600, and 1700 to 0000) were selected based on diurnal

variation in Tamb and RuT. Ruminal temperatures were averaged within period prior to analysis. Ruminal temperature and Tamb were analyzed using PROC GLM and PROC MIXED (SAS Inst., Inc., Cary, NC) with period as a repeated measure within cow. Plasma concentrations of progesterone were analyzed with PROC MIXED (SAS Inst., Inc.) with day as a fixed effect. Six variance structures were evaluated (first order autoregressive, compound symmetry, variance component, unstructured, Huynh-Feldt and Toeplitz) and variance structure was selected by the best goodness of fit statistic prior to analysis. Variance components for analyses were estimated using the restricted maximum-likelihood method. The Kenward-Roger procedure was used to determine denominator degrees of freedom. Least squares means were compared using LSD (pdiff option of SAS) when effects were significant. Estrus identification models were evaluated using PROC ANOVA (SAS Inst., Inc.). Calculated means for increases in RuT of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, and $\geq 0.7^{\circ}\text{C}$ were compared using the Student's T Test (SAS Inst., Inc.).

RESULTS

Exp. 1

Mean daily Tmax (www.mesonet.org) was $29.0 \pm 0.8^{\circ}\text{C}$ during the synchronized estrus and $35.7 \pm 0.8^{\circ}\text{C}$ during the natural estrus. Daily Tmax ranged from 18.3 ± 0.8 to $33.8 \pm 0.8^{\circ}\text{C}$ and 26.7 ± 0.8 to $39.8 \pm 0.8^{\circ}\text{C}$ during the synchronized (Figure 2) and natural (Figure 3) estruses, respectively. Diurnal variation in RuT during the synchronized and natural estruses occurred with maximum RuT (38.61 ± 0.19 , $38.88 \pm 0.17^{\circ}\text{C}$, respectively) occurring at 0200 and 1900 h and the nadirs (37.76 ± 0.19 , $37.92 \pm 0.17^{\circ}\text{C}$, respectively) occurring at 1200 and 1100 h, respectively. When $\text{RuT} < 35.3^{\circ}\text{C}$ were removed from the analysis, the nadir ($37.86 \pm 0.17^{\circ}\text{C}$) in RuT occurred at 1400 h and maximum RuT ($38.61 \pm 0.19^{\circ}\text{C}$) occurred at 0200 h during the synchronized estrus. Maximum RuT ($39.00 \pm 0.17^{\circ}\text{C}$) occurred at 1900 h and nadir ($38.03 \pm$

0.17°C) occurred at 1200h when RuT < 35.3°C were removed from the analysis during the natural estrus. Ruminal temperature < 35.3°C comprised less than 2% of data in the Exp. 1.

Mean RuT of cows during the 96 h before and after the synchronized estrus was $38.47 \pm 0.07^\circ\text{C}$ and RuT was $38.59 \pm 0.10^\circ\text{C}$ during 96 h before and after the natural estrus. Figures 4 and 5 depict RuT relative to the onset of synchronized estrus (as determined by HeatWatch) and subsequent natural estrus, respectively. Ruminal temperature was greater ($P < 0.001$, $39.10 \pm 0.10^\circ\text{C}$) during the 9 h following the onset of the synchronized estrus compared with 16 to 24 h before ($38.21 \pm 0.11^\circ\text{C}$) and 24 to 32 h ($38.10 \pm 0.10^\circ\text{C}$) after the onset estrus. Mean RuT was greater ($P < 0.01$, $39.25 \pm 0.14^\circ\text{C}$) during the 9 h after the onset of estrus compared with 16 to 24 h before ($38.53 \pm 0.14^\circ\text{C}$) and 24 to 32 h after ($38.91 \pm 0.14^\circ\text{C}$) onset of natural estrus. Plasma concentrations of progesterone were less ($P < 0.02$) from 2 d before to 2 d after onset of estrus compared with 3, 4 d before, and 4 d after the onset of estrus (Figure 6).

Ruminal temperature was greater ($P < 0.03$; $38.86 \pm 0.17^\circ\text{C}$; Figure 7) during the synchronized estrus in the 9 h after the onset of estrus compared with 16 to 24 h before ($38.14 \pm 0.19^\circ\text{C}$) and 24 to 32 h after ($37.91 \pm 0.17^\circ\text{C}$) onset of estrus when onset occurred at 0100 to 0800 h. When the onset of estrus occurred at 0900 to 1600 h, RuT was greater in the 9 h after the onset of estrus ($P < 0.003$, $39.05 \pm 0.19^\circ\text{C}$) compared with the same daily hours the day before ($38.10 \pm 0.19^\circ\text{C}$) and day after ($37.98 \pm 0.19^\circ\text{C}$) the onset of the synchronized estrus. Ruminal temperature was greater during the 9 h after the onset of the synchronized estrus ($P < 0.001$, $39.34 \pm 0.17^\circ\text{C}$) compared with 16 to 24 h before ($38.29 \pm 0.17^\circ\text{C}$) and 24 to 32 h after ($38.22 \pm 0.17^\circ\text{C}$) onset of estrus when onset occurred between 1700 and 0000 h. Ruminal temperature in the 9 h after the onset of synchronized estrus tended to be greater ($P = 0.06$) when onset of estrus occurred from 1700 to 0000 h compared with when onset occurred at 0100 to 0800 h. Mean hourly Tmax was $24.2 \pm 0.10^\circ\text{C}$ with hourly ranges of 10.5 to 39.8°C in the 96 h before and after the onset of the synchronized estrus.

Mean RuT during the 9 h before the onset of the natural estrus tended to be less ($P < 0.10$; Figure 8) than the 9 h mean RuT during 0 to 9 h after onset of estrus when the onset of estrus occurred from 0100 to 0800 h and 1700 to 0000 h. Ruminal temperature during the 9 h after the onset of the natural estrus was greater ($P < 0.03$, 39.35 ± 0.20) compared with the 16 to 24 h before ($38.57 \pm 0.20^{\circ}\text{C}$) and 24 to 32 h after ($38.60 \pm 0.20^{\circ}\text{C}$) the onset of estrus, when onset occurred from 0900 to 1600 h. Mean RuT during the 9 h after the onset of natural estrus was not different ($P > 0.35$) when onset occurred at 0100 to 0800 h, 0900 to 1600 h, and 1700 to 0000 h. Mean daily Tmax was greater ($P < 0.001$, $35.7 \pm 0.8^{\circ}\text{C}$) during the natural estrus compared with the synchronized estrus ($29.0 \pm 0.7^{\circ}\text{C}$). In the 96 h before and after onset of natural estrus, mean Tmax was $31.1 \pm 0.1^{\circ}\text{C}$ with hourly ranges of 22.5 to 39.8°C .

During the 24 h before and after the onset of estrus, increases in 9 h mean RuT of $\geq 0.3^{\circ}\text{C}$ or $\geq 0.5^{\circ}\text{C}$, compared with the mean RuT from 12 to 84 h before the 9 h period, correctly identified 94% and 88%, respectively, of the synchronized estruses (Table 1) and 100% of natural estruses (Table 2). An increase in RuT of $\geq 0.7^{\circ}\text{C}$ for any 9 h period, compared with the mean RuT from the 12 to 84 h before the 9 h period, correctly identified 75% and 93% of estrous cows during the 24 h before and after the onset of synchronized or natural estruses, respectively. In the 1 to 3 days before the onset of the synchronized or natural estrus, 9 h mean RuT increases of $\geq 0.7^{\circ}\text{C}$, compared with the pre-estrus mean, identified 31% and 29%, respectively, of non estrous as estrus. None of the cows had a 9 h mean RuT increase $\geq 0.3^{\circ}\text{C}$ in the 1 to 3 d following the onset of the synchronized estrus. Increases in RuT of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, and $\geq 0.7^{\circ}\text{C}$ identified estrus in 94, 94, and 38%, respectively in non estrous cows during the 4 to 15 d following the synchronized estrus.

During the natural (second) estrus, a 9 h mean RuT increase $\geq 0.7^{\circ}\text{C}$ (compared with the pre estrus mean) occurred in 50% of non estrus cows in the 4 to 15 d before the onset of estrus and in 43% of non estrus cows in the 1 to 3 days after the onset of estrus. Ruminal temperature

increases $\geq 0.7^{\circ}\text{C}$ occurred 8.38 ± 6.11 h after onset of the synchronized estrus and 5.16 ± 1.88 h before onset of the natural estrus. The interval from the onset of estrus (as determined by HeatWatch) to ovulation was 31.4 ± 2.7 h. The interval from the beginning of a 9 h mean RuT increase of $\geq 0.7^{\circ}\text{C}$ (compared with a pre estrus mean) to ovulation was 35.1 ± 2.8 h.

In the experiment, 14,335 RuT values were recorded for 19 cows. Ruminal temperature bolus recordings per cow per day ranged from 0 to 24, with a mean of 16.3 ± 0.3 ; 44.5% of evaluated days for cows had 24 readings per cow per day. At least 12 RuT readings per cow per day occurred in 71.5% of the days. A RuT was not obtained for a cow during a 24 h period 21.1% of the times.

Exp. 2

Mean daily Tmax (www.mesonet.org) was $30.4 \pm 0.7^{\circ}\text{C}$ during Exp. 2 (Figure 9) and ranged from 18.3 ± 0.7 to $38.2 \pm 0.7^{\circ}\text{C}$. Diurnal variation in RuT occurred with maximum RuT ($38.43 \pm 0.13^{\circ}\text{C}$) occurring at 0100 h and the nadir ($37.42 \pm 0.13^{\circ}\text{C}$) occurring at 1300 h. When RuT $< 35.3^{\circ}\text{C}$ were excluded from the analysis, maximum RuT ($38.43 \pm 0.10^{\circ}\text{C}$) and the nadir ($37.64 \pm 0.10^{\circ}\text{C}$) were similar compared with the inclusion of RuT $< 35.3^{\circ}\text{C}$. Ruminal temperature < 35.3 comprised less than 2% of data.

Mean RuT of cows in Exp. 2 was $38.20 \pm 0.02^{\circ}\text{C}$. Ruminal temperature was greater ($P < 0.001$; Figure 10) in the 9 h after the onset of estrus ($38.87 \pm 0.08^{\circ}\text{C}$) compared with the same daily hours the day before ($38.10 \pm 0.09^{\circ}\text{C}$) and the day after ($38.13 \pm 0.08^{\circ}\text{C}$) estrus. Plasma concentrations of progesterone were less than 1.0 ng/ml from 2 d before to 2 d after the onset of estrus and were less ($P < 0.001$; Figure 11) compared with 3 to 4 d before the onset of estrus. Ruminal temperatures during the 9 h after the onset of estrus were greater ($P < 0.003$, $38.76 \pm 0.12^{\circ}\text{C}$) compared with the 16 to 24 h before ($38.06 \pm 0.12^{\circ}\text{C}$) and 24 to 32 h after ($38.22 \pm 0.12^{\circ}\text{C}$) the onset of estrus, when onset of estrus occurred between 0100 and 0800 h (Figure 12).

When onset of estrus occurred between 0900 and 1600 h, mean RuT in the 9 h after the onset of estrus was greater ($P < 0.004$, $39.06 \pm 0.21^{\circ}\text{C}$) compared with 16 to 24 h before ($38.03 \pm 0.23^{\circ}\text{C}$) and 24 to 32 h after ($37.79 \pm 0.21^{\circ}\text{C}$) the onset of estrus. Mean RuT during the 9 h after onset of estrus was greater ($P < 0.001$; $38.95 \pm 0.13^{\circ}\text{C}$) compared with the 16 to 24 h before ($38.21 \pm 0.13^{\circ}\text{C}$) and 24 to 32 h after ($38.20 \pm 0.13^{\circ}\text{C}$) the onset of estrus, when estrus occurred between 1700 and 0000 h. Ruminal temperature during the 9 h after the onset of estrus did not differ ($P > 0.15$) among daily periods. Mean hourly Tmax was $23.5 \pm 0.1^{\circ}\text{C}$ and ranged from 11 to 38°C during the 96 h before to 96 h after the onset of estrus; 14 of 36 d had daily Tmax $\geq 32^{\circ}\text{C}$.

Increases in an 9 h RuT of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$ or $\geq 0.7^{\circ}\text{C}$, compared with the mean RuT 12 to 84 h before the 9 h mean, correctly identified 100%, 98% and 84% of estrous cows (Table 3), respectively. During the 72 h before to 72 h after onset of estrus, 93%, 42% and 16% of non estrous cows had 9 h mean RuT greater than the pre estrus mean by $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$ and $\geq 0.7^{\circ}\text{C}$, respectively. The start of the 9 h increase in RuT of $\geq 0.7^{\circ}\text{C}$, compared with a mean RuT occurring 12 to 84 h prior, occurred 12.2 ± 6.7 h after the onset of estrus as determined by HeatWatch.

In the experiment, 16,770 RuT values were recorded. Ruminal temperature bolus recordings per cow per day ranged from 0 to 24 with a mean of 16.8 ± 0.3 . Thirty percent of evaluated days had 24 readings per cow per day. At least 12 readings per cow per day were obtained on 78% of days. A RuT was not obtained for a cow during a 24 h period 9.3% of the time.

DISCUSSION

There was diurnal variation in RuT for cows in these experiments. A nadir occurred between 1200 and 1300 h and RuT increased to a maximum between 0000 and 0100h. Ipema et al. (2008) observed similar diurnal variation in RuT of a dairy cow, but the magnitude of change

in RuT was greater than in the current experiments and were likely due to effects of averaging over a much larger sample size. Time of day influenced vaginal temperature of cows which was least at midday and greatest in the evening (Bobowiec et al., 1990). Maximum vaginal temperature occurred at 1700 h and nadir occurred at 0500 h in dairy cows (Suthar et al., 2011). Variation in vaginal temperature was similar in lactating and non lactating dairy cows, but lactating cows had greater variance and greater sensitivity to daily Tamb (Araki et al., 1987). Diurnal variation in core body temperature was maintained in cows exposed to thermal stress, however, daily maximum and minimum body temperatures were increased compared with when cows were exposed to cooler environments (Beatty et al., 2006).

The difference in RuT between the natural and synchronized estruses in the current experiment is likely due to elevated Tamb that occurred during the natural estrus. Mean daily Tmax was $29.0 \pm 0.8^{\circ}\text{C}$ during the synchronized estrus and $35.7 \pm 0.8^{\circ}\text{C}$ during the natural estrus of Exp. 1 with ranges of 18 to 34°C and 27 to 40°C , respectively. Mean daily Tmax during Exp. 2 was $30.4 \pm 0.7^{\circ}\text{C}$ and ranged from 18 to 38°C . It is common for Tamb in Oklahoma to fluctuate dramatically in a 24 h period. The relationship between Tamb and body temperature when cattle are in the thermoneutral zone is not well defined. Mean RuT was not different in May and December (Bailey et al., 2009). Ruminal temperature (AlZahal et al., 2011; Cooper-Prado et al., 2011), vaginal temperature (Kyle et al., 1998) and rectal temperature (Piccione et al., 2003) were not affected by Tamb when Tamb were within the thermoneutral zone of cattle. Core body temperature and RuT of beef heifers were increased in response to a thermal challenge (Beatty et al., 2008). Mean rectal temperature of dairy cows were greater in the summer compared with winter (Alnimer et al., 2002). Frequent evaluation of Tamb is necessary to evaluate the effect of Tamb on RuT. Environmental variables including humidity, solar radiation, rainfall, wind speed, and animal factors may influence RuT and should be evaluated.

Consumption of water decreases RuT. Volume and temperature of consumed water effect the magnitude and duration of RuT depression (Dale et al., 1954; Bewley et al., 2008b; Boehmer et al., 2009). The magnitude of decrease in RuT after water consumption ranges from 0.5 to 11.0°C and persists for 1 to 2 h. Temperature and volume of consumed water influenced reticular temperature in dairy cows (Bewley et al., 2008b) and sheep (Bailey et al., 1962) but water consumption had no effect on core body temperature. Variance and skewedness of RuT data were reduced when RuT values associated with drinking events ($2 \times \text{SD}$) were excluded. These results were similar to Bailey et al. (2009), but comprised $< 2\%$ of each data set. Water intake of cows on the day of estrus is decreased compared with the 3 d before or after estrus (Lukas et al., 2008). Reduced water consumption during estrus compared with normal water consumption may contribute to increased RuT at estrus. The type and amount of consumed feed may influence RuT. Rectal temperature and subcutaneous skin temperatures of sheep were greater during and after feeding (Bailey et al., 1962). High fiber diets can increase heat production associated with fermentation in the fiber mat and alter temperature within the rumen (Dale et al., 1954). When high concentrate feeds were consumed, RuT was increased compared with high roughage diets (Beatty et al., 2008).

Mean daily RuT of cows during the current experiments were similar. Ruminal temperature was increased (0.34 to 0.89°C) during the 9 h following the onset of estrus compared with the mean RuT 16 to 24 h before and 24 to 32 h after the onset of estrus. The greater RuT during the 72 to 96 h after the onset of natural estrus in Exp. 1 ($39.14 \pm 0.05^\circ\text{C}$) and synchronized estrus in Exp. 2 ($38.49 \pm 0.05^\circ\text{C}$) was not observed after the synchronized estrus of Exp. 1 and is likely due to greater ambient temperatures ($31.4 \pm 0.3^\circ\text{C}$ and $25.3 \pm 0.2^\circ\text{C}$) that occurred during these experiments. Similarly, RuT was 1.05°C and 0.61°C greater in the 9 h after the onset of estrus compared with the same daily hours the day before and day after onset of estrus (Bailey et al., 2009; Cooper-Prado et al., 2011) as detected by HeatWatch and visual observation,

respectively. Vaginal temperature increased 0.44 to 1.0°C at estrus in beef and dairy cows (Mosher et al., 1990; Kyle et al., 1998; Fisher et al., 2008). Rectal temperature increased 1.3°C on the day of onset of estrus (Piccione et al., 2003). Vaginal temperature increased during the onset of estrus compared with pre-estrus means and remain elevated for 6.5 to 11 h (Mosher et al., 1990; Redden et al., 1993; Kyle et al., 1998). The nadir in vaginal temperature that occurred 4 h before or after ovulation (Suthar et al., 2011) was not observed for RuT in the current experiments. Differences between the magnitude of RuT increase during the synchronized and natural estruses are likely a result of elevated Tamb at the synchronized estrus rather than altered physiological function during the natural estrus and synchronization estruses. Rectal temperature of dairy cows was not different when cows were synchronized with prostaglandin F_{2α} at various times and when GnRH was added to the synchronization protocol (Alnimer et al., 2002). Vaginal temperature was less during estrus in dairy cows later in lactation compared with earlier lactation when cow had a negative energy balance (Bobowiec et al., 1990).

Time of day influenced RuT at estrus. When onset of estrus occurred in the morning (0100 to 0800), RuT was greater in the 9 h after the onset of estrus compared with the 16 to 24 h before the onset of estrus. The increase in RuT during the 9 h after the onset of estrus was not observed when Tamb was elevated, however reduced cow numbers for the analysis could have influenced the response. Vaginal temperatures of dairy cows were greatest in the evening and least at midday (Bobowiec et al., 1990). The influence of time of day may contribute to differences in RuT at estrus.

Plasma concentrations of progesterone decreased to less than 1.0 ng/ml in the 2 d before the onset of estrus. Because the onset of estrus and elevated RuT at estrus are concurrent, the decrease in plasma concentrations of progesterone preceding estrus and the in RuT are very similar. The decrease in plasma progesterone concentrations to a nadir approximately 2 d before the onset of estrus is established (Swanson et al., 1972; Wettemann et al., 1972). The increase in

vaginal temperature at estrus occurred after the decline in serum progesterone (Rajamahendran et al., 1989; Mosher et al., 1990), but vaginal temperature and serum progesterone were not correlated (Suthar et al., 2011). Vaginal temperature is greater in pregnant dairy cows and cows treated with progesterone (Suthar et al., 2012). Fisher et al. (2008) observed a relationship between vaginal temperature and plasma concentrations of LH, and vaginal temperature could be used to predict the LH surge in dairy cattle. The interval from estrual increases in body temperature and the LH surge is consistent and was less variable than intervals from increased vaginal temperature and decreased serum concentrations of progesterone and increased estradiol (Clapper et al., 1990).

The frequency that RuT were recorded may have influenced the detection of estrus in the present experiment. One bolus failed to record data for a cow in Exp. 1. The number of hourly RuT recorded was 16.3 and 16.8 per cow for Exp. 1 and 2, respectively. Twelve or fewer hourly RuT readings were recorded in 21 and 22% of days in Exp. 1 and 2, respectively. Data transmission of ruminal boluses in lying dairy cows was reduced compared with standing cows (Ipema et al., 2008). Boluses are less invasive than other methods for monitoring RuT but further improvements in bolus response are needed for the detection of subtle changes in RuT. Adequate reading frequency and bolus function may have limited the ability to accurately identify changes in RuT associated with estrus in the current experiments.

Ruminal temperature increases during 9 h of 0.3, 0.5 or 0.7°C, compared with a 72 h pre-estrus mean (-12 to -84 h), correctly identified 94, 88 and 75% of estrous cows during the synchronized estrus and 100, 100, and 93% of estrous cows during the natural estrus of Exp. 1. Increases in 9 h mean RuT of ≥ 0.3 , ≥ 0.5 , or $\geq 0.7^\circ\text{C}$, compared with the pre-estrus mean identified 100, 98, and 84% in Exp. 2. Identification of non estrus cows as estrus by a 9 h RuT increase of 0.3, 0.5 or 0.7°C, compared with a preceding 72 h RuT mean, did not occur in the 1 to 3 d after the onset of estrus and in 94, 94, and 38% of cows, respectively, during the 4 d before to

15 d after the synchronized estrus of Exp. 1. Using the same identification criteria, 50 to 100% and 29 to 86% of non estrus cows were identified as estrus in the 4 to 15 d and 1 to 3 d, respectively, before the onset of the natural estrus in Exp. 1. Increases in RuT (9 h) from a pre estrus mean (72 h) of ≥ 0.3 , ≥ 0.5 , or $\geq 0.7^{\circ}\text{C}$ identified 16 to 93% of non estrus cows as estrus in the 72 h before to 72 h after the onset of estrus in Exp. 2. Elevated Tamb may have contributed to incorrect identification of non estrous cows as estrus, as Tamb was greater during the natural compared with the synchronized estrus in Exp. 1. Decreased accuracy of identification of estrous cows during periods of elevated Tamb may be caused by decreased ability to maintain normal body temperature when cows are exposed to thermal stress. Greater daytime body temperature in beef cattle results from the failure to dissipate the heat load during overnight cooling periods and results in greater daytime body temperature (Mader et al., 2010). When cattle were exposed to elevated Tamb, the rate of increases in body temperature was greater when cattle were previously exposed to elevated Tamb compared with previous exposure to thermoneutral conditions (Brown-Brandl et al., 2005). Correct identification of estrus by an increase in RuT of $\geq 0.3^{\circ}\text{C}$ and $\geq 0.7^{\circ}\text{C}$ during an 8 h evaluation period, compared with a mean pre-estrus RuT from 12 to 84 h before the 8 h period, occurred in 42% to 95% of cows in May and 100% of cows in December (Bailey et al., 2009). None of the non estrous cows were identified as estrus in by a RuT increase of $\geq 0.7^{\circ}\text{C}$ when cows were studied during cooler ambient temperatures (Bailey et al., 2009).

SUMMARY AND CONCLUSIONS

Ruminal temperature of beef cows is greater during estrus when the onset occurs at any time during the day. Ruminal temperature is greater are cows were exposed to elevated ambient temperatures. Increases in RuT at estrus may be useful for identifying the onset of estrus. Ruminal temperature is an effective measure of core body temperature and use of RuT boluses is non invasive, requires minimal labor, and allows for the frequent monitoring of core body

temperature. Further study is needed to evaluate the effect of diurnal variation and elevated T_{amb} on RuT of beef cows.

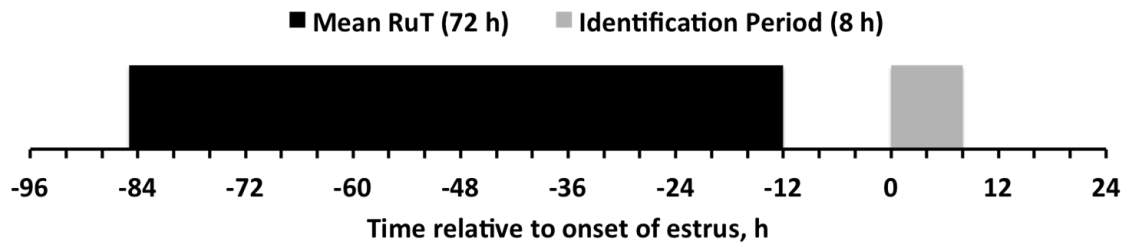


Figure 1. Identification of estrus by ruminal temperature (RuT) was determined by an increase in mean RuT for any 9 h period (grey box) of ≥ 0.3 , ≥ 0.5 , or $\geq 0.7^{\circ}\text{C}$ compared with the mean RuT that occurred 12 to 84 h prior to the 9 h identification period (black bar). The 72 h mean RuT period and 9 h identification period included minimums of 12 and 4 RuT values, respectively.

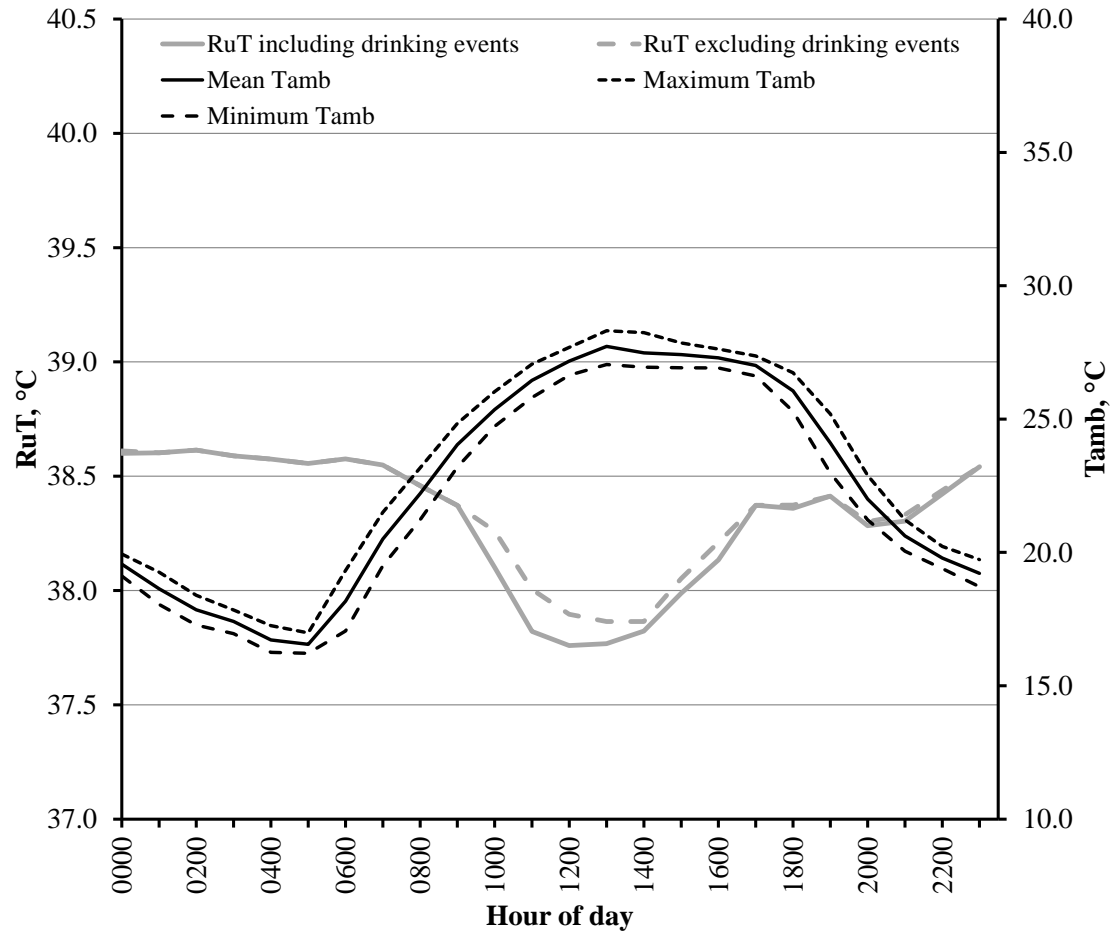


Figure 2. Diurnal variation in ambient temperature (Tamb) and ruminal temperature (RuT) of beef cows (n = 19) during the synchronized estrus in Exp. 1. Solid grey line includes all RuT values; broken grey line excludes RuT values < 35.3°C (drinking events). Solid black line is hourly Tamb; broken black lines are hourly maximum and minimum Tamb, respectively. SE for all RuT for hour x cow averaged 0.19. SE for RuT excluding values < 35.3°C for hour x cow averaged 0.17.

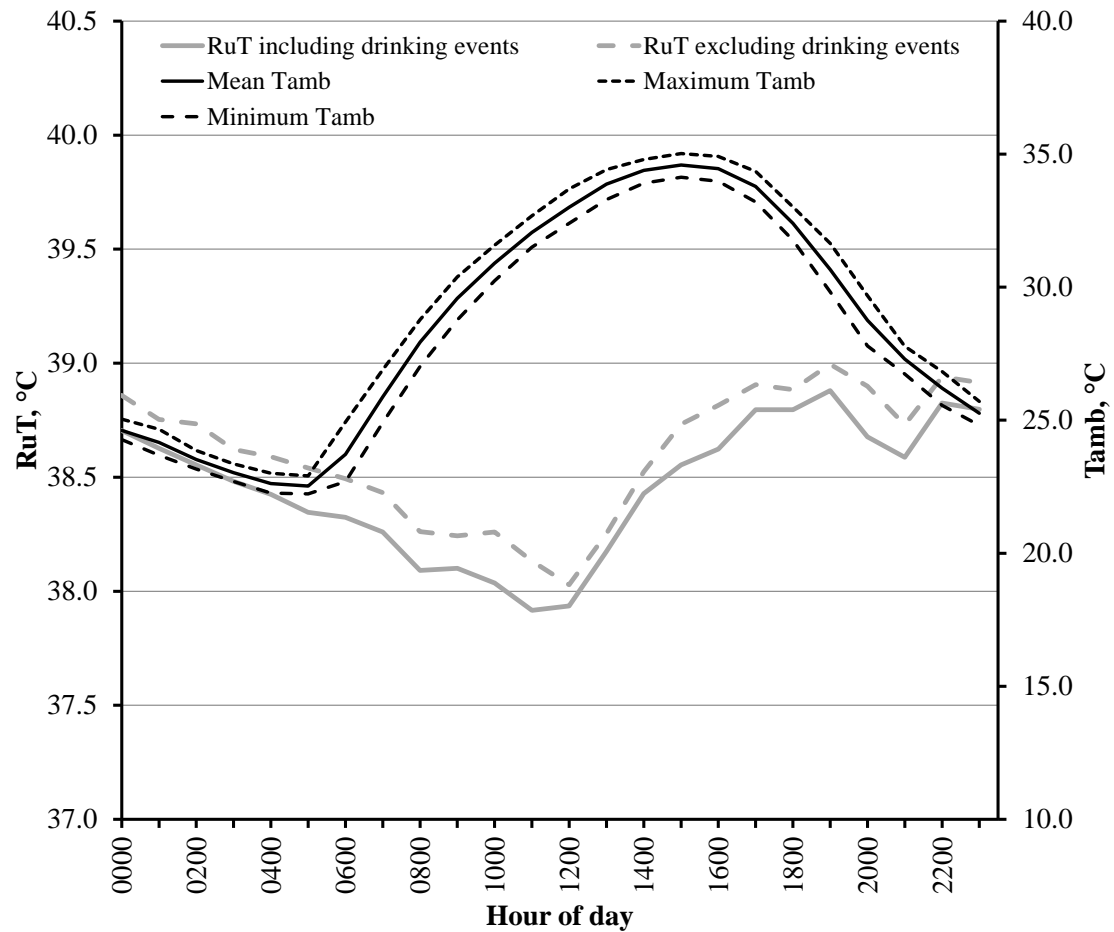


Figure 3. Diurnal variation in ambient temperature (Tamb) and ruminal temperature (RuT) of beef cows (n = 19) during the subsequent natural estrus in Exp. 1. Solid grey line includes all RuT values; broken grey line excludes RuT values < 35.3°C (drinking events). Solid black line is hourly Tamb; broken black lines are hourly maximum and minimum Tamb, respectively. SE for all RuT for hour x cow averaged 0.17. SE for RuT excluding values < 35.3°C for hour x cow averaged 0.17.

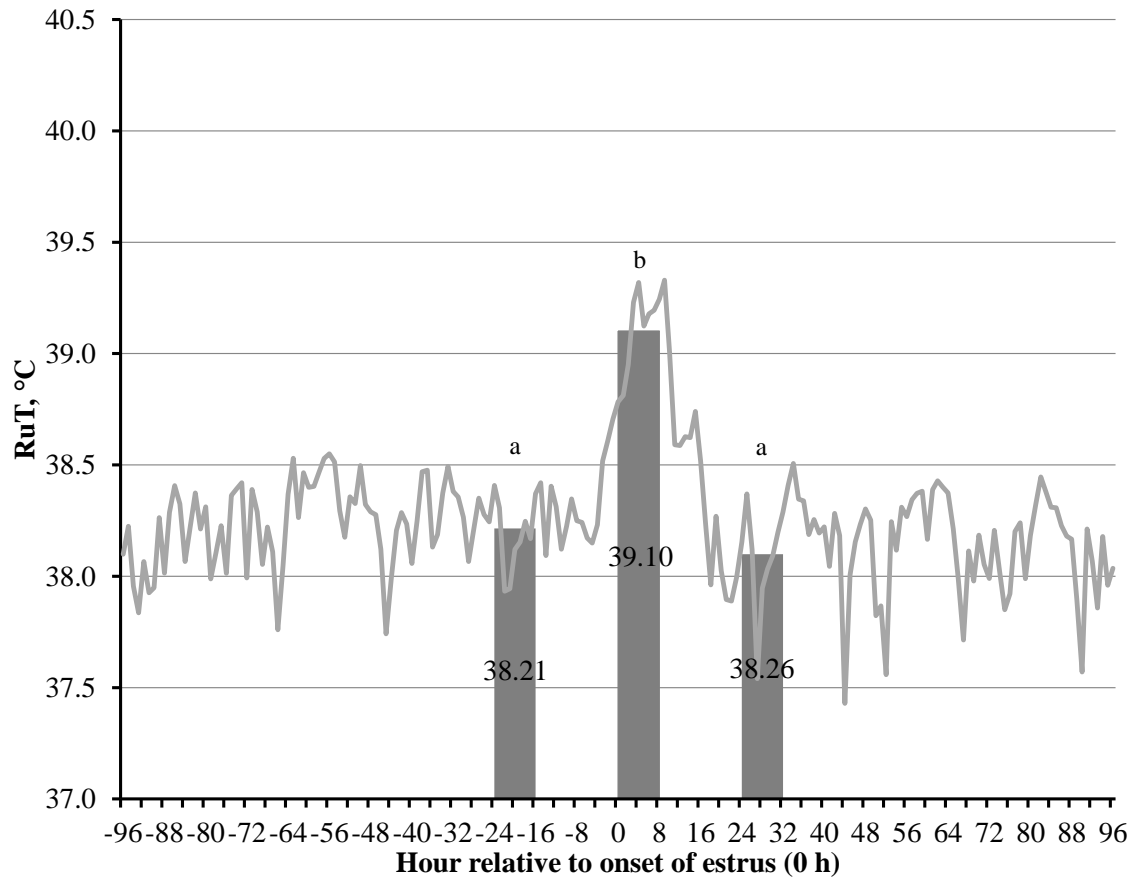


Figure 4. Mean ruminal temperature (RuT) relative to the onset of synchronized estrus (HeatWatch; 0 h) in beef cows ($n = 16$) in Exp. 1. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus ($SE = 0.10$). Mean hourly maximum ambient temperature was $23.3 \pm 0.2^{\circ}\text{C}$. ^{a, b} Means for periods without a common superscript differ ($P < 0.001$).

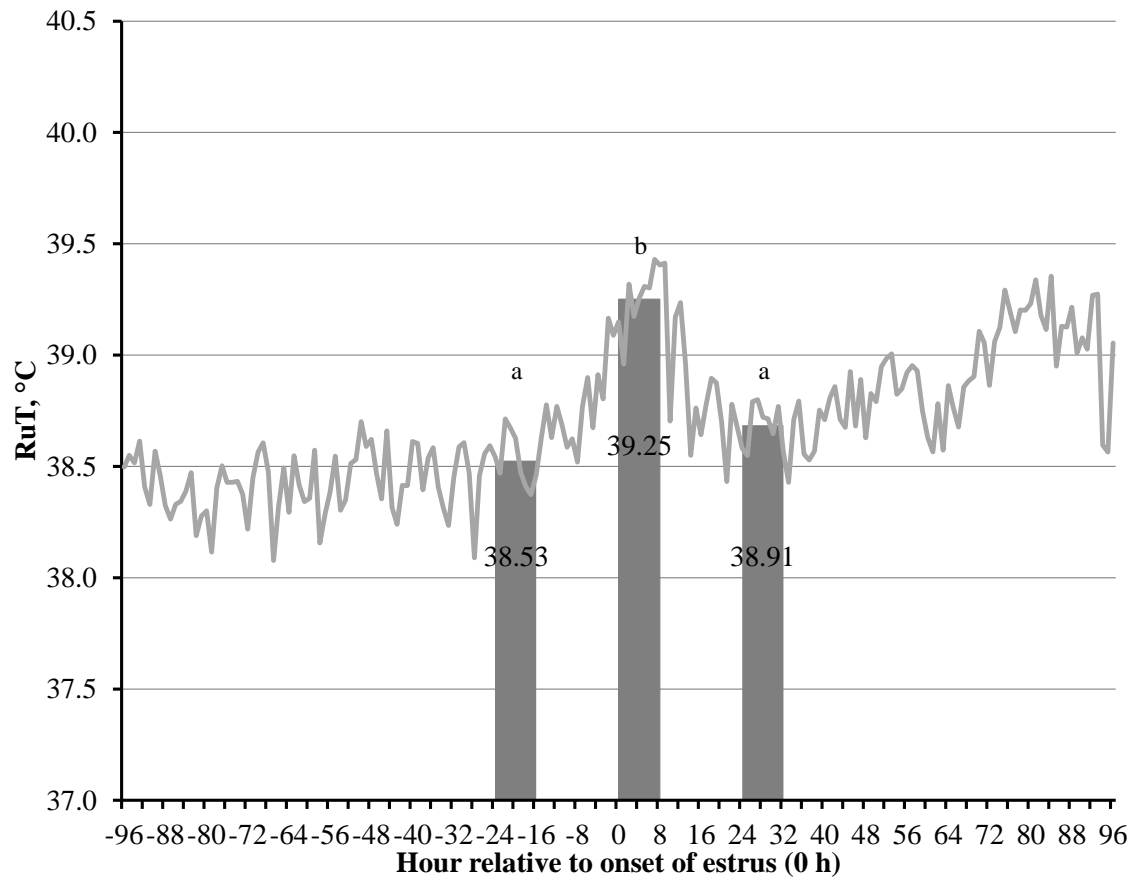


Figure 5. Mean ruminal temperature (RuT) relative to the onset of subsequent natural estrus (HeatWatch; 0 h) in beef cows (n = 14) in Exp. 1. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus (SE = 0.14). Mean hourly maximum ambient temperature was $29.5 \pm 0.3^{\circ}\text{C}$. ^{a, b} Means for periods without a common superscript differ ($P < 0.01$).

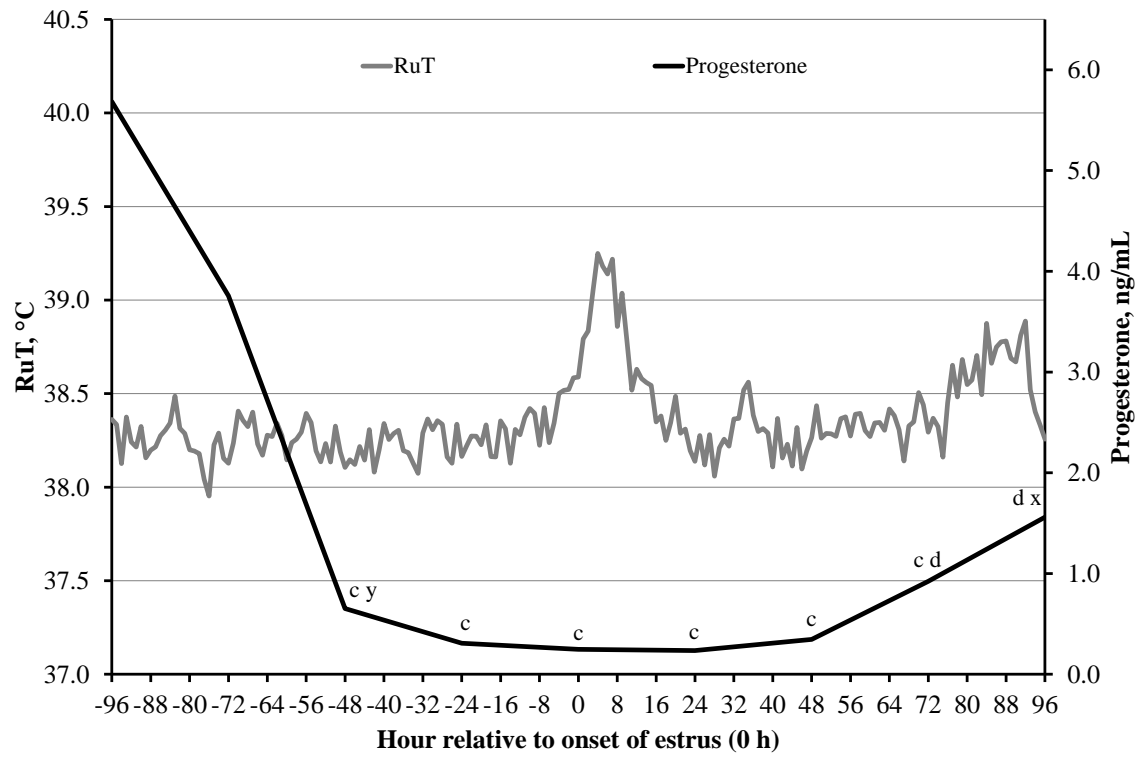


Figure 6. Ruminal temperature (RuT) and concentration of progesterone in plasma relative to onset of synchronized estrus (HeatWatch; 0h) in beef cows (n = 18) in Exp. 1. ^{a, b, c, d} Means without a common letter differ ($P < 0.02$). SE for progesterone over days averaged 0.40.

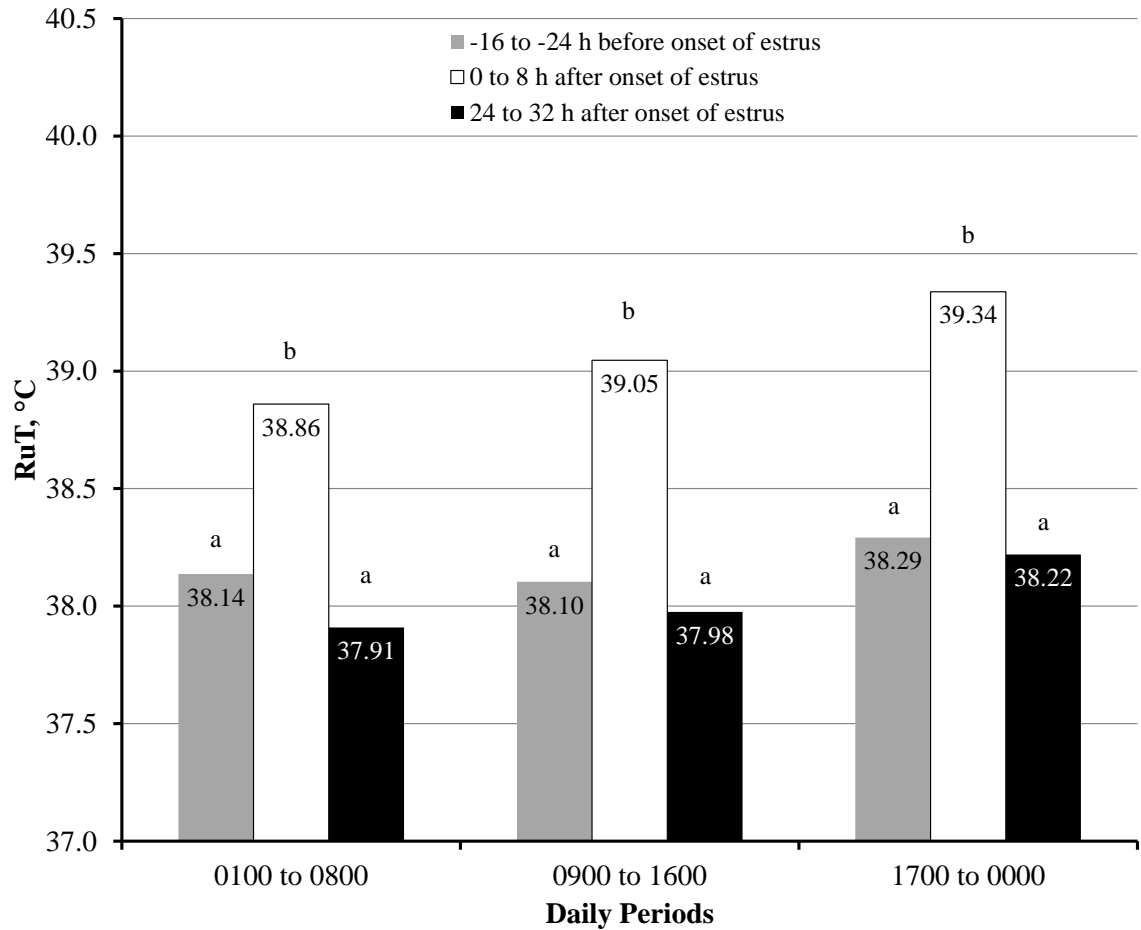


Figure 7. Effect of time of day and time relative to onset of synchronized estrus (HeatWatch; 0 h) on ruminal temperature (RuT) of beef cows in Exp. 1. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus during daily periods of 0100 to 0800 ($n = 4$; $SE = 0.17$), 0900 to 1600 ($n = 7$; $SE = 0.17$), and 1700 to 0000 h ($n = 5$; $SE = 0.17$). Daily maximum ambient temperature (T_{max}) ranged from 11 to 34°C and 6 of 24 d during the experiment had $T_{max} \geq 32^\circ\text{C}$. ^{a, b} Means within a daily period without a common superscript differ ($P < 0.05$).

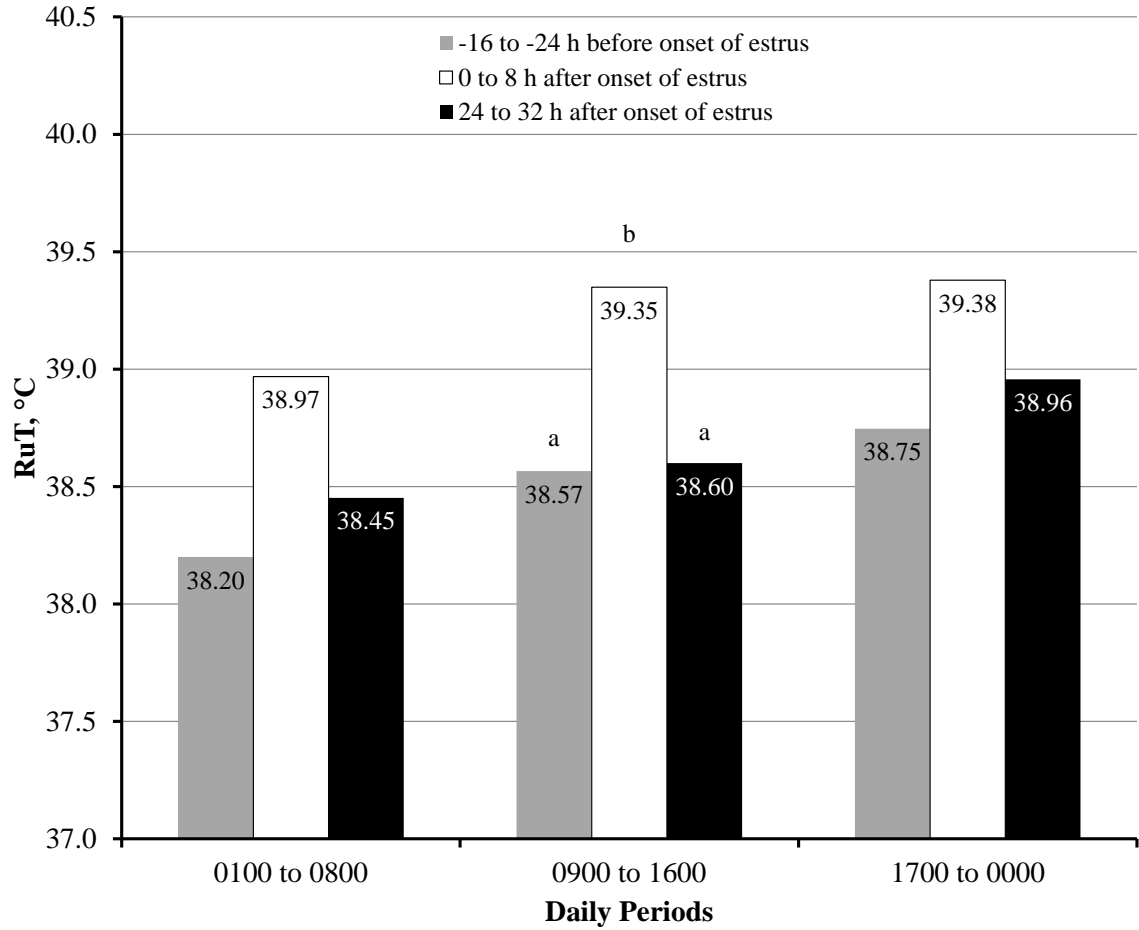


Figure 8. Effect of time of day and time relative to onset of natural estrus (HeatWatch; 0 h) on ruminal temperature (RuT) of beef cows in Exp. 1. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus during daily periods of 0100 to 0800 ($n = 4$; $SE = 0.27$), 0900 to 1600 ($n = 5$; $SE = 0.20$), and 1700 to 0000 h ($n = 5$; $SE = 0.25$). Daily maximum ambient temperature (T_{max}) ranged from 17 to 40°C and 16 of 18 d during the experiment had $T_{max} \geq 32^\circ\text{C}$. ^{a, b} Means within a daily period without a common superscript differ ($P < 0.05$).

Table 1. Identification of estrus in beef cows using increases in mean ruminal temperature (RuT) of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, or $\geq 0.7^{\circ}\text{C}$ for any 9 h period compared with mean RuT from 12 to 84 h before the 9 h period during the synchronized estrus of Exp. 1¹.

Exp. 1 – synchronized estrus	RuT increase		
	$\geq 0.3^{\circ}\text{C}$	$\geq 0.5^{\circ}\text{C}$	$\geq 0.7^{\circ}\text{C}$
No. of cows	16	16	16
1 to 3 d before onset of estrus ²			
RuT increase identified estrus in a non estrous cow, %	75%	56%	31%
24 h before to 24 h after onset of estrus			
RuT increase correctly identified estrus, %	94%	88%	75%
RuT increase identified estrus in a non estrous cow ³ , %	25%	6%	6%
1 to 3 d after onset of estrus			
RuT increase identified estrus in a non estrous cow, %	0%	0%	0%
4 to 15 d after onset of estrus			
RuT increase identified estrus in a non estrous cow, %	94% ^a	94% ^a	38% ^b

¹ Daily maximum ambient temperature (Tmax) ranged from 11 to 34°C; 6 of 24 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

² Onset of estrus was determined by HeatWatch.

³ Identification of non estrus as estrus cows excluded the 24 h period after cows were identified as estrus.

^{a, b} Means within row without a common superscript differ ($P < 0.05$).

Table 2. Identification of estrus in beef cows using increases in mean ruminal temperature (RuT) of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, or $\geq 0.7^{\circ}\text{C}$ for any 9 h period compared with a mean RuT from 12 to 84 h before the 9 h period during the natural estrus of Exp. 1¹.

Exp. 1 – natural (second) estrus	RuT increase		
	$\geq 0.3^{\circ}\text{C}$	$\geq 0.5^{\circ}\text{C}$	$\geq 0.7^{\circ}\text{C}$
No. of cows	14	14	14
4 to 15 d before onset of estrus ²			
RuT increase identified estrus in a non estrous cow, %	100% ^{3 a}	100% ^a	50% ^b
1 to 3 d before onset of estrus			
RuT increase identified estrus in a non estrous cow, %	86% ^a	50% ^{ab}	29% ^b
24 h before to 24 h after onset of estrus			
RuT increase correctly identified estrus, %	100%	100%	93%
RuT increase identified estrus in a non estrous cow ³ , %	71% ^x	43% ^{xy}	36% ^y
1 to 3 d after onset of estrus			
RuT increase identified estrus in a non estrous cow, %	79% ^x	71% ^{xy}	43% ^y

¹ Daily maximum ambient temperature (Tmax) ranged from 17 to 40°C; 16 of 18 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

² Onset of estrus was determined by HeatWatch.

³ Identification of non estrus as estrus cows excluded the 24 h period after cows were identified as estrus.

^{a, b} Means within row without a common superscript differ ($P < 0.05$).

^{x, y} Means within row without a common superscript differ ($P < 0.10$).

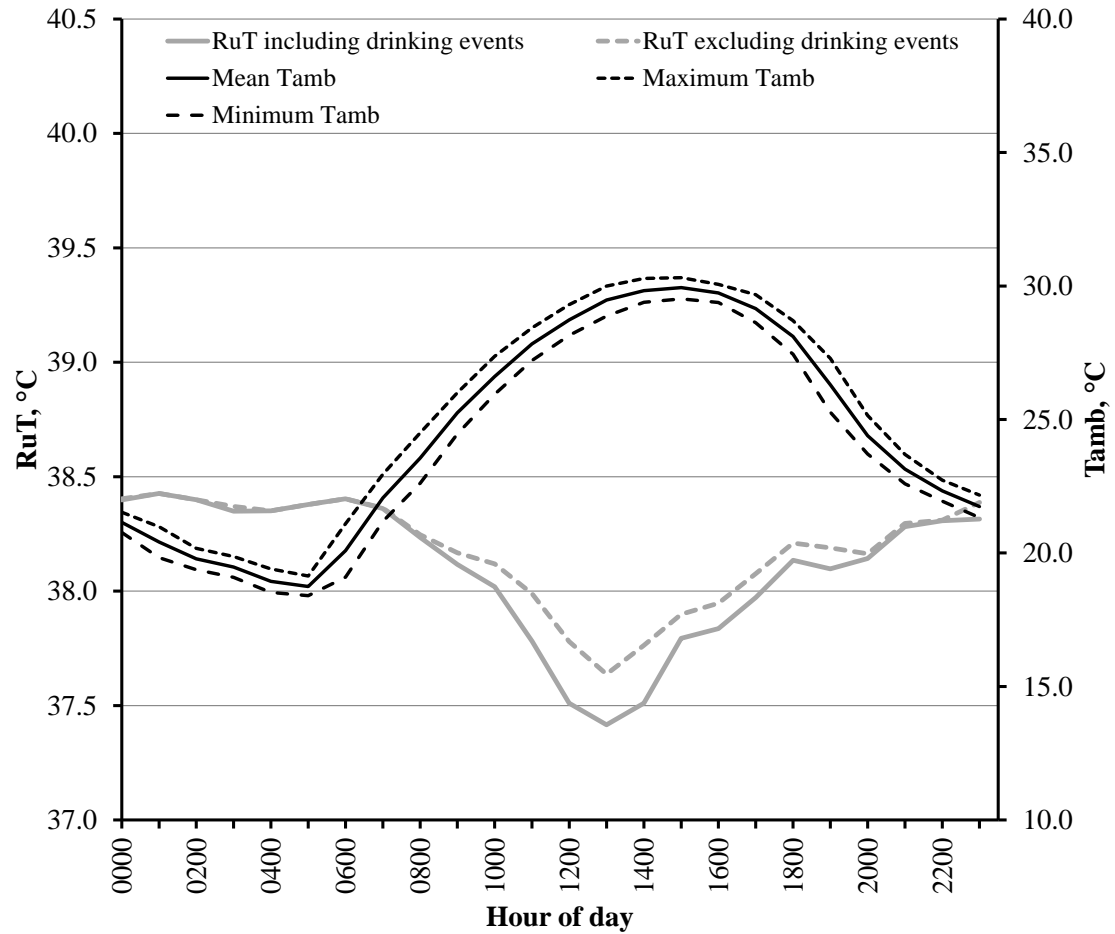


Figure 9 Diurnal variation in ambient temperature (Tamb) and ruminal temperature (RuT) of beef cows (n = 45) during synchronized estrus in Exp. 2. Solid grey line includes all RuT values; broken grey line excludes RuT values < 35.3°C (drinking events). Solid black line is hourly Tamb; broken black lines are hourly maximum and minimum Tamb, respectively. SE for all RuT for hour x cow averaged 0.13. SE for RuT excluding values < 35.3°C for hour x cow averaged 0.10.

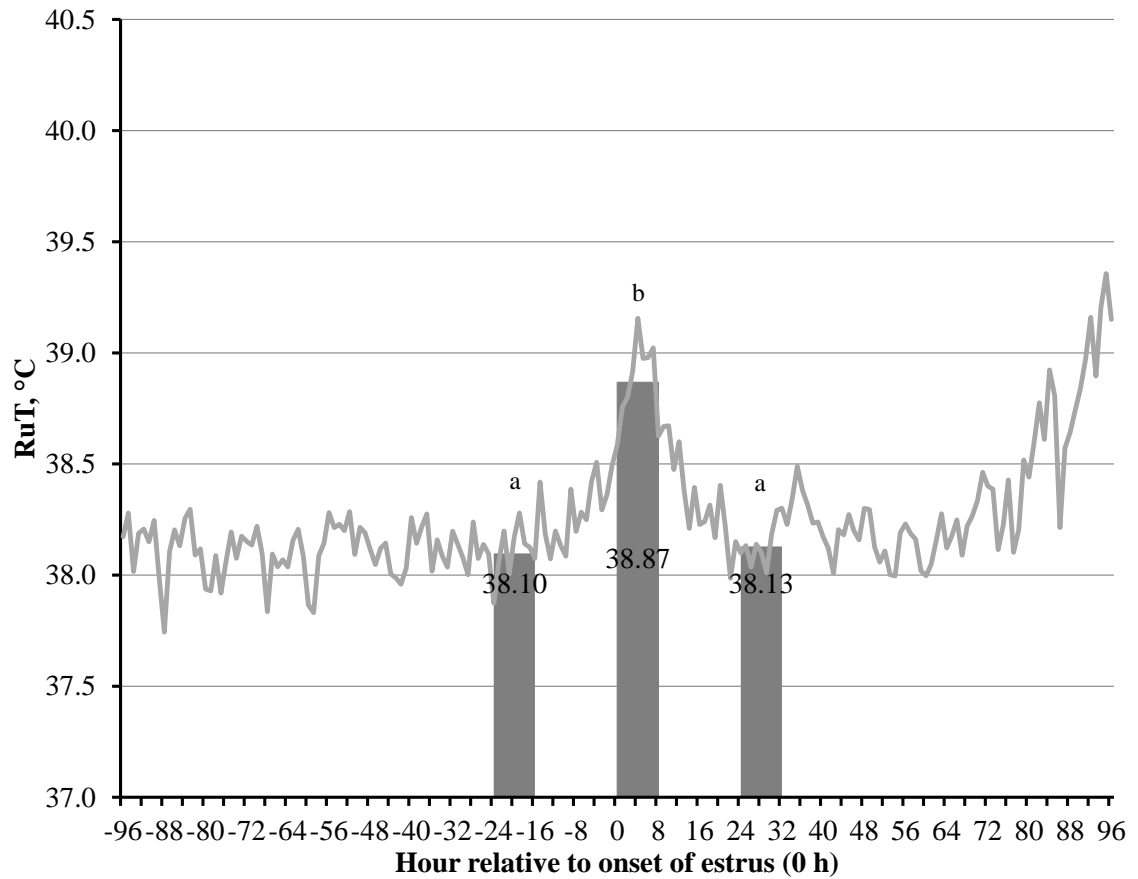


Figure 10. Mean ruminal temperature (RuT) relative to the onset of estrus (HeatWatch; 0 h) in beef cows ($n = 43$) in Exp. 2. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus ($SE = 0.08$). Mean hourly maximum ambient temperature was $25.01 \pm 0.20^{\circ}\text{C}$. ^{a, b} Means for periods without a common superscript differ ($P < 0.001$).

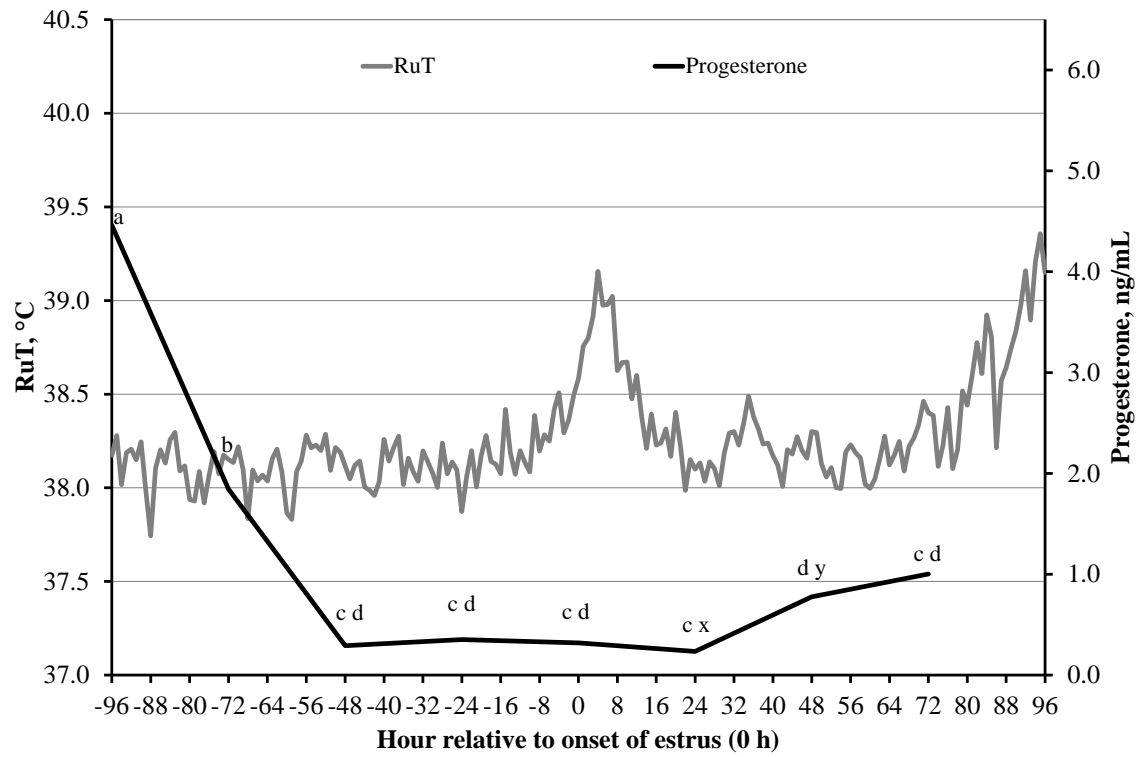


Figure 11. Ruminal temperature (RuT) and concentration of progesterone in plasma relative to onset of synchronized estrus (HeatWatch; 0h) in beef cows ($n = 43$) in Exp. 2. ^{a, b, c} Means without a common letter differ ($P < 0.01$). SE for progesterone over days averaged 0.26.

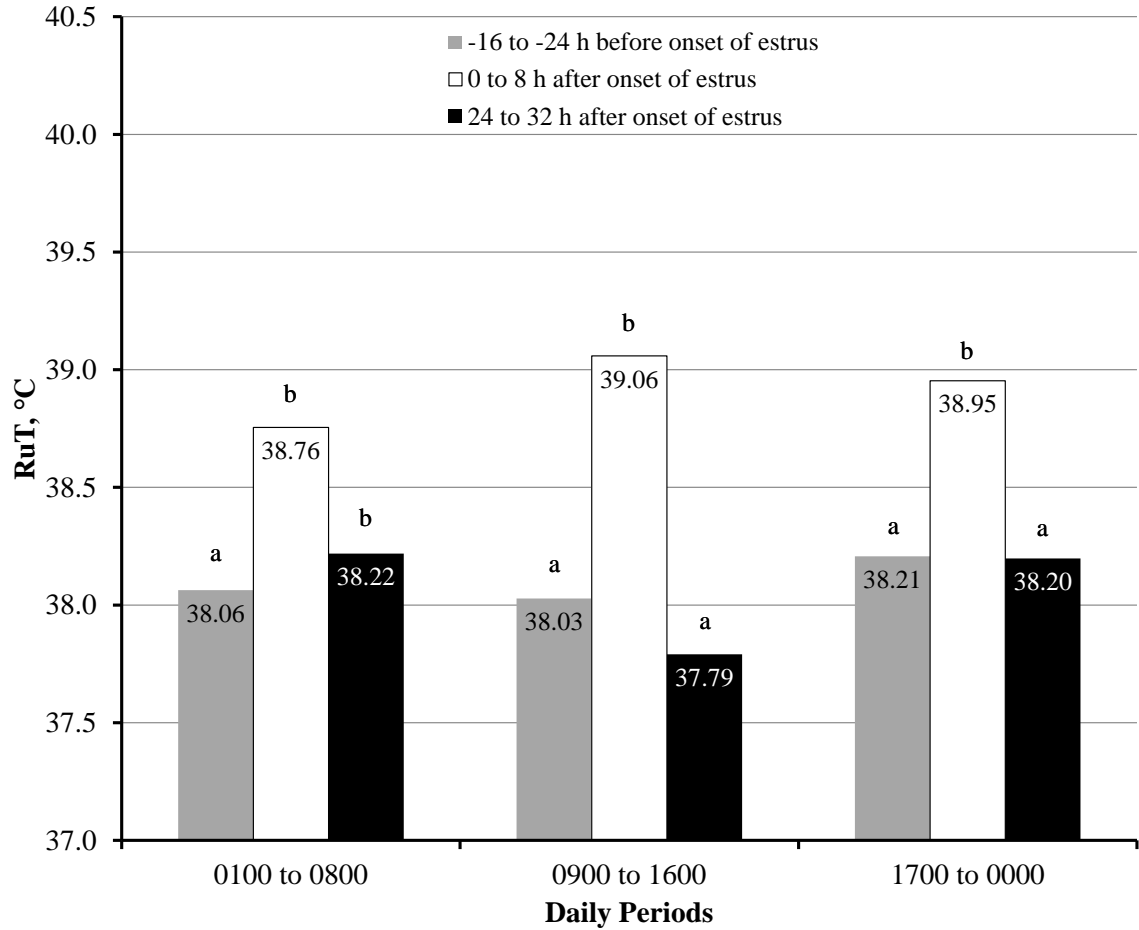


Figure 12. Effect of time of day and time relative to onset of synchronized estrus (HeatWatch; 0 h) on ruminal temperature (RuT) of beef cows ($n = 16$) in Exp. 2. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus during daily periods of 0100 to 0800 ($n = 23$; $SE = 0.12$), 0900 to 1600 ($n = 8$; $SE = 0.21$), and 1700 to 0000 h ($n = 12$; $SE = 0.13$). Daily maximum ambient temperature (T_{max}) ranged from 10 to 38°C and 14 of 36 d during the experiment had $T_{max} \geq 32^\circ\text{C}$. ^{a, b} Means within a daily period without a common superscript differ ($P < 0.01$).

Table 3. Identification of estrus in beef cows using increases in mean ruminal temperature (RuT) of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, or $\geq 0.7^{\circ}\text{C}$ for any 9 h period compared with a mean RuT from 12 to 84 h before the 9 h period during the synchronized estrus of Exp. 2¹.

Exp. 2	RuT increase		
	$\geq 0.3^{\circ}\text{C}$	$\geq 0.5^{\circ}\text{C}$	$\geq 0.7^{\circ}\text{C}$
No. of cows	43	43	43
72 h before to 72 h after onset of estrus ²			
RuT increase correctly identified estrus, %	100% ^a	98% ^a	84% ^b
RuT increase identified estrus in a non estrous cow ³ , %	93% ^a	42% ^b	16% ^c

¹ Daily maximum ambient temperature (Tmax) ranged from 10 to 38°C; 14 of 36 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

² Onset of estrus was determined by HeatWatch.

³ Identification of non estrus as estrous cows excluded the 24 h period after cows were identified as estrus.

^{a, b, c} Means within row without a common superscript differ ($P < 0.05$).

CHAPTER IV

EFFECT OF AMBIENT TEMPERATURE ON RUMINAL

TEMPERATURE OF BEEF COWS

Abstract: Postpartum, lactating, Angus cows (4-7 yr of age) were used to evaluate the effect of elevated ambient temperature (T_{amb}) on ruminal temperature (RuT). Cows ($n = 12$) were administered RuT transmitting boluses (SmartStock, LLC) and RuT was evaluated during 8 d in the summer (June and August) and winter (January). Additionally, Rectal temperature (RT), RuT, and respiration rate (RR) were evaluated in cows ($n = 24$) during two consecutive days when daily T_{max} was 37 (HOT) or 28°C (WARM) in August. Temperature boluses were programmed to transmit RuT every hour. Ambient temperature was recorded each hour (www.mesonet.org) and ranged from 2 to 20°C (January) and 12 to 37°C (June and August). Mean daily RuT for all cows was $38.23 \pm 0.17^{\circ}\text{C}$. When hourly maximum ambient temperature (T_{max}) was between 34 and 36°C, RuT was greater ($P < 0.001$) compared with when hourly T_{max} were less than 34°C. Ruminal temperature was correlated with hourly T_{max} ($r = 0.18$, $P < 0.001$) and temperature humidity index ($r = 0.17$, $P < 0.01$; THI, Thom, 1959) when data for all days and hours were evaluated. On the HOT day, RuT, RT and RR were greater ($P < 0.05$; $40.2 \pm 0.1^{\circ}\text{C}$, $40.8 \pm 0.1^{\circ}\text{C}$, 114 ± 3 bpm, respectively) compared with the WARM day ($37.5 \pm 0.1^{\circ}\text{C}$, $38.1 \pm 0.1^{\circ}\text{C}$, 36 ± 3 bpm, respectively). Ruminal temperature was correlated ($P < 0.001$) with

RT ($r = 0.97$) and RR ($r = 0.95$). Elevated T_{amb} may influence the usefulness of RuT as a predictor of physiological events in beef cows.

INTRODUCTION

Cows, as obligate homeotherms, have the ability to regulate internal body temperature over a wide range of environmental conditions. Cows exchange heat with the external environment through chemical, behavioral, and physiological mechanisms allowing core body temperature to remain constant. Cows produce heat through metabolism and microbial fermentation of feed, ensuring optimal temperatures for biological processes. Metabolizable energy for maintenance accounts for approximately 70% of ME consumed (Ferrell and Jenkins, 1987) and is utilized for sustaining vital body activities. A primary maintenance function is the regulation of core body temperature (NRC, 1996). The thermoneutral zone (TNZ) of cows is the range of ambient temperatures (T_{amb}) in which the heat production of cows is offset by heat loss to the environment (NRC, 1891). The TNZ of cattle can be shifted by as much as 15°C allowing cattle to acclimate to gradual changes in ambient (NRC, 1891). Body temperature of cows fluctuates throughout the day with maximum temperature in the early morning and the nadir in midday (Bitman et al., 1984; Hahn et al., 1990; Lefcourt and Adams, 1996; Beatty et al., 2006; Ipema et al., 2008). When T_{amb} exceeds the TNZ, animals are heat stressed and must utilize physiological mechanisms to dissipate heat load.

The ability of cows to dissipate heat is limited when T_{amb} or thermal radiation are greater than skin temperature, and cattle must utilize evaporative heat loss mechanisms. Respiration rate is increased in thermally stressed beef (Robertshaw, 1985; Al-Haidary et al., 2001) and dairy cows (Sanchez et al., 1994). Sweating is increased when cattle are exposed to elevated T_{amb} (Berman, 1971; Gebremedhin et al., 2008). The efficiency of heat dissipation is influenced by humidity, wind velocity, and animal insulation (Gebremedhin et al., 2008). When cows are unable to dissipate heat, body temperature increases (Mader et al., 2010) with increasing

Tamb (Berman, 1971; Miller and Alliston, 1974; Abilay et al., 1975; Bitman et al., 1984; Lefcourt and Adams, 1996).

Temperature boluses (SmartStock, LLC, Pawnee, OK) have been developed for frequent, non invasive measurement of ruminal temperature (RuT; Cooper-Prado et al., 2011; Rose-Dye et al., 2011). Ruminal temperature is an indicator of estrus, parturition, and health of beef cows. Ruminal temperature increases 0.6 to 1.0°C at estrus in beef cows (Bailey et al., 2009; Boehmer et al., 2010; Cooper-Prado et al., 2011). Ruminal temperature decreased 0.33°C the 2 d prior to parturition in beef cows (Cooper-Prado et al., 2011). Following pathogenic challenge, RuT of steers increased from 0.3 to 0.8°C (Rose-Dye et al., 2011). The effect of elevated Tamb on RuT is not clearly defined. Therefore, the objectives of this experiment were (1) to evaluate the effect of elevated Tamb on RuT, and (2) to evaluate the relationship between RuT, RR and RT during thermal stress.

MATERIALS AND METHODS

Animals and Management

Experimental procedures used in this study were approved by the Oklahoma State University Animal Care and Use Committee. Mature, lactating, Angus cows (4 to 7 yr of age, n =12) were used to evaluate the effect of Tamb on RuT. Cows were managed in a drylot (0.25 ha) at the South Range Cow Research Center with *ad libitum* hay and water. Cows weighed 537 ± 7 kg and had a BCS of 4.4 ± 0.1 . The effect of daily maximum Tamb (Tmax) of $< 32^{\circ}\text{C}$ or $\geq 32^{\circ}\text{C}$ RuT, RT, and RR was evaluated for 24 cows.

Ruminal Temperature, Rectal Temperature, and Respiration Rate

Cows were administered RuT boluses (8.25 cm x 3.17 cm; 114 g) with a balling gun. Bolus records were transmitted by three receiver/repeater antennas located in the drylot within

100 m of a base station receiver linked to a PC data recovery system (SmartStock, LLC, Pawnee, OK). Boluses were programmed to transmit bolus ID, RuT, date and time each hour. Each hourly record also included temperature reading for the previous 11 h. Ruminant temperatures were recorded during 8 d in January, June, and August. In addition, RuT, RT, and RR were determined on two sequential days in August. Respiration rate was determined by counting diaphragm movement of cows for 60 s periods. Rectal temperatures were measured with an digital thermometer (Agricultural Electronics, Montclair, CA; model # M216) at a depth of 10 to 15 cm. Respiration rates and RT were measured twice per animal by each of two researchers at 1400 h.

Environmental Data

Environmental data were collected (www.mesonet.org) from a weather station 8 km from the experimental site, on 8 d in January, June, and July. Daily Tmax was 32°C or greater on 4 of the 7 d in June and August. During the two sequential days in August when RuT, RR and RT were recorded, daily Tmax was 37°C on the first day (HOT) and Tmax was 28°C on the second day (WARM). Ambient temperature and relative humidity were recorded every 5 min during the experimental period and maximum, minimum and mean ambient temperature was calculated for each hour. Temperature humidity index was calculated (Thom, 1959).

Statistical Analyses

Simple correlations between RuT, RT RR, Tamb, and THI were determined using PROC CORR (SAS Inst. Inc., Cary, NC). Effects of Tamb and THI on RuT, RT, and RR were determined with PROC GLM (SAS Inst. Inc.) and means were compared by Student's t-test. Ruminant temperature and Tamb were analyzed with PROC GLM and PROC MIXED (SAS Inst. Inc.) with day as a repeated measure within cow. Goodness of fit statistics were used to determine variance structure (first order autoregressive, compound symmetry, variance

component, unstructured, Huynh-Feldt and Toeplitz) prior to analysis. Estimates of variance components for analyses were achieved using the restricted maximum-likelihood method. Denominator degrees of freedom were determined by the Kenward-Roger procedure. Least squares means were compared using the PDIFF option (SAS Inst. Inc.) when effects were significant. Pairwise comparison of RuT means within Tmax and THI were determined using SCHEFFE (SAS Inst. Inc.) with a predetermined significance level of 0.05.

RESULTS

Mean daily maximum ambient temperature (Tmax) was $20.0 \pm 0.4^{\circ}\text{C}$ in January, $32.9 \pm 1.0^{\circ}\text{C}$ in June, and $31.8 \pm 2.0^{\circ}\text{C}$ in August with hourly ranges of 2 to 20°C , 20 to 34°C , and 12 to 37°C , respectively. Relative humidity ranged from 50 to 66 % in January, 63 to 83 % in June, and 55 to 89 % in August. Mean RuT during the experiment was $38.23 \pm 0.02^{\circ}\text{C}$. Diurnal variation in RuT when daily Tmax was 20°C or less (Figure 1a) occurred with maximum RuT ($38.55 \pm .01^{\circ}\text{C}$) at 0200 h and the nadir ($37.52 \pm 0.13^{\circ}\text{C}$) occurred at 1600 h. Maximum RuT ($38.69 \pm 0.14^{\circ}\text{C}$, Figure 1b) occurred at 0000 h and the nadir ($37.24 \pm 0.14^{\circ}\text{C}$) at 1200 h when daily Tmax was greater than 20°C and less than 32°C . Diurnal variation in RuT occurred with a maximum ($39.19 \pm 0.16^{\circ}\text{C}$) at 1900 and the nadir ($37.44 \pm 0.17^{\circ}\text{C}$) at 1200 h when Tmax was $\geq 32^{\circ}\text{C}$.

Ruminal temperature was greater ($P < 0.001$; $39.17 \pm 0.09^{\circ}\text{C}$) when daily maximum Tamb were 34 to 36°C compared with when maximum daily Tamb were 19 to 21°C ($37.98 \pm 0.08^{\circ}\text{C}$), 22 to 24°C ($38.01 \pm 0.06^{\circ}\text{C}$), 25 to 27°C ($38.15 \pm 0.05^{\circ}\text{C}$), 28 to 30°C ($38.17 \pm 0.06^{\circ}\text{C}$), and 31 to 33°C ($38.21 \pm 0.06^{\circ}\text{C}$; Figure 2). Mean RuT was greater ($P < 0.001$, Figure 3) when THI was 87 to 89 compared with when THI was less than 87 . Ruminal temperature was correlated with Tamb ($r = 0.19$, $P < 0.001$) and THI ($r = 0.20$, $P < 0.001$) when data for all hours and days ($n = 1251$ observations) during January, June, and August were evaluated.

Mean hourly maximum temperature during the HOT day was $30.2 \pm 0.3^{\circ}\text{C}$ (range: 23 to 37°C) and $24.7 \pm 0.1^{\circ}\text{C}$ (range: 21 to 28°C) during the WARM day. Ruminal temperature was correlated ($n = 40$ observations, $P < 0.001$) with RT ($r = 0.95$), RR ($r = 0.97$), Tmax ($r = 0.67$), and THI ($r = 0.68$). On the HOT day (daily Tmax: 37°C), RuT, RT, and RR were greater ($P < 0.01$, $40.2 \pm 0.1^{\circ}\text{C}$, $40.8 \pm 0.1^{\circ}\text{C}$, 114 ± 3 bpm; Table 1) compared with the WARM day (daily Tmax: 28°C ; $37.5 \pm 0.1^{\circ}\text{C}$, $38.1 \pm 0.1^{\circ}\text{C}$, 36 ± 3 bpm; respectively).

DISCUSSION

Ambient temperature during an Oklahoma summer are variable with prolonged periods of elevated Tamb. Daily Tmax averaged 20°C in January, 33°C in June, and 32°C in August. The greatest range and variation in Tamb occurred in August. During the experiment, 4 of 7 d in June and August had Tamb of 32°C or greater.

Body temperature of cows decreases in early morning and increases throughout the afternoon (Bitman et al., 1984; Hahn et al., 1990; Lefcourt and Adams, 1996; Beatty et al., 2006; Ipema et al., 2008). Reticular temperature and rectal temperature of dairy cows was greater in the afternoon compared with the morning (Bewley et al., 2008a). Maximum RuT occurred at 0000 and decreased to the nadir at 1200 when cows were not thermally stressed in the current experiments. When daily Tmax increased to $\geq 32^{\circ}\text{C}$, a nychthermal pattern occurred with maximum RuT at 1900 h and nadir at 1200h. Nychthermal pattern of body temperature was maintained when beef heifers were exposed to thermal stress (Beatty et al., 2006). The different times of day when RuT was maximal when daily Tmax were $< 32^{\circ}\text{C}$ or $\geq 32^{\circ}\text{C}$, may have resulted from additional heat loads and limited heat dissipation of cows exposed to thermal stress. Increases in core body temperature of cows usually occurs 2 to 5 h after exposure to elevated Tamb (Hahn, 1999). Mader et al, (2010) indicated that failure of cows to dissipate heat load during overnight cooling periods results in greater daytime body temperatures. In contrast to this

experiment, the magnitude of diurnal variation in body temperature was not affected when heifers were exposed to elevated Tamb (Al-Haidary et al., 2001).

Ruminal temperature was correlated with Tmax, THI, RT, and RR. Others have observed that RuT was correlated with rectal temperature (Burns et al., 2002; Prendiville et al., 2002; Sievers et al., 2004). Respiration rate in cattle is positively related to Tamb (Brown-Brandl et al., 2005) and THI (Mader et al., 2006). Similarly, body temperature is correlated with Tamb and THI (Berman, 1971; Prendiville et al., 2002; Scharf et al., 2010). Ruminal temperatures in this experiment were unaffected by temperature humidity indices less than 86 and increased when THI was 87 or greater. Temperature humidity index for cattle is a function of Tamb (Thom, 1959). Dikmen et al. (2008) stated that dry bulb temperature was nearly as good a predictor of RT as THI of lactating Holsteins in a subtropical environment. Scharf et al. (2010) observed a stronger relationship between body temperature and Tamb than THI, solar radiation, and black globe temperature.

In the current experiments, RuT, rectal temperature, and respiration rate were increased when cows were exposed to elevated Tamb. Rectal temperature was greater in beef (Miller and Alliston, 1974; Pratt and Wettemann, 1986) and dairy cattle (Abilay et al., 1975) exposed to elevated Tamb. Respiration rate of beef (Robertshaw, 1985; Al-Haidary et al., 2001) and dairy cows (Sanchez et al., 1994) exposed to thermal stress was greater compared with cows exposed to thermoneutral conditions. In contrast, RuT was not affected by Tamb when cows were exposed to thermoneutral conditions (Bailey et al., 2009; Cooper-Prado et al., 2011). Tympanic temperature mirrors changes in Tamb when cattle are exposed to hot conditions, indicating that thermoregulatory mechanisms are limited during thermal stress (Mader et al., 2009).

Ruminal temperature was not influenced by ambient temperatures less than 33°C, and RuT increased when Tamb was 34°C or greater in this experiment. The upper critical limit of the

thermoneutral zone of cattle is not clearly defined. Rectal temperatures were independent of black globe temperatures between 9 and 28°C (Berman, 1971). Body temperature of cattle varied slightly until T_{max} exceeded 25.6°C (Lefcourt and Adams, 1996). Hahn et al. (1992) observed the T_{amb} threshold for thermal stress in cattle was 25°C. Acclimation of cows to increased ambient temperature was not evaluated in the current experiments. Robinson et al. (1986) observed the thermoneutral zone of beef steers was influenced by exposure to previous T_{amb} .

When T_{max} was $\leq 33^\circ\text{C}$, month and season did not influence RuT in this experiment. Similarly, RuT in beef cows did not differ in May and December (Bailey et al., 2009). However, when cattle were exposed to thermal stress, tympanic temperatures of beef cattle were greater in the summer compared with the winter (Arias et al., 2011). Season (spring, summer, fall, and winter) influenced reticular and rectal temperature in dairy cows (Bewley et al., 2008a) despite similar temperatures during the spring, summer, and fall. The effects of elevated T_{amb} may be diminished when comparing RuT over long periods. The thermoneutral zone of cattle is dynamic and can shift by as much as 15°C (NRC, 1891; Robinson et al., 1986), with acclimation rates of 0.1 to 0.4°C of body temperature per day (Hahn et al., 1990). Mader et al. (2010) suggested that cattle exposed to cooler ambient temperatures at night are able to dissipate the thermal load generated during daytime exposure to thermal stress.

SUMMARY AND CONCLUSIONS

Ruminal temperature of beef cows is increased when cows are exposed to elevated T_{amb} . When exposed to elevated ambient temperature, cows have increased RuT, rectal temperature, and respiration rate. The efficacy of RuT for the prediction of estrus or other physiological functions may be limited when cows are exposed to elevated T_{amb} . Additional studies are

needed to evaluate the effect of elevated T_{amb} on use of RuT to predict physiological function of cattle.

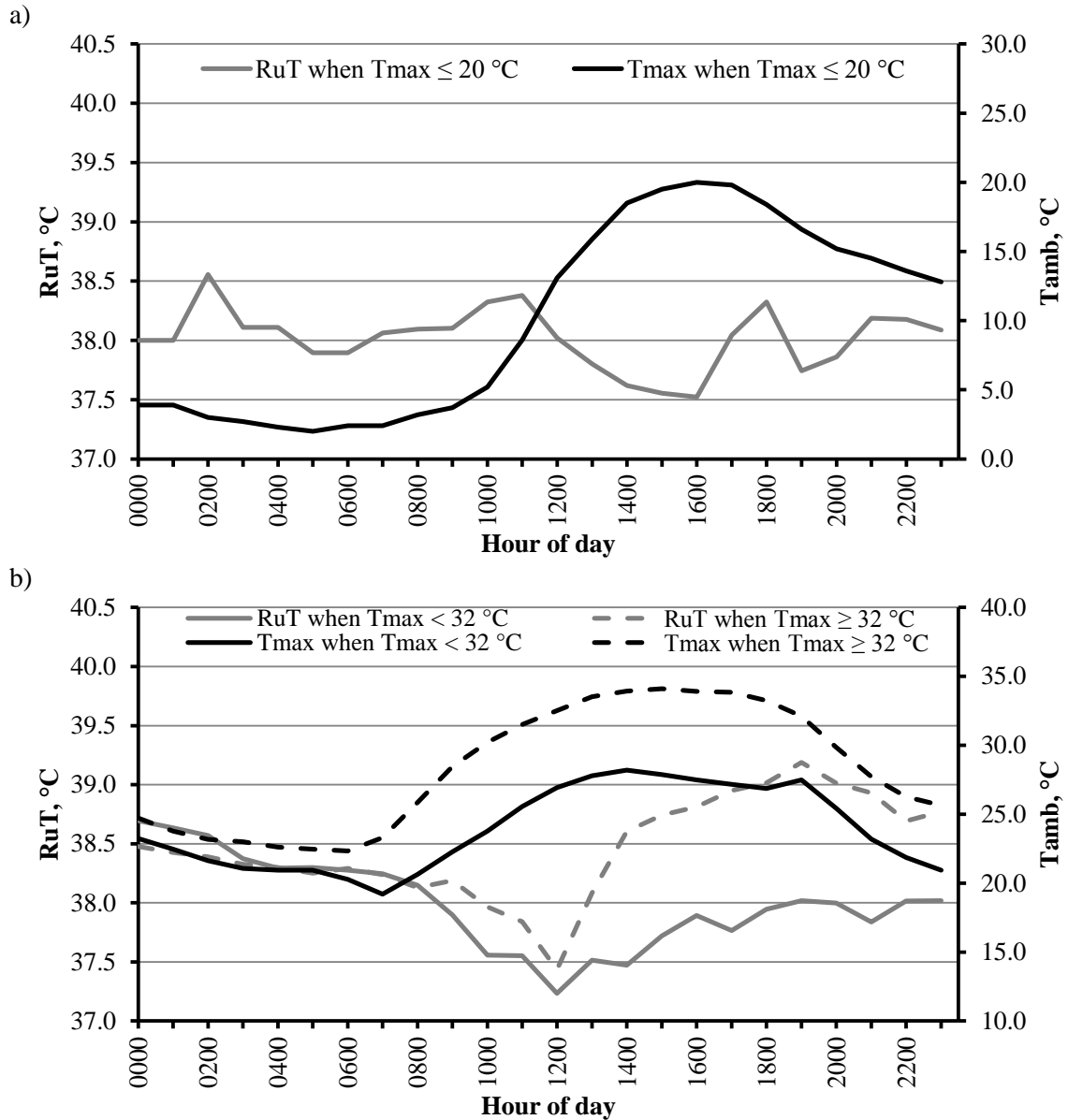


Figure 1A. Diurnal variation in maximum ambient temperature (T_{max}) and ruminal temperature (RuT) of beef cows (n = 8). A. Solid grey line includes all RuT values and solid black line includes all hourly T_{max} when daily T_{max} ≤ 20 °C. SE for RuT when daily T_{max} < 20 °C, over hour x cow was 0.20. B. Solid grey line includes RuT values when daily T_{max} < 32 °C; broken grey line includes RuT values when daily T_{max} ≥ 32 °C. Solid black line includes hourly T_{max} when daily T_{max} < 32 °C; broken black line includes hourly T_{max} when daily T_{max} ≥ 32 °C. SE for RuT when daily T_{max} < 32 °C, over hour x cow was 0.19. SE for RuT when daily T_{max} < 32 °C, over hour x cow was 0.14.

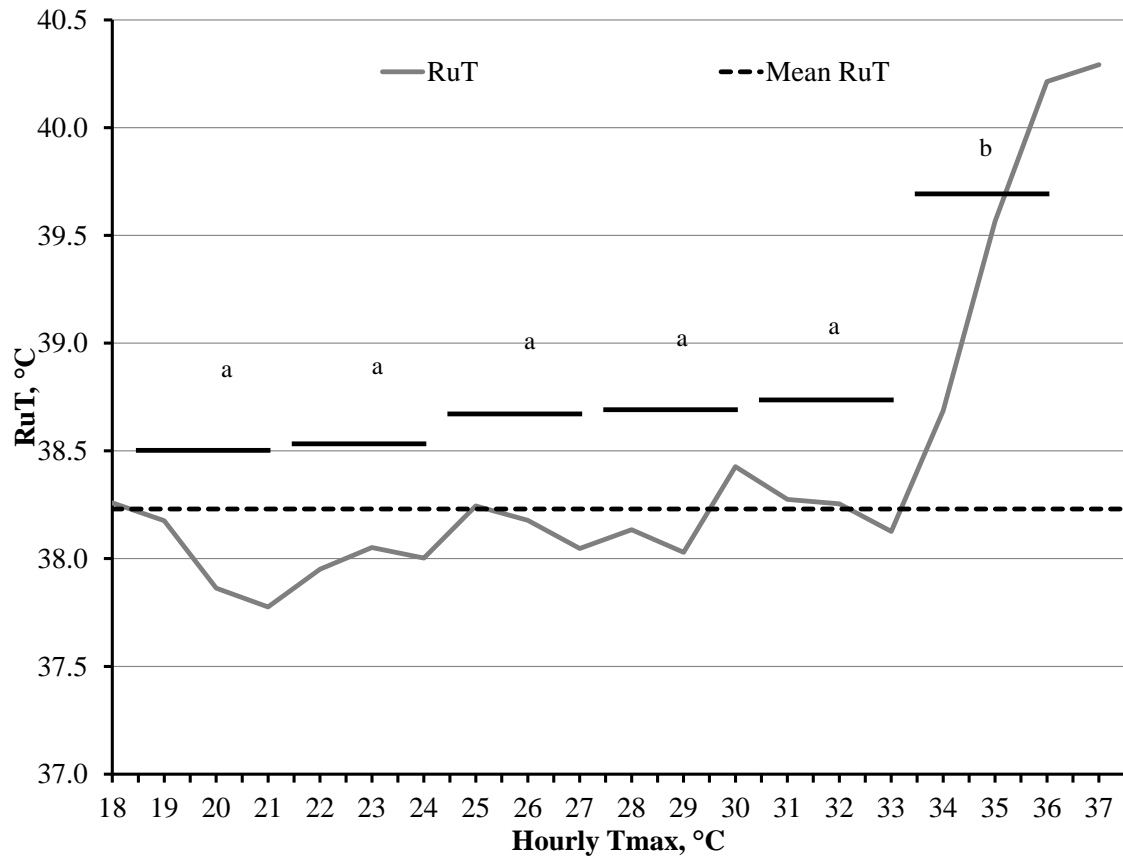


Figure 2. Ruminal temperature (RuT) in beef cows ($n = 11$) relative to hourly maximum ambient temperature (Tmax). Broken gray line is mean RuT during the experiment ($38.23 \pm 0.02^{\circ}\text{C}$).

^{a, b} Means without a common letter differ ($P < 0.001$). SE of RuT over hour averaged 0.22.

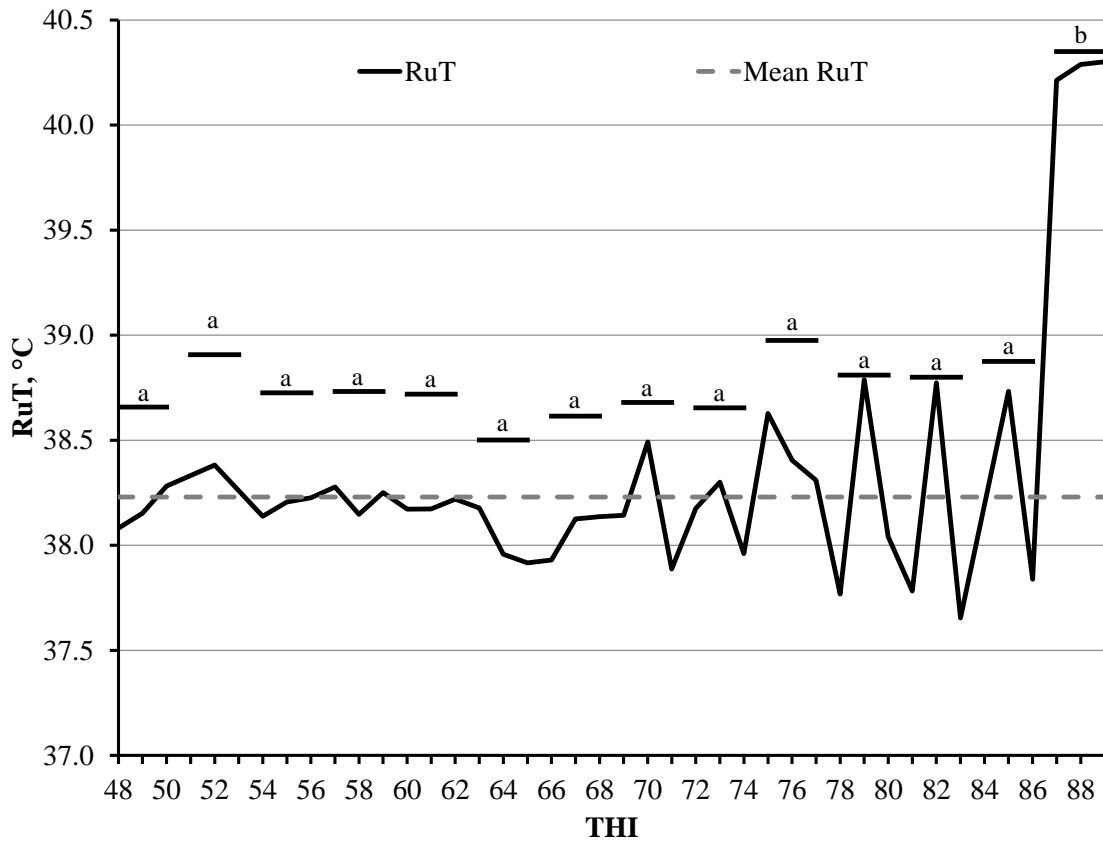


Figure 3. Ruminal temperature (RuT) in beef cows (n = 11) relative to hourly mean temperature humidity index (THI). Broken gray line is mean RuT during the experiment ($38.23 \pm 0.02^{\circ}\text{C}$).

^{a, b} Means without a common letter differ ($P < 0.001$). SE of RuT over hour averaged 0.22.

Table 1. Effect of WARM (27°C) and HOT (37°C) maximum ambient temperature (Tmax) on rectal temperature (RT), ruminal temperature (RuT), and respiration rate (RR) of beef cows (n = 20).

Item	Tmax	
	WARM (27°C)	HOT (37°C)
RT, °C	38.1 ± 0.1 ^a	40.8 ± 0.1 ^b
RuT, °C	37.5 ± 0.1 ^a	40.2 ± 0.1 ^b
RR, bpm	36 ± 3 ^a	114 ± 3 ^b

^{a, b} Means within row without a common superscript differ ($P < 0.01$).

CHAPTER V

PREDICTION OF ESTRUS IN BEEF COWS USING RUMINAL TEMPERATURE

Abstract: Postpartum, lactating, Angus cows (4 to 7 yr of age) were used to evaluate changes in ruminal temperature (RuT) for the prediction of estrus. In Exp. 4, cows ($n = 62$), were synchronized with PGF_{2 α} at 93 ± 2 d postpartum and RuT was evaluated during June and July. In Exp. 5, cows ($n = 60$) were synchronized with PGF_{2 α} at 66 ± 2 d postpartum and RuT was evaluated during May. Cows were administered RuT transmitting boluses (SmartStock, LLC), which were programmed to transmit RuT every hour. The onset of estrus was determined by HeatWatch (CowChips, LLC.) Maximum ambient temperature (Tmax) was recorded each hour (www.mesonet.org) and ranged from 19 to 35°C in Exp. 4 and 7 to 33°C in Exp. 5. In Exp. 4, mean RuT was greater ($P < 0.001$, $39.03 \pm 0.12^\circ\text{C}$) during the 9 h after the onset of estrus compared with 16 to 24 h before ($38.28 \pm 0.12^\circ\text{C}$) and 24 to 32 h after ($38.41 \pm 0.12^\circ\text{C}$) the onset of estrus. Time of day tended to influence RuT in the 9 h after the onset of estrus ($P = 0.08$). Daily Tmax of 32°C or greater influenced ($P < 0.004$) RuT in the 9 h after the onset of estrus compared with when daily Tmax was less than 32°C. Correct identification of estrus was similar ($P > 0.10$) when an increase of $\geq 0.3^\circ\text{C}$ (66 %), $\geq 0.5^\circ\text{C}$ (66 %), or $\geq 0.7^\circ\text{C}$ (61%) in RuT during a 9 h period was used compared with the preceding 12 to 84 h. Identification of a non estrus cow as estrus was greatest ($P < 0.05$, 98 %) when a 9 h RuT increase of $\geq 0.3^\circ\text{C}$ from the preceding 12 to 84 h was used compared with increases of $\geq 0.5^\circ\text{C}$ (81 %), and $\geq 0.7^\circ\text{C}$ (73 %). In Exp. 5,

mean RuT during the 9 h after the onset of estrus was greater ($P < 0.001$; $38.58 \pm 0.09^{\circ}\text{C}$) compared with the 16 to 24 h before ($37.92 \pm 0.09^{\circ}\text{C}$) and 24 to 32 h after ($37.90 \pm 0.10^{\circ}\text{C}$) the onset of estrus. Ruminal temperature in the 9 h after the onset of estrus tended to be greater ($P < 0.10$; $38.49 \pm 0.17^{\circ}\text{C}$, $38.86 \pm 0.19^{\circ}\text{C}$) when onset of estrus occurred at 0900 to 1600 h and 1700 to 0000 h, respectively, compared with when onset occurred at 0100 to 0800 h ($38.40 \pm 0.12^{\circ}\text{C}$). Mean RuT during the 9 h after the onset of estrus were not different ($P = 0.12$) when Tmax was less than 32°C or 32°C or greater. Correct identification of estrus was similar ($P > 0.10$) when an increase of $\geq 0.3^{\circ}\text{C}$ (92 %), $\geq 0.5^{\circ}\text{C}$ (87 %), and $\geq 0.7^{\circ}\text{C}$ (79%) in RuT during a 9 h period was used compared with the preceding 12 to 84 h. Identification of a non estrus cow as estrous was greatest ($P < 0.05$, 95 %) when a 9 h RuT increase of $\geq 0.3^{\circ}\text{C}$ from the preceding 12 to 84 h was used and an increase of $\geq 0.7^{\circ}\text{C}$ (40 %) identified the least number of non estrus cows as estrus; a RuT increase of $\geq 0.5^{\circ}\text{C}$ identified 75 % of non estrus cows as estrus. Ruminal temperature is greater at estrus in beef cows and RuT has potential for the prediction of estrus and timing of AI.

INTRODUCTION

Profitability of a cow calf herd can be enhanced through the use of AI and estrous synchronization. Genetic merit of progeny can be increased by AI and use of genetically superior bulls. In the U.S., estrous synchronization and AI are only used in 8% of U.S. beef herds (USDA, 2011) and time and labor are the major detractors from the use of these technologies (Thibier and Wagner, 2002). The most common and effective estrous detection method is twice daily visual observation, however it is subjective and requires time and labor input (At-Taras and Spahr, 2001). Radiotelemetric estrous detection systems have been developed to identify estrus. The HeatWatch system is highly effective for identification of estrous cows by recording mounts

received by an animal (White et al., 2002; Peralta et al., 2005). Estrous detection systems may utilize changes in physiology at estrus to determine when to AI. Vaginal temperature increases (0.5 to 1.0°C) in cows at estrus (Mosher et al., 1990; Kyle et al., 1998; Suthar et al., 2011) and may be an effective predictor of the LH surge, ovulation (Fisher et al., 2008) and onset of estrus (Kyle et al., 1998). Use of vaginal temperature to identify the onset of estrus may be limited due to maintenance of equipment and inflammation of the reproductive tract (Leidl and Stolla, 1976; Rorie et al., 2002).

Temperature boluses (SmartStock, LLC) allow frequent and non-invasive measurement of ruminal temperature (RuT, Rose-Dye et al., 2011). Increases in RuT of 0.6 to 1.0°C occur at estrus in beef cows (Bailey et al., 2009; Cooper-Prado et al., 2011) and a $\geq 0.7^\circ\text{C}$ increase in RuT can be used to determine estrus (Bailey et al., 2009). The effect of ambient temperature (T_{amb}) on RuT is not well defined. Body temperature is greater when cattle are exposed to elevated ambient temperature (Hahn et al., 1990) and body temperature varies throughout the day (Lefcourt et al., 1999; Beatty et al., 2006). Usefulness of body temperature for the prediction of estrus is limited by variation in body temperature and the ability to separate the influence of many variables that effect body temperature (Kyle et al., 1998; Firk et al., 2002). Our hypotheses are that RuT is increased at estrus in beef cows throughout the day and RuT can be used to predict the time of AI. Therefore, the objectives of this study were 1) to evaluate the use of RuT for the prediction of estrus and, 2) evaluate the effect of elevated T_{amb} and diurnal variation in RuT on the efficacy of RuT to predict estrus.

MATERIALS AND METHODS

Exp. 4

Experimental procedures used in this study were approved by the Oklahoma State University Animal Care and Use Committee. Postpartum, lactating, Angus cows (4 to 7 yr of age, $n = 62$) were used to evaluate changes in RuT during the estrous cycle in June and July. Cows weighed 536 ± 7 kg and had a BCS of 4.4 ± 0.1 (Wagner et al., 1988). Cows and calves were managed in a drylot (0.25 ha) at the South Range Cow Research Center with *ad libitum* hay and water. Cows were administered PGF_{2 α} (Lutalyse[®] 25 mg, i.m.; Pfizer, Inc., New York, NY) at 93 ± 2 d postpartum to synchronize estrus. Cows that did not exhibit estrus after initial treatment with PGF_{2 α} were administered a second treatment of PGF_{2 α} at 10 d after the first treatment.

The HeatWatch system (CowChips, LLC, Manalapan, NJ) was used to monitor the onset of estrus. Then onset of estrus can be accurately determined by HeatWatch (Walker et al., 1996; At-Taras and Spahr, 2001; Floyd et al., 2009). HeatWatch detected 100% of visually observed estruses and the number of mounts received per cow by the two detection methods were correlated (Floyd et al., 2009). Pressure sensitive radio transmitters were attached to the tail head when cows were treated with PGF_{2 α} . Patches were monitored daily for proper attachment and secured with adhesive as needed. The onset of estrus was defined as the first of two mounts (≥ 2 s) received within a 4 h period (White et al., 2002). The end of estrus was defined as the last mount received, with a mount occurring 4 h before and no mounts occurring in the following 12 h period.

Cows were administered RuT boluses (SmartStock, LLC, Pawnee, OK; 8.25 cm x 3.17 cm; 114 g), 4 to 5 d prior to PGF_{2α} treatment with a balling gun. Bolus records were transmitted through three receiver/repeater antennas located in the drylot within 100 m of a base station receiver linked to a PC data recovery system (SmartStock, LLC, Pawnee, OK). Boluses were programmed to transmit bolus ID, RuT, date and time each hour. Hourly records also included temperature readings for the previous 11 h. Ruminal temperature was recorded from 4 d prior to the first PGF_{2α} treatment until 4 d after estrus as determined by RuT. Outliers associated with drinking events (Bewley et al., 2008b; Cooper-Prado et al., 2011) were identified as RuT values less than 2 x SD ($> 35.3^{\circ}\text{C}$) from the mean RuT. Ruminal temperatures associated with drinking events were not excluded from analyses. Estrus was determined as a RuT increase of $\geq 0.7^{\circ}\text{C}$ for a 9 h period compared with the mean RuT during 12 to 84 h before the start of the 9 h identification period (Figure 1). Cows were AI with semen from one of two Angus bulls, by a single technician, 8 to 16 h after the onset of the first hour in the 9 h identification period in which average RuT was increased $\geq 0.7^{\circ}\text{C}$. The pre-estrus mean RuT included ≥ 12 RuT values and the 9 h identification period included ≥ 4 RuT values. Cows were also evaluated for RuT increases of $\geq 0.3^{\circ}\text{C}$ and $\geq 0.5^{\circ}\text{C}$ during the experimental period. When inadequate RuT values were recorded during the 48 to 96 h after PGF_{2α} treatment, the cow was excluded from estrous detection analyses, but was evaluated for RuT increases when cows were not in estrus. The 24 h period following the onset of estrus was excluded from the analysis of RuT increases when cows were non estrus. Two boluses failed to record RuT, and onset of estrus, as determined by HeatWatch, did not occur in 18 cows in Exp. 4, therefore 20 cows were excluded from analyses. Insufficient RuT data was recorded in the 72 h before and after estrus in 1 cow and the cow was excluded from the analysis.

Ambient temperature and relative humidity were recorded every 5 min from a weather station (www.mesonet.org) 8 km from the experimental site. Maximum, minimum, and mean ambient temperatures were calculated for each hour. Daily Tmax ranged from 23 to 35°C in June and 25 to 39°C in July. Temperature humidity index was calculated (Thom, 1959).

Exp. 5

This experiment was replication of Exp. 4 during cooler environmental temperatures.

Postpartum, lactating, Angus cows (4 to 7 yr of age, n = 60) were used to evaluate RuT associated with synchronized estrus. Cows weighed 541 ± 8 kg and had a BCS of 4.2 ± 0.1 . Cows were managed and estrus was synchronized at 66 ± 2 d postpartum as described for Exp. 4. Ambient temperature and relative humidity were recorded for 13 d in May and daily Tmax ranged from 16 to 33°C. Two boluses failed to record RuT and insufficient RuT data were recorded at estrus in 2 cows. Onset of estrus by HeatWatch did not occur in 18 cows, so the cows were excluded from analyses.

Statistical Analyses

Mean RuT during the 9 h after the onset of estrus (HeatWatch) was compared with 16 to 24 h before and 24 to 32 h after the onset of estrus when onset of estrus occurred at different times during a day. Selected daily periods (0100 to 0800, 0900 to 1600 and 1700 to 0000) were based on core body temperature at estrus and RuT at estrus (Bailey et al., 2009; Cooper-Prado et al., 2011). Periods evaluated the same daily hours for the day before, the day of and the day after estrus to minimize effects of diurnal variation in RuT (Cooper-Prado et al., 2011). Ruminal temperature and Tamb were analyzed using PROC MIXED (SAS Inst. Inc., Cary, NC), with day

as a repeated measure within cow, and periods were fixed effects. Six variance structures (first order autoregressive, compound symmetry, variance component, unstructured, Huynh-Feldt, and Toeplitz) were determined by the goodness of fit statistic prior to analysis. Variance components for analyses were estimated using the restricted maximum-likelihood method. The Kenward-Roger procedure was used to determine denominator degrees of freedom. Least squares means were compared using LSD (pdiff option of SAS) when effects were significant. Estrus identification models and pregnancy rates were evaluated using PROC GLM (SAS Inst. Inc.). Calculated means for RuT thresholds and pregnancy status were compared using the Student's t Test (SAS Inst. Inc.).

RESULTS

Exp. 4

Mean daily Tmax was $31.4 \pm 0.4^{\circ}\text{C}$ and ranged from 23 ± 1 to $35 \pm 1^{\circ}\text{C}$. Mean daily relative humidity was $74 \pm 1\%$ and ranged from $36 \pm 1\%$ to $96 \pm 1\%$. Mean hourly RuT of cows was $38.29 \pm 0.02^{\circ}\text{C}$. Diurnal variation in RuT occurred with the maximum ($38.77 \pm 0.12^{\circ}\text{C}$; Figure 2) at 1900 h and nadir ($37.52 \pm 0.12^{\circ}\text{C}$) at 1200 h. Maximum RuT ($39.06 \pm 0.10^{\circ}\text{C}$) occurred at 1800 h on days when daily Tmax was 32°C or greater and the nadir ($37.61 \pm 0.10^{\circ}\text{C}$) occurred at 1200 h. Maximum RuT ($38.49 \pm 0.10^{\circ}\text{C}$) occurred at 1900 h and the nadir ($37.41 \pm 0.10^{\circ}\text{C}$) at 1200 h on days when daily Tmax did not exceed 32°C . Mean RuT was greater ($P < 0.001$; $38.63 \pm 0.02^{\circ}\text{C}$) on days when daily Tmax was 32°C or greater compared with days when daily Tmax was less than 32°C ($38.28 \pm 0.02^{\circ}\text{C}$). Ruminal temperatures < 36.3 (drinking events) comprised 3.4% of data in this experiment and exclusion of these values reduced the variance and skewedness.

Figure 3 depicts RuT relative to onset of estrus, as determined by HeatWatch. Ruminal temperature was greater ($P < 0.001$, $39.03 \pm 0.12^{\circ}\text{C}$) in the 9 h following the onset of estrus compared with 16 to 24 h before ($38.28 \pm 0.12^{\circ}\text{C}$) and 24 to 32 h after ($38.41 \pm 0.12^{\circ}\text{C}$) onset of estrus. Mean hourly Tmax was $27.2 \pm 0.1^{\circ}\text{C}$ during the 96 h before and after the onset of estrus.

Mean RuT was greater ($P = 0.01$, $38.59 \pm 0.16^{\circ}\text{C}$) in the 9 h after onset of estrus compared with 16 to 24 h before ($37.99 \pm 0.16^{\circ}\text{C}$) onset of estrus, and tended to be greater ($P = 0.07$) than 24 to 32 h after ($38.14 \pm 0.17^{\circ}\text{C}$) when onset occurred between 0100 and 0800 h (Figure 4). Ruminal temperature during the 9 h after the onset of estrus tended to be greater ($P = 0.08$; $38.80 \pm 0.34^{\circ}\text{C}$) than 16 to 24 h before ($37.73 \pm 0.44^{\circ}\text{C}$) the onset and did not differ ($P > 0.10$) from 24 to 32 h after ($37.97 \pm 0.31^{\circ}\text{C}$) the onset of estrus, when onset occurred between 0900 and 1600 h. When the onset of estrus occurred between 1700 and 0000 h, mean RuT during the 9 h after the onset of estrus was greater ($P < 0.03$; $39.33 \pm 0.22^{\circ}\text{C}$) compared with 16 to 24 h before ($38.52 \pm 0.21^{\circ}\text{C}$) onset of estrus and ($P = 0.06$) compared with 24 to 32 h after ($38.67 \pm 0.22^{\circ}\text{C}$) onset of estrus. Time of day tended ($P = 0.08$) to influence mean RuT in the 9 h after the onset of estrus at 1700 to 0000 h compared with 0100 to 0800 h. Mean RuT at estrus at 0900 to 1600 h was not different ($P > 0.35$) from mean RuT during the 9 h after the onset of estrus at 0100 to 0800 h or 1700 to 0000 h.

Daily Tmax influenced ($P < 0.004$, Figure 5) mean RuT during the 9 h after the onset of estrus when daily Tmax was less than 32°C or 32°C or greater. Ruminal temperature in the 9 h after the onset of estrus did not differ ($P > 0.35$; $38.27 \pm 0.19^{\circ}\text{C}$) compared with the 16 to 24 h before ($38.03 \pm 0.16^{\circ}\text{C}$) and 24 to 32 h after ($37.93 \pm 0.23^{\circ}\text{C}$) onset of estrus when onset occurred on a day when Tmax was less than 32°C . Mean RuT during the 9 h after the onset of estrus was

greater ($P < 0.001$; $39.23 \pm 0.13^{\circ}\text{C}$) compared with 16 to 24 h before ($38.40 \pm 0.15^{\circ}\text{C}$) and 24 to 32 h after ($38.49 \pm 0.13^{\circ}\text{C}$) onset of estrus, when onset occurred on a day when T_{max} was 32°C or greater.

Increases in 9 h mean RuT of $\geq 0.3^{\circ}\text{C}$, and $\geq 0.5^{\circ}\text{C}$, compared with the mean RuT from 12 to 84 h before the 9 h period, correctly identified 66% of estruses (Table 1); an increase of $\geq 0.7^{\circ}\text{C}$ occurred in 61% of estrus cows. Correct identification of estrus cows by an increase in 9 h mean RuT from the preceding 12 to 84 h was not influenced ($P > 0.05$) by RuT increase thresholds of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$ and $\geq 0.7^{\circ}\text{C}$. A RuT increase of $\geq 0.5^{\circ}\text{C}$ and $\geq 0.7^{\circ}\text{C}$ for any 9 h period, compared with mean from 12 to 84 h before the 9 h period, decreased ($P < 0.05$; 81%, 73%, respectively) the number of non estrous cows identified as estrus compared with a RuT increase of $\geq 0.3^{\circ}\text{C}$ (98%). A 9 h mean increase in RuT of $\geq 0.7^{\circ}\text{C}$, compared with the pre estrus mean, occurred 37.8 ± 17.4 h before the onset of estrus as determined by HeatWatch. Fifty eight cows were bred based on a 0.7°C increase in RuT. Onset of estrus, as determined by HeatWatch, was not identified in 20 cows, of which estrus was predicted by RuT in 18 cows. Cows AI based on RuT, without HeatWatch determined onset, resulted in 6 pregnancies. Pregnancy rate of cows AI based on an increase in mean (9 h) RuT, compared with the mean RuT during the previous 12 to 84 h, averaged 40%. Pregnancy rate of cows was not influenced by $T_{\text{amb}} \geq 32^{\circ}\text{C}$ on the day of onset, as predicted by RuT, ($P = 0.46$; Table 2) or in the 3 d before the onset of estrus ($P = 0.58$).

Ruminal temperature boluses recorded 19,128 RuT values from 41 cows. Mean daily recording frequency per cow was 14.1 ± 0.2 and ranged from 0 to 24 records per cow per day. During the experiment, 23% of cow days had 24 records per cow per day. At least 12 records per

cow per day occurred in 67% of the cow days. Ruminal temperature was not recorded on 18% of the cow days.

Exp. 5

Mean daily Tmax was $24.8 \pm 1.4^{\circ}\text{C}$ and ranged from $16 \pm 1^{\circ}\text{C}$ to $33 \pm 1^{\circ}\text{C}$. Mean hourly relative humidity was $68 \pm 1\%$ with a range of $28 \pm 1\%$ to $98 \pm 1\%$. Mean hourly RuT during the experiment was $38.00 \pm 0.02^{\circ}\text{C}$. Diurnal variation in RuT occurred with maximum RuT ($38.19 \pm 0.10^{\circ}\text{C}$, Figure 6) at 2200 h and the nadir ($37.58 \pm 0.10^{\circ}\text{C}$) at 1400 h. Maximum RuT ($38.35 \pm 0.10^{\circ}\text{C}$) occurred at 2200 h on days when daily Tmax were 32°C or greater and the nadir ($37.37 \pm 0.10^{\circ}\text{C}$) occurred at 1200 h. When daily Tmax was less than 32°C , diurnal variation occurred with maximum RuT ($38.17 \pm 0.10^{\circ}\text{C}$) at 2200 h and the nadir ($37.54 \pm 0.10^{\circ}\text{C}$) at 1400 h. Ruminal temperatures less than 35.6 comprised 3.2% of data in this experiment and exclusion of these values reduced the variance and skewedness.

Ruminal temperature during the 9 h after the onset of estrus was greater ($P < 0.001$, $38.58 \pm 0.09^{\circ}\text{C}$; Figure 7) compared with 16 to 24 h before ($37.92 \pm 0.09^{\circ}\text{C}$) and 24 to 32 h after ($37.90 \pm 0.09^{\circ}\text{C}$) onset of estrus. Mean hourly Tmax was $22 \pm 1^{\circ}\text{C}$ during the 96 h before and after the onset of estrus and ranged from $7 \pm 1^{\circ}\text{C}$ to $33 \pm 1^{\circ}\text{C}$. Mean RuT was greater in the 9 h after the onset of estrus ($P < 0.003$; $38.40 \pm 0.11^{\circ}\text{C}$; Figure 8), when onset occurred between 0100 and 0800 h, compared with the 16 to 24 h before ($37.88 \pm 0.12^{\circ}\text{C}$) and 24 to 32 h after ($37.86 \pm 0.12^{\circ}\text{C}$) the onset of estrus. When onset of estrus occurred between 0900 and 1600 h, RuT was greater during the 9 h after the onset of estrus ($P < 0.03$; $38.79 \pm 0.22^{\circ}\text{C}$) compared with 16 to 24 h before ($37.84 \pm 0.20^{\circ}\text{C}$) and 24 to 32 h after ($38.09 \pm 0.23^{\circ}\text{C}$) the onset of estrus. The 9 h mean RuT after onset of estrus was greater ($P < 0.01$; $38.86 \pm 0.19^{\circ}\text{C}$) compared with 16 to 24 h before

($38.04 \pm 0.19^{\circ}\text{C}$) and 24 to 32 h after ($37.88 \pm 0.23^{\circ}\text{C}$) the onset of estrus when onset occurred during 1700 to 0000 h. When onset of estrus occurred between 0900 and 1600 h and 1700 to 0000 h, RuT tended to be greater ($P < 0.10$) in the 9 h after the onset of estrus compared with when onset occurred between 0100 to 0800 h. There was no difference ($P > 0.77$) between mean RuT in the 9 h after the onset of estrus at 1700 to 0000 h compared with when onset occurred at 0900 to 1600 h.

Ruminal temperature in the 9 h after the onset of estrus was not affected ($P = 0.12$, Figure 9) by daily Tmax on the day of onset. Mean (9 h) RuT was greater ($P < 0.001$; $38.63 \pm 0.09^{\circ}\text{C}$) after estrus compared with 16 to 24 h before ($37.93 \pm 0.09^{\circ}\text{C}$) and 24 to 32 h after ($37.89 \pm 0.10^{\circ}\text{C}$) onset when Tmax was $< 32^{\circ}\text{C}$. Ruminal temperature during the 9 h after the onset of estrus did not differ ($P > 0.40$; $38.22 \pm 0.34^{\circ}\text{C}$) from the same daily hours the day before (16 to 24 h, $37.80 \pm 0.34^{\circ}\text{C}$) or after (24 to 32 h, $38.10 \pm 0.38^{\circ}\text{C}$) the onset of estrus when Tmax was $\geq 32^{\circ}\text{C}$. During the experiment, 1 of 13 d had daily Tmax $\geq 32^{\circ}\text{C}$.

Increases in RuT of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, and $\geq 0.7^{\circ}\text{C}$ for any 9 h period, compared with the mean RuT from 12 to 84 h before the 9 h period, correctly identified 92%, 87% and 79% of estrus cows during the 72 h before and after then onset of estrus (Table 3). Correct identification of estrus cows by RuT did not differ between RuT increase thresholds ($P > 0.10$; $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$ and $\geq 0.7^{\circ}\text{C}$). The number of non estrus cows identified as estrus was influenced ($P < 0.05$) by the magnitude of increase in RuT for a 9 h period compared with the preceding 12 to 84 h. A 9 h mean RuT increase of $\geq 0.3^{\circ}\text{C}$, compared with the mean from the preceding 12 to 84 h, identified the maximum number of non estrus cows as estrous (95 %), with the minimum number of non estrus cows identified by a $\geq 0.7^{\circ}\text{C}$ RuT increase (40 %), and a $\geq 0.5^{\circ}\text{C}$ RuT increase falsely

identifying 75 % of non estrus cows. An increase of $\geq 0.7^{\circ}\text{C}$ in RuT compared with the pre estrus mean commenced at 8.4 ± 6.1 h after the onset of estrus as determined by HeatWatch. Onset of estrus was predicted by RuT in 16 of the 20 cows not identified as estrous by HeatWatch. Three pregnancies resulted from cows AI based on RuT without a HeatWatch determined onset of estrus. Pregnancy rate of cows inseminated based on RuT averaged 37%. Daily Tmax of $\geq 32^{\circ}\text{C}$ on the day of onset of estrus, or in the 3 d before onset of estrus did not influence ($P = 0.57$; Table 3) pregnancy rate of cows bred by a RuT increase of $\geq 0.7^{\circ}\text{C}$, compared with when daily Tmax were $< 32^{\circ}\text{C}$.

Ruminal temperature boluses recorded 12,358 RuT values for 58 cows. Mean daily RuT recordings per cow was 19.3 ± 0.3 and ranged from 0 to 24 records per cow per day. During the experiment, 46% of days for cows had 24 records per cow per day and 12 hourly readings per cow occurred in 88% of cows. Ruminal temperature was not obtained during a 24 h period for a cow in 3% of evaluated days.

DISCUSSION

Body temperature of cows increases at estrus. Ruminal temperature increased during the 9 h after the onset of estrus compared with the 16 to 24 h before and 24 to 32 h after the onset in these experiments. The magnitude of increase in RuT in these experiments was similar to increases observed by Bailey et al. (2009) and Cooper-Prado et al. (2011) during the 8 h after the onset set of estrus, compared with the same daily hours the day before and day after onset of estrus in beef cows. Ruminal temperature increased $\geq 0.7^{\circ}\text{C}$ for 9 h approximately 7 h after the onset of estrus (Boehmer and Wettman, 2012). Rectal temperature increased 1.3°C on the day of onset of estrus (Piccione et al., 2003) and vaginal temperature increases 0.44 to 1.0°C in

estrous cows (Mosher et al., 1990; Kyle et al., 1998; Fisher et al., 2008). Increased vaginal temperature at estrus and the LH surge were positively correlated (Rajamahendran et al., 1989) and the interval between the vaginal temperature increase and LH surge was less variable than relationships during estradiol and progesterone (Clapper et al., 1990). Vaginal temperature increased at the onset of estrus and remained elevated for 6.5 to 11 h (Mosher et al., 1990; Redden et al., 1993; Kyle et al., 1998). Ruminal temperature during the 9 h after the onset of estrus in Exp. 4 tended to be influenced by time of day. Increasing RuT throughout the day is probably due to additional heat load from greater ambient temperatures in Exp. 4, and the effect was not observed in Exp. 5 when Tamb were less. Increased mean RuT during the 9 h after the onset of estrus, compared with the same daily hours the day before and the day after the onset of estrus occurred during all daily periods except when estrus was initiated during 0900 to 1600 h in Exp. 4. This difference may be related to exposure of cows to elevated ambient temperatures in this experiment. These results indicate that increases in RuT associated with estrus occur throughout the day; however, additional study is needed to determine the influence of diurnal variation and Tamb on RuT.

Diurnal variation in RuT occurred with the nadir at 1200 and 1400 h and maximal RuT occurring at 1800 and 2200 h in Exp. 4 and 5, respectively. A nychthermal pattern in body temperature of beef cows has been documented with temperature decreasing in early morning and increasing throughout the afternoon (Bitman et al., 1984; Hahn et al., 1990; Beatty et al., 2006). Increased in core body temperature of cows usually occurs 2 to 5 h after exposure to elevated Tamb (Hahn, 1999). Differences in Tamb between Exp. 4 and 2 probably contributed to the greater maximum RuT in Exp. 4. Nychthermal pattern of body temperature was maintained when

beef heifers were exposed to thermal stress (Beatty et al., 2006). Elevated Tamb increased mean body temperature of beef heifers, but in contrast to these experiments, the magnitude of variation between maximal and minimal body temperature was not affected (Al-Haidary et al., 2001). Daily change in vaginal temperature of dairy cows averaged 0.48°C when Tamb ranged from 0 to 20°C (Fisher et al., 2008). The greater magnitude in diurnal variation in RuT in the current experiments is probably due to greater Tamb.

Body temperature is influenced by feed and water consumption, endocrine secretions, immunological responses and environmental conditions. Ruminal temperature is greater in beef steers following an immune challenge (Rose-Dye et al., 2011). No immunizations were given in the current experiment and no cows were treated for illness. Consumption of water decreases RuT (Bewley et al., 2008b; Boehmer et al., 2009). Water consumption is decreased at estrus (Lukas et al., 2008) and RuT is increased in fasting cows (Dale et al., 1954). Compared with a high fiber diet, consumption of a low fiber diet increased rectal temperatures (Arieli et al., 2004). The consumption of feed and water may contribute to variation in RuT and require further investigation.

Body temperature of cows may be influenced by plasma concentrations of estradiol and progesterone (Wrenn et al., 1958). Maximum concentrations of estradiol during the estrous cycle occur at estrus (Wettemann et al., 1972) and concentrations of progesterone are minimal at estrus (Swanson et al., 1972; Wettemann et al., 1972; Hendricks, 1976). Estradiol (Mosher et al., 1990) concentrations at estrus are positively related to increases in body temperature. A relationship between increased body temperature and progesterone has not been established.

Ruminal temperature (Cooper-Prado et al., 2011), vaginal temperature (Kyle et al., 1998), and rectal temperature (Piccione et al., 2003) were not influenced by Tamb not associated with heat stress. In contrast to the current experiments during which daily Tamb regularly exceeded 32°C, previous experiments were mostly conducted under thermoneutral conditions. The increase in RuT during the 9 h after the onset of estrus was greatest when daily Tmax was \geq 32°C in Exp. 4. The magnitude of the increase in RuT may be greater when cows are exposed to elevated Tamb. Daily Tmax was \geq 32°C on 16 of 29 d during Exp. 4. Increases in RuT at estrus on days when maximal temperatures were cooler may have been reduced by an elevation in RuT during the days before and after the onset. Only 1 d during Exp. 5 had a daily Tmax of \geq 32°C. A minimal sample size, or a greater heat dissipation response, may have contributed to the lessor RuT at estrus when onset occurred on a hot day in Exp. 5. Greater daytime body temperatures occur in beef cows that fail to dissipate heat load during overnight cooling (Mader et al., 2010).

Physiological predictors of estrous may be more effective than behavioral indicators. Standing estrus, as determined by visual observation is positively correlated with increased vaginal temperature at estrus (Rajamahendran et al., 1989). Vaginal temperature predicted estrous in cows that displayed reduced or no mounting behavior and pregnancy occurred after AI based on increases in VT (Kyle et al., 1998). In the current experiments, some estrous cows that were identified by increased RuT, but not HeatWatch, became pregnant after AI. Body temperature at estrus may be influenced less by environmental, social, and management factors compared with animal behavior.

Models and algorithms for the identification and prediction of estrus based on increased body temperature have been developed for vaginal temperature (Redden et al., 1993; Kyle et al.,

1998; Fisher et al., 2008) and RuT (Bailey et al., 2009; Cooper-Prado et al., 2011) . Efficacy of temperature based estrous detection models are affected by the frequency of temperature data, periods used to determine increases in body temperature, and Tamb. Kyle et al., (1998) suggested that greater pre-estrus baselines and greater identification periods (≥ 4 h) may reduce the number of cows incorrectly identified as estrus without negatively affecting correct identification. Increases in vaginal temperature of $\geq 0.3^{\circ}\text{C}$ (Redden et al., 1993) and $\geq 0.4^{\circ}\text{C}$ (Kyle et al., 1998) correctly identified 81% and 88% of estruses, respectively. A RuT increase of $\geq 0.7^{\circ}\text{C}$ correctly identified 100% of estruses in one experiment and 42% of estruses in another (Bailey et al., 2009). Sinusoidal translation of vaginal temperature data eliminated the effect of diurnal variation (Fisher et al., 2008). Algorithms for analysis of vaginal temperature detected 81% of estrous cows, and estrus occurred within 12 h of the LH surge, allowing sufficient time for AI (Fisher et al., 2008)

8SUMMARY AND CONCLUSIONS

Ruminal temperature of beef cows is increased at the onset of estrus and these increases can be used to identify the onset of estrus. The efficacy of RuT for the prediction of estrus may be limited by diurnal variation in RuT and elevated Tamb. Ruminal temperature boluses allow for frequent, real time collection of data, are non invasive, and require minimal labor. Further studies on the influence of elevated ambient temperature, and diurnal variation in ruminal temperature, are needed to develop the application of RuT as an estrous detection system.

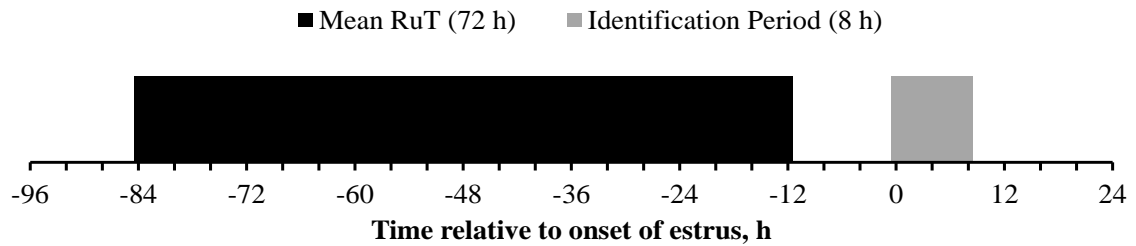


Figure 1. Prediction of estrus by ruminal temperature (RuT) was determined by an increase in mean RuT for any 9 h period (grey box) of 0.3°C, 0.5°C, or 0.7°C compared with the mean RuT that occurred 12 to 84 h prior to the 9 h identification period (black box). The 72 h mean RuT period and 9 h identification period included a minimum of 12 and 4 RuT values, respectively.

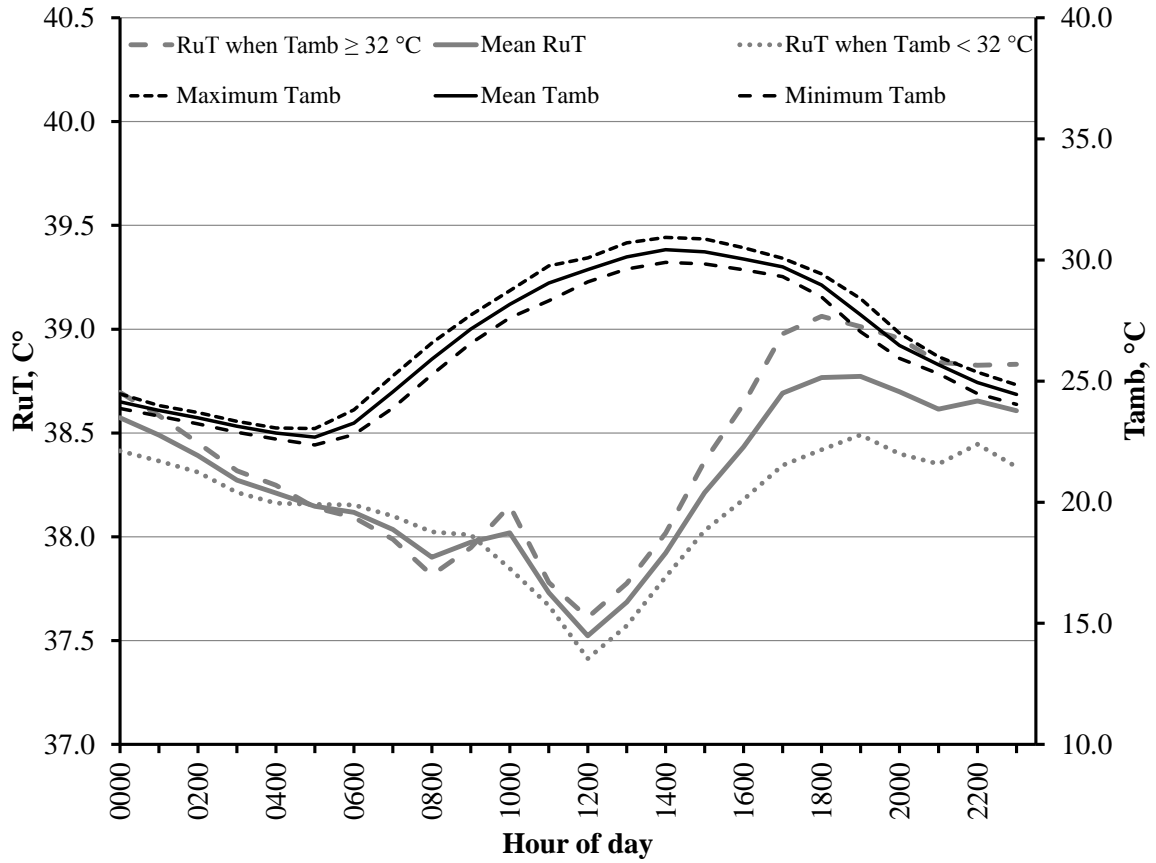


Figure 2. Diurnal variation in ambient temperature (Tamb) and ruminal temperature (RuT) of beef cows (n = 60) in Exp. 4. Solid grey line includes all RuT values, broken grey line excludes RuT values when daily maximum ambient temperature (Tmax) < 32°C (heat stress), dotted grey line excludes RuT values when daily Tmax ≥ 32°C (no heat stress). Solid black line is hourly mean Tamb, broken black lines are maximum and minimum Tamb, respectively. SE for all RuT over hour x cow averaged 0.12. SE for RuT when daily Tmax < 32°C, over hour x cow averaged 0.10. SE for RuT when daily Tmax ≥ 32°C, over hour*cow averaged 0.10.

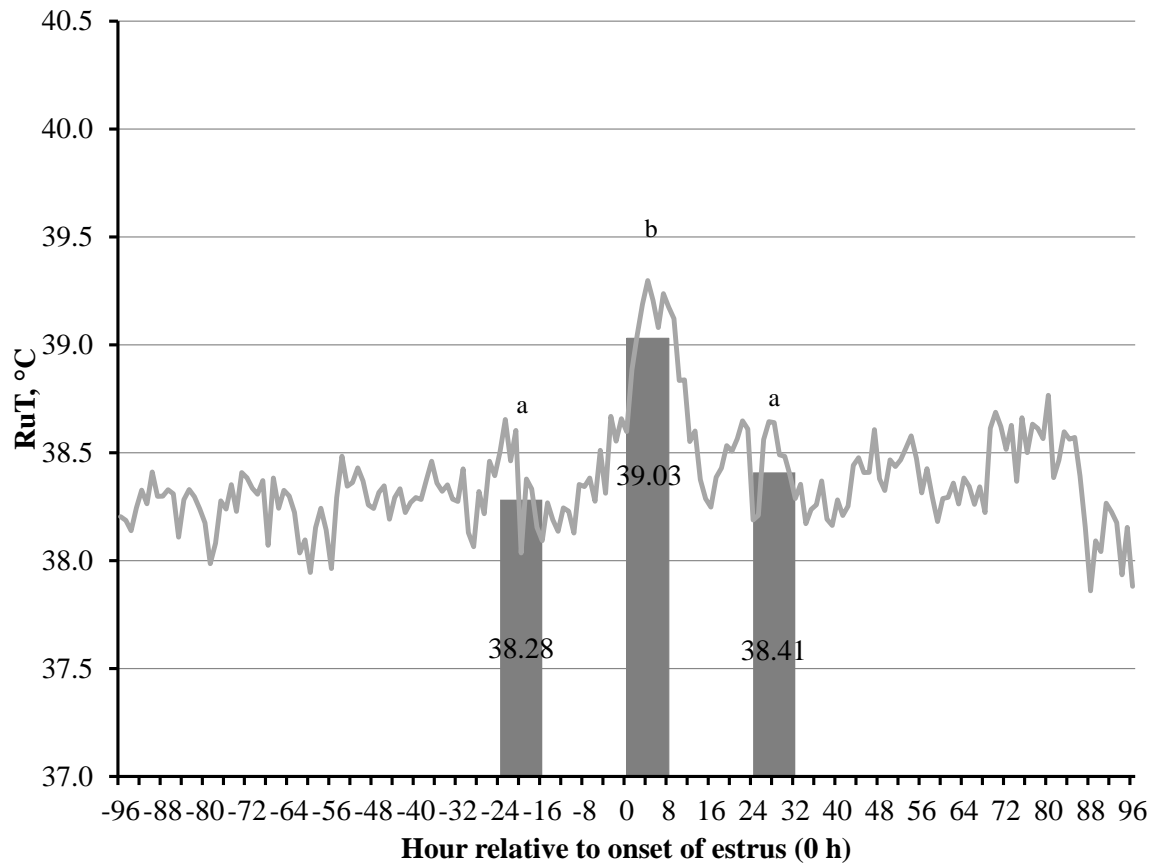


Figure 3. Mean ruminal temperature (RuT) relative to the onset of synchronized estrus (0 h) in beef cows (n = 42) in Exp. 4. ¹ Onset of estrus was determined by HeatWatch. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus. Mean hourly maximum ambient temperature was $27.2 \pm 0.1^{\circ}\text{C}$. ^{a, b} Means without a common superscript differ ($P < 0.001$).

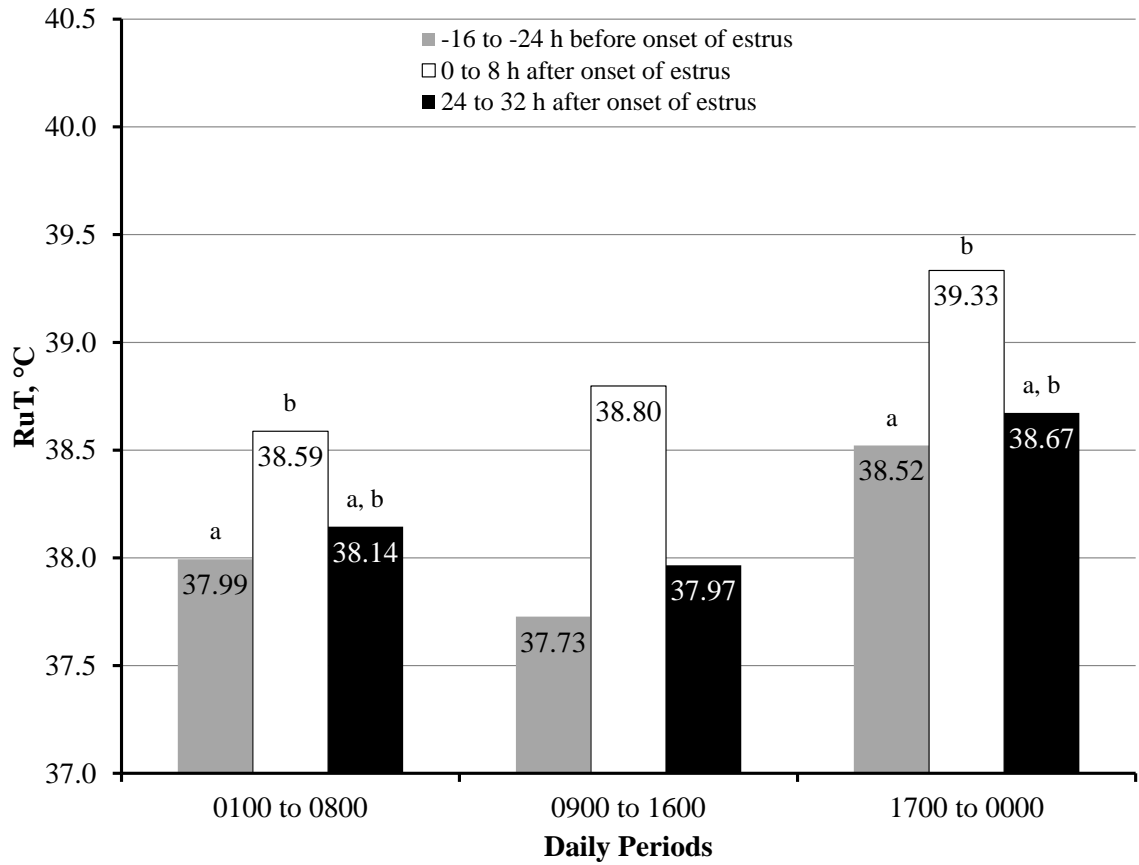


Figure 4. Effect of time of day and time relative to onset of synchronized estrus¹ (0 h) on ruminal temperature (RuT) of beef cows in Exp. 4. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus during daily periods of 0100 to 0800h (n = 12; SE = 0.24), 0900 to 1600 h (n = 8; SE = 0.42), and 1700 to 0000 h (n = 22; SE = 0.27), respectively. Daily maximum ambient temperature (Tmax) ranged from 23 to 35°C; 16 of 29 d during the experiment had Tmax ≥ 32°C. Onset of estrus was determined by HeatWatch. ^{a, b} Means within period without a common superscript differ ($P < 0.05$).

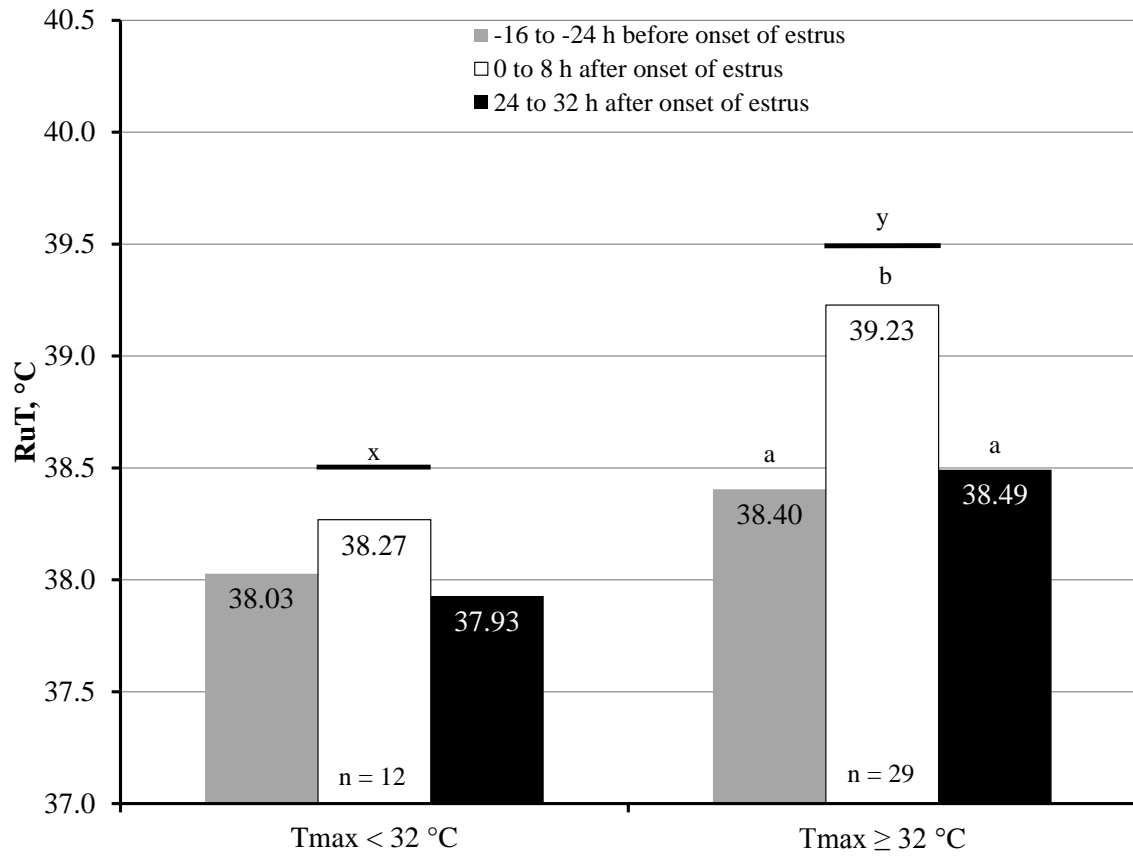


Figure 5. Effect of time relative to onset of estrus (0 h) and daily maximum ambient temperatures (T_{max}) of $< 32^{\circ}\text{C}$ or $\geq 32^{\circ}\text{C}$ on ruminal temperature (RuT) in beef cows ($n = 41$) in Exp. 4. Onset of estrus determined by HeatWatch. ^{a, b} Means within period without a common superscript differ ($P < 0.001$). ^{x, y} Means at estrus across period without a common superscript differ ($P < 0.004$).

Table 1. Prediction of estrus in beef cows using increases in mean ruminal temperature (RuT) of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, or $\geq 0.7^{\circ}\text{C}$ for any 9 h period compared with a mean RuT from 12 to 84 h before the 9 h period in Exp. 4¹.

	RuT increase		
	$\geq 0.3^{\circ}\text{C}$	$\geq 0.5^{\circ}\text{C}$	$\geq 0.7^{\circ}\text{C}$
No. of cows	41	41	41
-72 h before to 72 h after onset of estrus ²			
RuT increase correctly identified estrus, %	66%	66%	61%
RuT increase identified estrus in a non estrous cow ³ , %	98% ^a	81% ^b	73% ^b

¹ Daily maximum ambient temperature (Tmax) ranged from 23 to 35°C; 16 of 29 d during experiment had Tmax $\geq 32^{\circ}\text{C}$

² Onset of estrus was determined by HeatWatch.

³ Identification of non estrus as estrus cows excluded the 24 h period after cows were identified as estrus.

^{a, b} Means within row without a common superscript differ ($P < 0.05$).

Table 2. Pregnancy rate of cows AI¹ following estrous prediction by a ruminal temperature (RuT) increase of $\geq 0.7^{\circ}\text{C}$ for any 9 h period compared with the mean RuT that occurred 12 to 84 h prior to the 9 h identification period on days with maximum ambient temperature (Tmax) $< 32^{\circ}\text{C}$ or $\geq 32^{\circ}\text{C}$.

	Daily Tmax		P-value
	$< 32^{\circ}\text{C}$	$\geq 32^{\circ}\text{C}$	
Exp. 4 ²			
No. of cows	17	41	0.46
Pregnant, %	47%	37%	
Exp. 5 ³			
No. of cows	44	6	0.57
Pregnant, %	46%	33 %	

¹ Cows were AI 8 to 16 h after onset of estrus as determined by RuT.

² Daily Tmax ranged from 23 to 35°C; 16 of 29 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

³ Daily Tmax ranged from 16 to 33°C; 1 of 13 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

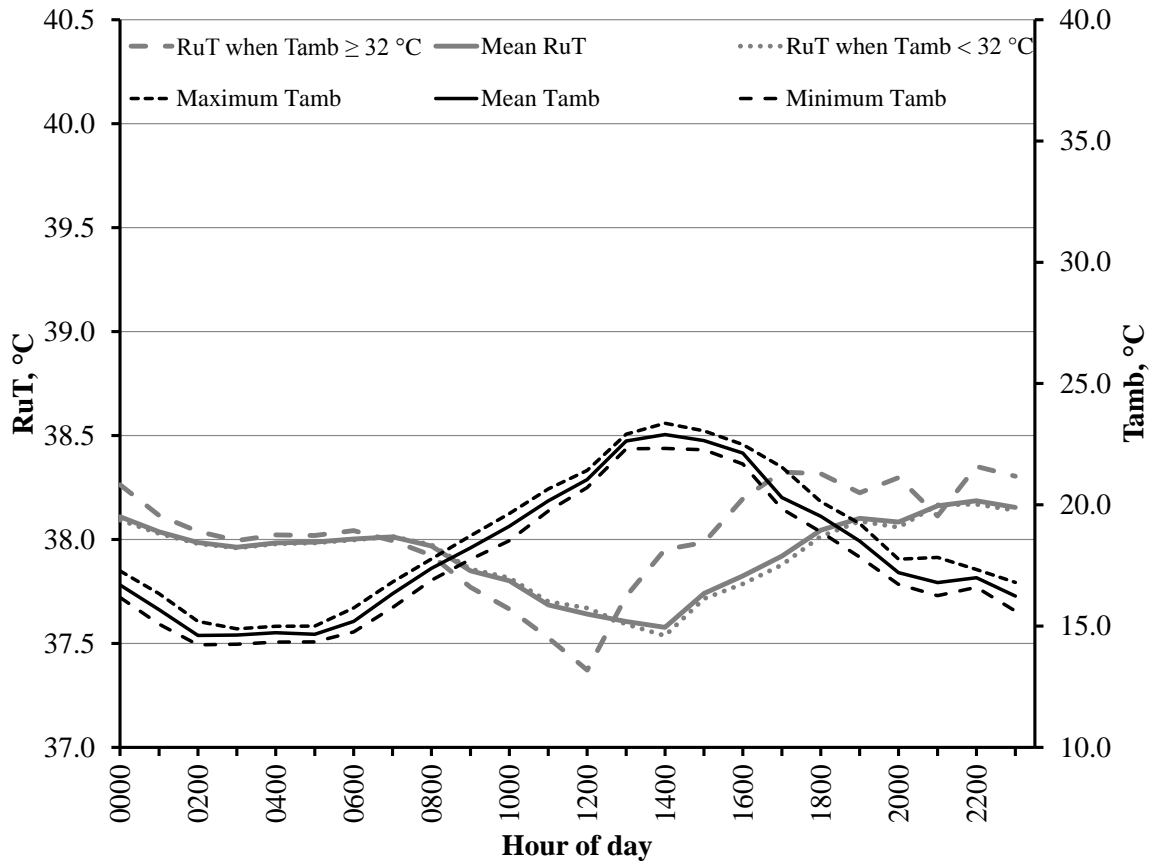


Figure 6. Diurnal variation in ambient temperature (Tamb) and ruminal temperature (RuT) of beef cows (n = 58) in Exp. 5. Solid grey line includes all RuT values, broken grey line excludes RuT values when daily maximum ambient temperature (Tmax) < 32°C (heat stress), dotted grey line excludes RuT values when daily Tmax ≥ 32°C (no heat stress). Solid black line is hourly mean Tamb, broken black lines are maximum and minimum Tamb, respectively. SE for all RuT over hour x cow averaged 0.10. SE for RuT when daily Tmax < 32°C, over hour x cow averaged 0.09. SE for RuT when daily Tmax ≥ 32°C, over hour x cow averaged 0.09.

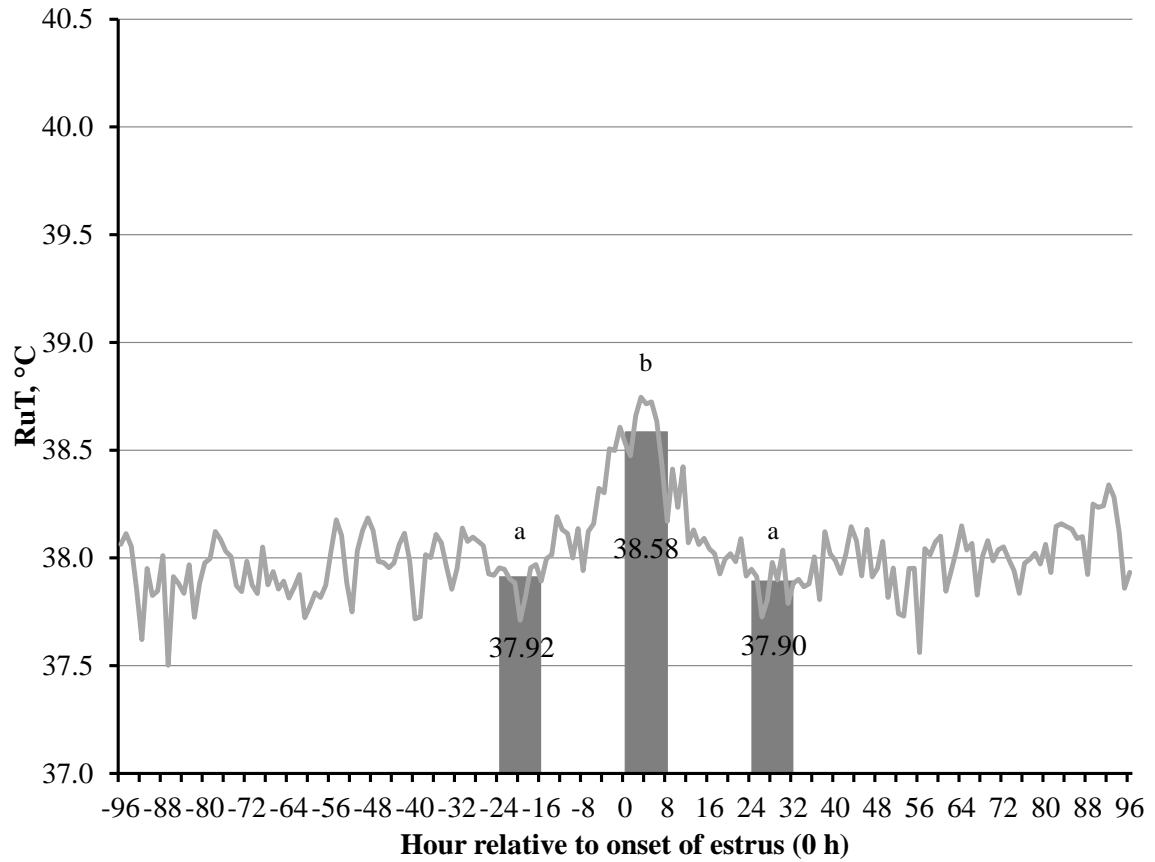


Figure 7. Mean ruminal temperature (RuT) relative to the onset of synchronized estrus (0 h) in beef cows ($n = 38$) in Exp. 5. Onset of estrus was determined by HeatWatch. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus. Mean hourly maximum ambient temperature was $22 \pm 1^\circ\text{C}$. ^{a,b} Means without a common superscript differ ($P < 0.001$).

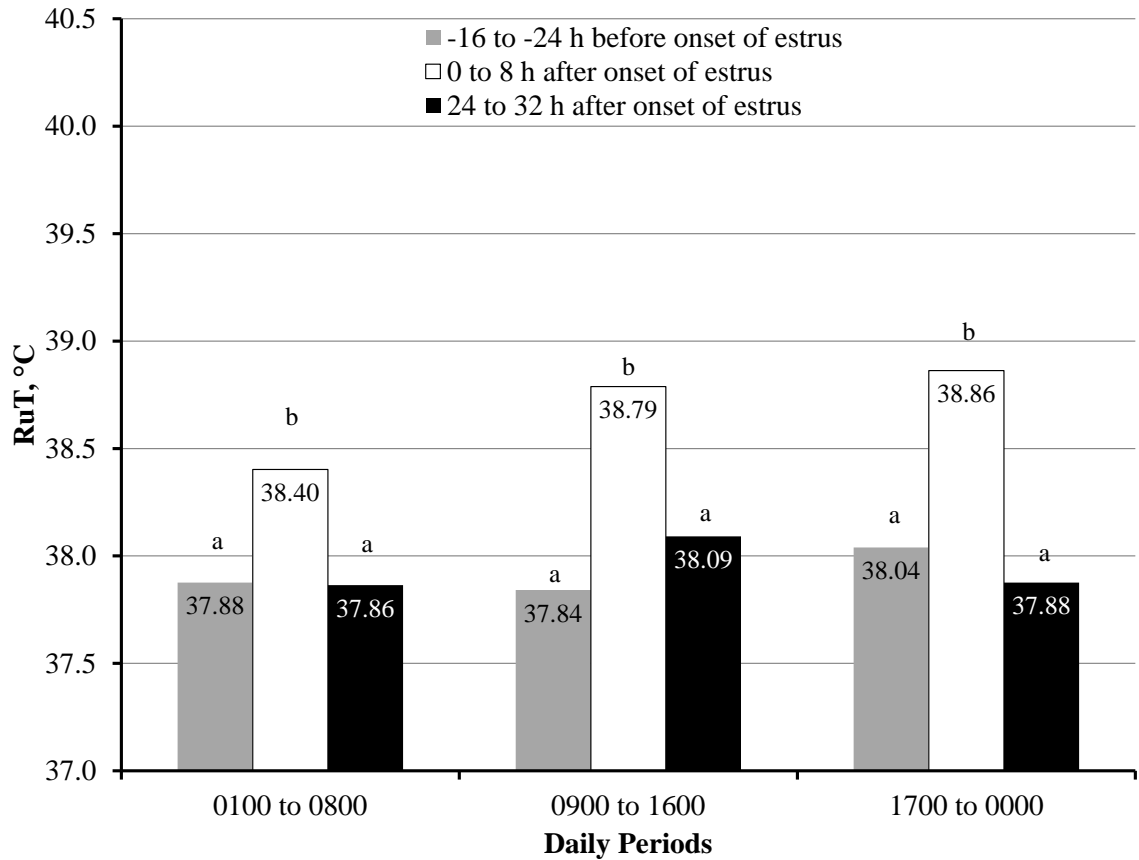


Figure 8. Effect of time of day and time relative to onset of synchronized estrus¹ (0 h) on ruminal temperature (RuT) of beef cows in Exp. 5. Bars represent mean RuT for 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 32 h after onset of estrus during daily periods of 0100 to 0800 h (n = 19; SE = 0.24), 0900 to 1600 h (n = 12; SE = 0.42), and 1700 to 0000 h (n = 7; SE = 0.0.26), respectively. Daily maximum ambient temperature (Tmax) ranged from 16 to 33°C; 1 of 13 d during the experiment had Tmax ≥ 32°C. Onset of estrus was determined by HeatWatch. ^{a, b} Means within period without a common superscript differ ($P < 0.05$).

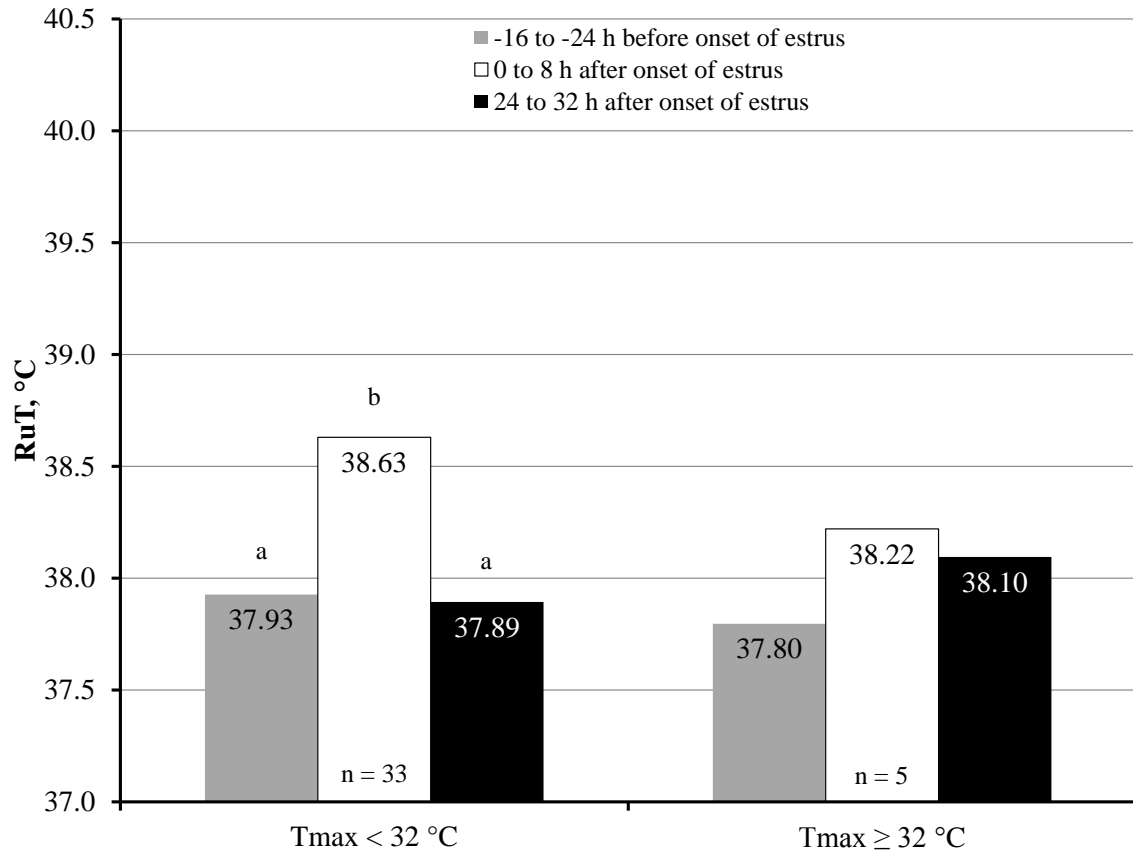


Figure 9. Effect of time relative to onset of estrus (0 h) and daily maximum ambient temperatures (T_{max}) of $< 32^{\circ}\text{C}$ or $\geq 32^{\circ}\text{C}$ on ruminal temperature (RuT) in beef cows ($n = 38$) in Exp. 5. Onset of estrus determined by HeatWatch. ^{a, b} Means within period without a common superscript differ ($P < 0.001$).

Table 3. Prediction of estrus in beef cows using increases in mean ruminal temperature (RuT) of $\geq 0.3^{\circ}\text{C}$, $\geq 0.5^{\circ}\text{C}$, or $\geq 0.7^{\circ}\text{C}$ for any 9 h period compared with a mean RuT from 12 to 84 h before the 9 h period in Exp. 5¹.

	RuT increase		
	$\geq 0.3^{\circ}\text{C}$	$\geq 0.5^{\circ}\text{C}$	$\geq 0.7^{\circ}\text{C}$
No. of cows	40	40	40
-72 h before to 72 h after onset of estrus ²			
RuT increase correctly identified estrus, %	92%	87%	79%
RuT increase identified estrus in a non estrous cow ³ , %	95% ^a	75% ^b	40% ^c

¹ Daily maximum ambient temperature (Tmax) ranged from 16 to 33°C; 1 of 13 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

² Onset of estrus was determined by HeatWatch.

³ Identification of non estrus as estrus cows excluded the 24 h period after cows were identified as estrus.

^{a, b, c} Means within row without a common superscript differ ($P < 0.05$).

Table 3. Pregnancy rate of cows AI¹ following estrous prediction by a ruminal temperature (RuT) increase of $\geq 0.7^{\circ}\text{C}$ for any 9 h period compared with the mean RuT that occurred 12 to 84 h prior to the 9 h identification period on days with maximum ambient temperature (Tmax) $< 32^{\circ}\text{C}$ or $\geq 32^{\circ}\text{C}$.

	Daily Tmax		P-value
	$< 32^{\circ}\text{C}$	$\geq 32^{\circ}\text{C}$	
Exp. 4 ²			
Cows, no.	17	41	0.46
Pregnant, %	47%	37%	
Exp. 5 ³			
Cows, no.	44	6	0.57
Pregnant, %	46%	33 %	

¹ Cows were AI 8 to 16 h after onset of estrus as determined by RuT.

² Daily Tmax ranged from 23 to 35°C; 16 of 29 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

³ Daily Tmax ranged from 16 to 33°C; 1 of 13 d during experiment had Tmax $\geq 32^{\circ}\text{C}$.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Changes in ruminal temperature (RuT) associated with estrus were evaluated in mature, postpartum, Angus cows. Cows were administered boluses programmed to transmit RuT each hour and estrous cycles were synchronized. The onset of estrus was determined using HeatWatch. Estrus was identified as an increase in RuT of 0.7°C during 9 h compared with a mean RuT 12 to 84 h before the 9 h period. Ruminal temperature was greater ($P < 0.02$) in the 9 h after the onset of synchronized estrus compared with 16 to 24 h before and 24 to 32 h after the onset. During the subsequent, natural estrus RuT was greater ($P < 0.04$) compared with the same hours the day before and day after onset of estrus. An increase in RuT of $\geq 0.7^{\circ}\text{C}$ occurred 5 h before to 12 h after the onset of estrus. Ruminal temperature increased $\geq 0.7^{\circ}\text{C}$ at estrus in ≥ 75 % of cows, compared with the preceding 12 to 84 h and 50 % or fewer non estrus cows were identified as estrus.

The effect of ambient temperature on RuT of beef cows was evaluated in mature, Angus cows. Cows were administered boluses programmed to transmit RuT each hour. Ambient temperature was recorded every 5 min and maximum (T_{max}), mean, and minimum temperature was calculated each hour. Temperature humidity index (THI) was calculated each hour. Mean daily T_{max} was $20 \pm 1^{\circ}\text{C}$ in January (hourly range: 2 to 20°C), $33 \pm 1^{\circ}\text{C}$ in June (hourly range: 20 to 34°C), and $32 \pm 2^{\circ}\text{C}$ in August (hourly range: 12 to 37°C). Ruminal temperature was

greater ($P < 0.001$) when daily Tmax ranged from 34 to 36°C compared with when daily Tmax was 33°C or less. When maximum daily THI was 87 to 89, RuT was greater ($P < 0.001$) compared with when THI was 86 or less. Ruminal temperature, rectal temperature, and respiration rate were greater during a day when hourly Tmax was 37°C (HOT) compared with the next sequential day when hourly Tmax was 28°C (WARM). Ruminal temperature was positively correlated with rectal temperature, respiration rate, Tmax, and THI.

Postpartum, lactating, Angus cows were used to evaluate changes in RuT for the prediction of estrus in beef cows. Estrous cycles of cows were synchronized and cows were administered boluses programmed to transmit RuT each hour. Estrus was predicted using an increase in RuT of 0.7°C or greater for 9 h compared with a pre estrus mean RuT during the preceding 12 to 84 h. The onset of estrus was also detected by HeatWatch. Ambient temperature was recorded every hour. Ruminal temperature was greater ($P < 0.001$) during the 9 h after the onset of estrus compared with 16 to 24 h before and 24 to 23 h after the onset of estrus. Mean 9 h RuT was increased ($P < 0.05$) after estrus compared with the same daily hours the day before and day after onset of estrus when onset occurred in the morning and daily Tmax averaged 31.4°C. Increased RuT ($P < 0.05$; 9 h) compared with the same daily hours the day before and day after estrus, occurred during all daily periods when mean daily Tmax was 24.8°C. Daily Tmax affected the RuT increase during the 9 h after the onset of estrus compared with the 16 to 24 h before and 24 to 32 h after the onset of estrus. When daily Tmax was 32°C or greater, RuT during the 9 h after onset was greater ($P < 0.001$) compared with when daily Tmax was less than 32°C. An increase in RuT of 0.7°C or greater for 9 h, compared with a pre estrus mean occurring from 12 to 84 before the 9 h period, correctly predicted 61% and 79% of estrous cows. Identification of a non estrous cow as estrus by a RuT increase of 0.7°C or greater, compared with the preceding 12 to 84 h, occurred in 73% and 40% of cows. Pregnancy rate of cows AI

based on RuT increases of 0.7°C or greater, compared with the preceding 12 to 84 h, was 40% or greater and was not influenced by daily Tmax.

In conclusion, RuT increases in beef cows at estrus. The use of radiotelemetric boluses for measuring RuT is non invasive, requires minimal labor and time, and allows for the frequent, real time collection of data from cows in their natural environment. The efficacy of RuT for the identification and prediction of estrus and timing of AI may be influenced by diurnal variation in RuT and Tamb. Ruminant temperature is positively related to rectal temperature and respiration rate in beef cows. Timing of AI was predicted by RuT and resulted in pregnancy. This study indicates that use of RuT has potential for estrous detection in cattle. Estrous detection systems can enhance the effectiveness of AI. Opportunities exist within the cow calf segment of the beef industry to enhance genetic merit of progeny and profitability of a cowherd by AI cows to genetically superior bulls.

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VITA

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Thesis: USE OF RUMINAL TEMPERATURE FOR IDENTIFICATION AND PREDICTION
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Candidate for the Degree of Master of Science

Major Field: Animal Science

Scope and Method of Study: Postpartum, Angus cows were used to evaluate changes in ruminal temperature (RuT) for the identification and prediction of estrus. Cows were administered RuT transmitting boluses and synchronized with PGF_{2α}. Ruminal temperature and ambient temperature were recorded hourly. The onset of estrus was determined by HeatWatch. Estrus was determined as a RuT increase of $\geq 0.7^{\circ}\text{C}$ for a 9 h period compared with the mean RuT during the 12 to 84 h before the start of the 9 h period. Cows predicted as estrous based on RuT were AI to Angus bulls, 8 to 16 h after the first hour of the 9 h period in which RuT increased $\geq 0.7^{\circ}\text{C}$. Ruminal temperature was evaluated during the 16 to 24 before and 24 to 32 h after the onset of estrus. The effect of ambient temperature (Tamb) on RuT was evaluated in postpartum, Angus cows. Cows were exposed to Tamb ranging from 12 to 37°C. Relationships among RuT, maximal Tamb (Tmax) and temperature humidity index (THI) were evaluated during 8 d in January, June, and August. Relationships between rectal temperature (RT), respiration rate (RR), Tmax, THI, and RuT were evaluated on two sequential days in August when Tmax was 37°C (HOT) and 28°C (WARM).

Findings and Conclusions: Ruminal temperature was greater during the 9 h after the onset of estrus compared with the 16 to 24 h before and 24 to 32 h after the onset of estrus. Increased RuT at estrus occurred when onset of estrus was at 0100 to 0800, 0900 to 1600, 1700 to 0000 h. Time of day influenced RuT in the 9 h after the onset of estrus. Daily Tmax of $\geq 32^{\circ}\text{C}$ increased the magnitude of diurnal variation in RuT and influenced RuT at estrus compared with when ambient temperature was $< 32^{\circ}\text{C}$. Correct identification of estrous cows by a RuT increase of $\geq 0.7^{\circ}\text{C}$ occurred in 61% to 93% of cows. Non estrous cows were identified as estrus by a RuT increase of $\geq 0.7^{\circ}\text{C}$ in 16 to 73 % of cows. Pregnancy rate of cows AI based on RuT was 40% or greater and was not influenced by daily Tmax. When cows were exposed to Tmax $\geq 34^{\circ}\text{C}$ or THI ≥ 87 , RuT was increased compared with Tmax $< 34^{\circ}\text{C}$ or THI < 87 , respectively. Ruminal temperature, RT, and RR were greater on the HOT day compared with the WARM day. Ruminal temperature was positively correlated with RT, RR, Tmax, and THI. These results indicate that the use of RuT has potential for estrous detection in cattle. Estrous detections systems that utilize changes in physiology are less subjective than visual observation of estrous behavior, require less time, and labor expense. A RuT based estrous detection system may increase the use of AI in the cow-calf industry. Insemination of cows to genetically superior bulls provides producers the opportunity to decrease the calving interval, increase the number and weight of calves, and enhance the profitability of a cowherd.

ADVISER'S APPROVAL: Dr. Robert P. Wettemann
