Effects of providing artificial shade to pregnant grazing beef heifers on vaginal temperature, growth, activity, and behavior

Gleise M. Silva,[†] Lautaro R. Cangiano,[†] Thiago F. Fabris,[‡] Victoria R. Merenda,[‖] Ricardo C. Chebel,[‡] Jose Carlos Batista Dubeux Jr.,[†] Nicolas DiLorenzo,[†,◉] and Jimena Laporta[$,1]

[†]North Florida Research and Education Center, University of Florida, Marianna, FL 32446, USA; [‡]Department of Animal Sciences, University of Florida, Gainesville, FL 32608, USA; [‖]College of Veterinary Medicine, University of Florida, Gainesville, FL 32608, USA; and [$]Department of Animal and Dairy Sciences, University of Wisconsin-Madison, Madison, WI 53706, USA

ABSTRACT: This experiment evaluated the effects of providing artificial shade during summer on activity, behavior, and growth performance of pregnant grazing beef heifers. Thirty-six black-hided Angus and Angus crossbred pregnant heifers [418 ± 9 kg body weight (BW); approximately 90 d of gestation] were stratified by breed, blocked by BW, and allocated to 12 "Pensacola" bahiagrass pastures (*Paspalum notatum* Flüggé; 1.3 ha, $n = 3$ heifers/pasture) with or without access to artificial shade (SHADE vs. NO SHADE; 6 pastures each) for 7 wk during summer. The shade structures were composed of shade cloth (11 × 7.3 m length, 2.4 m height: 26.8 m^2 of shade per heifer). Shrunk BW was recorded on enrollment (day 0) and week 7 (day 47), whereas full BW was obtained on week 2 (day 14), 4 (day 28), and 6 (day 42) to assess average daily gain (ADG). Vaginal temperature was recorded for five consecutive days during weeks 1, 3, 5, and 7 using an intravaginal digital thermo-logger, and individual GPS devices were used to quantify the use of shade for an 8-h period. Activity was monitored using automated monitoring devices (HR-LDn tags SCR Engineers Ltd., Netanya, Israel) through the experimental period. Vaginal temperature was lower ($P < 0.01$) for heifers in the SHADE compared with heifers in the NO SHADE treatment from 1200 to 1600 h and 1100 to 1900 h for weeks 1 and 3, respectively. Heifers in the SHADE treatment spent 70% of the 8-h period evaluated under the shaded structure. Provision of shade increased ($P < 0.01$) daily lying time (11.4 ± 0.2 vs. 10.3 ± 0.2 h/d) and standing bouts per day ($P < 0.01$; 12.6 ± 0.4 vs. 10.8 ± 0.4 bouts/d), whereas it reduced ($P < 0.01$) standing bout duration (61.6 ± 3.0 vs. 82.9 ± 3.0 min/bout) relative to heifers without access to shade. The interaction between treatment and hour affected ($P < 0.01$) daily rumination time because heifers with access to SHADE had greater rumination between 1000 and 1200 h. Although ADG tended ($P = 0.08$) to be greater for the heifers in the SHADE treatment (0.20 vs. −0.02 kg, respectively), the access to shade did not ($P = 0.79$) affect the final BW. In conclusion, providing artificial shade during summer to pregnant grazing beef heifers was effective in reducing vaginal temperatures and exerted changes in heifer behaviors that translated into slight improvements in growth performance.

Key words: activity, artificial shade, beef heifers, cow-calf, heat abatement, grazing systems, rumination

INTRODUCTION

The term heat stress refers to the effects of climatic conditions on animal physiology or performance (West, 2003). In homeotherm animals, heat stress is observed when the equilibrium between accumulated and dissipated heat is disrupted, and its degree is influenced by intrinsic (i.e., animal) and extrinsic (i.e., climatic) factors. Climatic variables that compromise heat dissipation and trigger heat stress include air temperature, relative humidity, and solar radiation, particularly when associated with low wind speed (Blackshaw and Blackshaw, 1994). Exposure to these environmental factors results in feed intake reductions, behavioral modifications, elevated stress indicators, and impaired animal performance (Hahn, 1999; Brown-Brandl et al., 2003, 2017; Sejian et al., 2018). Mitigating the effects of heat stress could be achieved by physical alteration of the environment (Beede and Collier, 1986), such as protecting cattle from direct solar radiation exposure by providing natural or artificial shade (Rovira and Velazco, 2010). Numerous studies have been conducted on the impact of heat stress in feedlot cattle and have led to the development of practical management tools for heat abatement as the use of artificial shade (Mitlöhner et al., 2001; Brown-Brandl et al., 2005). The use of artificial shade in feedlot cattle improved feed efficiency (Sullivan et al., 2011) and carcass quality (Mitlöhner et al., 2002).

The southeastern United States is characterized by a long, warm summer coupled with high relative humidity, which can impair animal thermoregulation and consequently reduce productivity (West, 2003). Beef cows in the southern United States are 22% of the national cowherd (7.3 million beef cows; USDA 2019) and are at risk of heat stress exposure for extended periods throughout the year. For example, heat stress conditions are observed in 220 d/yr in the state of Florida, followed by Louisiana and Texas (165 d/yr each), and Alabama (140 d/yr; Ferreira et al., 2016). Furthermore, air temperature is predicted to increase between 2.4 and 6.4 °C in the 21st century (Nardone et al., 2010), which will further contribute to impairments in animal well-being and livestock production (Brown-Brandl et al., 2005) if heat abatement strategies are not implemented. When shade is provided, grazing dairy cows modify their behavior to avoid solar radiation by seeking shade (Tucker et al., 2008). The use of artificial shade reduces body temperature and respiration rates in beef feedlot animals and dairy cattle (Brown-Brandl et al., 2005; Collier et al., 2006; Schütz et al., 2010). The use of shade for heat abatement, however, does not consistently translate into performance improvements (Brown-Brandl et al., 2005) as other climatic conditions, such as humidity, cannot be reduced with the provision of shade.

There is limited information on the effects of heat stress in grazing systems, especially in cow-calf operations in the southern United States, as well as on mitigation strategies that could be implemented to improve performance. We hypothesized that pregnant beef heifers on grazing systems during summer would effectively use artificial shade and this would reduce core body temperature and improve growth when compared with heifers without access to shade. Objectives were to evaluate the use of the shaded structures by pregnant heifers and to determine the effects of shade provision on vaginal temperature, behavior, and growth of pregnant beef heifers grazing bahiagrass pastures during summer.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee of the University of Florida (protocol #201709952) approved all procedures for the experiment conducted at the North Florida Research and Education Center (NFREC; Marianna, FL) from July 17 to September 2, 2017.

Experimental Design, Animals, and Treatments

Thirty-six black-hided Angus and Angus crossbred pregnant heifers [418 ± 9 kg initial body weight (BW) and approximately 90 d of gestation] were used in a randomized complete block design. Heifers were stratified by breed and blocked by initial BW and randomly allocated to 12 Pensacola bahiagrass pastures (*Paspalum notatum* Flüggé; 1.3 ha/pasture, *n* = 3 heifers/pasture), with or without access to artificial shade (SHADE vs. NO SHADE; six pastures each). The shade structures were composed of a shade cloth that was 2.4 m high and measured 11 × 7.3 m in length, which provided 26.8 m² of shade per heifer. The daily minimum, maximum, and average temperature–humidity index (THI) during the experimental period were 60, 92, and 76, respectively. The Livestock Weather Safety Index indicates THI equal to or greater than 75 as an alarming condition for cattle. Heifers were exposed to THI equal or greater than 75 for 46 d, which corresponds to

96% of the experimental period. All heifers were offered free-choice access to water.

Environmental Measurements

Air temperature and relative humidity were recorded every 15 min using two Hobo Pro series Temp probes (Onset Computer Corp., Pocasset, MA). Temperature–humidity index was calculated according to Dikmen et al. (2008): THI = (1.8 × T + 32) − [(0.55 − 0.0055 × RH) × (1.8 × T − 26)], where T = air temperature (°C) and RH = relative humidity (%). Probes were centrally located among two pastures and adjacent to the shade structure pole protected from environmental conditions. Environmental conditions, including air temperature, relative humidity, solar radiation, and wind speed, were obtained from the University of Florida Automated Weather Network (FAWN) and are summarized in Table 1.

Table 1. Weekly average, maximum air temperature, relative humidity, solar radiation, and wind speed during weeks 1, 3, 5, and 7 of a 47-d experimental period (July to September) in which pregnant beef heifers were provided or not access to artificial shade (11 × 7.3 m in length and 2.4 m high)

Item[a]	Week of experiment[b]				Average conditions[c]
	1	3	5	7	
Air temperature, °C	27.1	25.5	28.4	25.8	27.3
Max	33.6	31.8	35.4	32.5	34.1
Min	22.6	20.4	23.7	22.1	22.6
Relative humidity, %	86.2	82.2	84.8	87.0	84
Max	92	95	91	93	95
Min	80	72	80	73	72
Solar radiation, w/m²	219.4	197.2	220.5	151.0	204.2
Max	301.1	293.7	243.4	211.1	301.1
Min	134.5	67.3	161.6	101.9	67.3
Wind speed, km/h	4.81	4.92	4.81	6.61	5.28
Max	21.3	17.5	17.8	20.1	19.1
Min	0.02	0.03	0.04	0.02	0.02
THI[d]	80	75	70	77	75

[a]Data from FAWN.

[b]Weeks 1, 3, 5, 7 in which vaginal temperature and HOBOs measurements were obtained.

[c]Average environmental conditions throughout the entire experiment (July 17 to September 2, 2017).

[d]THI = (1.8 × T + 32) − [(0.55 − 0.0055 × RH) × (1.8 × T − 26)], where T = air temperature (°C) and RH = relative humidity (%) as described by Dikmen et al. (2008). Air temperature and relative humidity for THI calculations were recorded every 15 min using Hobo Pro series Temp probes (Onset Computer Corp., Pocasset, MA).

Heifer Data Collection

Individual heifer shrunk BW, after 16 h water and feed withdrawal, was obtained at enrollment (day 0) and on week 7 (day 47). Full BW was recorded in weeks 2 (day 14), 4 (day 28), and 6 (day 42). All heifers were weighed in the morning using a calibrated scale (Tru-Test Datamars XR5000, Canada). Vaginal temperature was recorded (10 min intervals for five consecutive days) during weeks 1, 3, 5, and 7, using temperature probes (i-button DS1921H-F5#; accuracy ± 0.065 °C; Maxim, Irving, TX) placed intravaginally with a hormone-free controlled internal drug release device (Pfizer Animal Health, New York, NY). All temperature probes were tested prior to first use. The vaginal temperature was averaged per hour of the day for weeks 1, 3, 5, and 7 and was analyzed separately.

To estimate the effective use of the shaded structure within each pasture, individual GPS devices (Polar GPS, Cat. # M430) were used to track the location and trajectory of a subset of heifers in the SHADE treatment (n = 10) for an 8-h period during weeks 1, 3, 5 and 7 (from 0900 to 1600 h). The trajectory was tracked using the Google Earth Pro software. Each heifer's path was followed individually, and the position and duration (located under the shaded structure = Y or not = N) within each hour were recorded.

Behavioral Responses

On day 2, relative to enrollment, heifers were fitted with a collar containing an HR-LDn tag (SCR Engineers Ltd., Netanya, Israel) placed in the proximal third of the neck, immediately behind the left ear. The HR-LDn tags are composed of a neck-mounted device consisting of an accelerometer sensor, a processing unit, and wireless communication functionality. Based on the continuous data sensed by the three-axis accelerometer, machine-learning algorithms determine heifer states. Merenda et al. (2019) previously validated the use of HR-LDn tags in beef heifers. Information was processed, stored, and collected using DataFlow II (SCR Engineers Ltd., Netanya, Israel). Time ruminating and activity within 2-h intervals were recorded and, from that, total daily rumination and activity were calculated. Lying time (min/day) and lying bouts (bouts/day) were measured using HOBO Pendant G data loggers (Onset, Bourne, MA). Data loggers were set to collect lying behavior at 30-s intervals (Ledgerwood et al., 2010) and were placed on the

hind leg of the heifer on day 18 relative to enrollment. Lying times, lying bouts, and lying-bout duration were computed for each heifer using a macro in SAS (SAS Institute Inc., Cary, NC) developed by N. Chapinal (University of British Columbia, Vancouver, BC, Canada, personal communication).

Pasture Data Collection and Laboratory Analyses

To account for the effects of pasture herbage allowance (HA), the put-and-take method was used (Mott and Lucas, 1952). Briefly, herbage mass [HM; kg dry matter)/ha)] was determined using the double-sampling technique (Haydock and Shaw, 1975). Thirty disk-settling heights of an aluminum disk were taken every 14 d in each pasture. The heights were the indirect measurements (30 heights taken at random locations in every pasture), whereas harvested samples were the direct measurements. Three samples per pasture were collected every 28 d to create a regression equation (n = 36) that was used to estimate the total HM and the HA (kg DM/ha of forage/total heifer BW) in each pasture. To maintain similar HA between treatments, we used "put-and-take" heifers when needed to adjust the stocking rate. Target HA was 3 kg DM of forage per total heifer BW. Every 14 d, forage samples from each pasture were collected to determine herbage nutritive value. Samples were dried at 55 °C in air-circulated dryer and grounded using a Wiley Mill (Model 4, Thomas-Wiley Laboratory Mill, Thomas Scientific) to pass a 2-mm stainless-steel screen. In vitro organic matter digestibility (IVOMD) was determined using the two-stage technique described by Moore and Mott (1974). To estimate crude protein (CP), quantification of total nitrogen was determined by rapid combustion using a micro elemental N analyzer (Vario Micro cube, Elementar Analysensysteme GmbH., Langenselbold, Germany), following official method 992.15 (AOAC, 1995). To determine forage DM, samples were weighed (1.5 g) into tared beakers and placed in an oven at 100 °C.

Statistical Analysis

Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, version 9.4), with pasture as the experimental unit. For ADG and BW, the model included the fixed effect of treatment and the random effect of block. For repeated-measures variables (vaginal temperature, activity, rumination, lying/standing behaviors, HA, HM, CP, and

IVOMD), the lowest Akaike information criterion was used to select the best covariance structures. The model included the fixed effects of treatment, time, and the interaction between treatment and time and the random effect of block and date, except for the forage measurements, where block was the only random effect. Pasture within treatment was the subject for the repeated-measures analyses. The GPS data (i.e., frequency and proportion of time heifers spent under the shade) was calculated using Microsoft excel. All results are reported as least-squares and standard error of the mean unless otherwise noted. Significance was declared when $P \leq 0.05$ and tendencies declared when $0.10 \geq P > 0.05$.

RESULTS

Environmental Measures

Air temperature, relative humidity, solar radiation, and wind speed from day 0 to 47 (July 17 to September 2, 2017) are summarized in Fig. 1. Data for weeks 1, 3, 5, and 7 (weeks when vaginal temperature was measured) are summarized in Table 1.

HM, Allowance, and Chemical Composition

There was no ($P > 0.10$) treatment by week interaction for any of the herbage measurements (Table 2). Pastures with shade, however, tended ($P = 0.09$) to have reduced HM and had ($P = 0.01$) greater CP concentrations than pastures without artificial shade. Herbage mass increased ($P < 0.01$) in week 7 compared with weeks 1, 3, and 5. Herbage allowance was not ($P = 0.27$) affected by treatment, but it differed among weeks ($P < 0.01$).

Evaluation of the Use of Shade Structures

Heifers in the SHADE treatment spent 70% of the 8-h period evaluated under the shade. The percentage of heifers under the shade increased from 0900 to 1300 h. Only 38% of heifers were under the shade between 0900 and 1000 h, whereas 100% of heifers were under the shade between 1300 and 1400 h (Fig. 2).

Vaginal Temperature

On weeks 1 and 3, the interaction between treatment and hour of the day affected ($P < 0.01$) vaginal temperature. Compared with heifers in the NO SHADE treatment, heifers in the SHADE
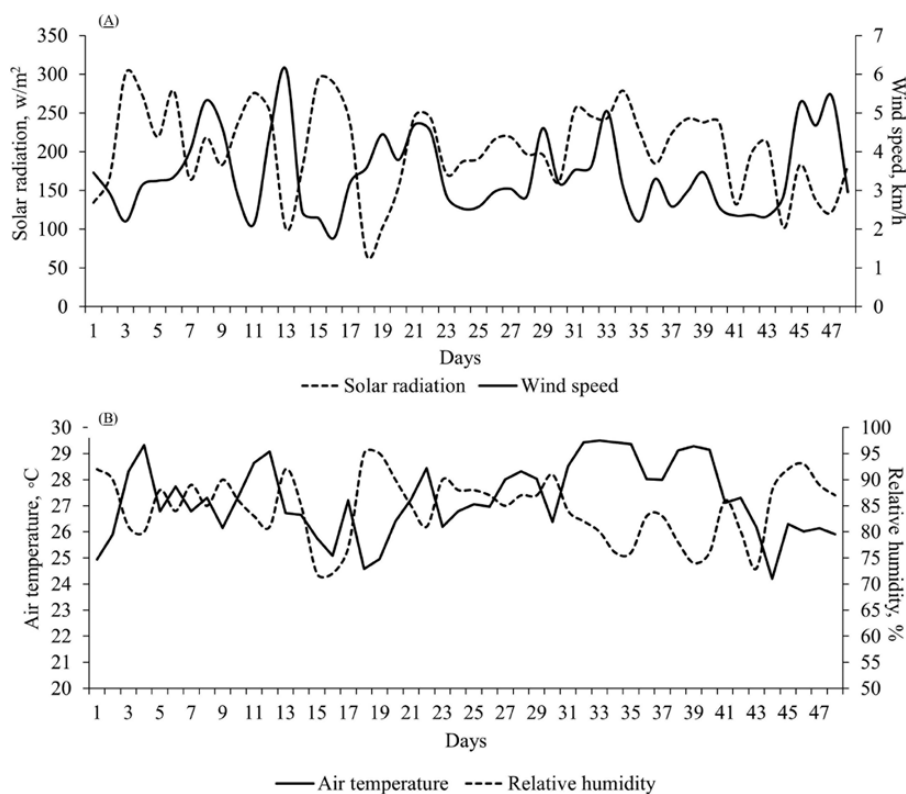
Figure 1. Daily average solar radiation and wind speed (A) and air temperature and relative humidity (B) throughout the 47-d experimental period (July 17 to September 2, 2017) in which pregnant beef heifers grazed bahiagrass pasture with or without access to artificial shade. Data obtained from the FAWN.

Table 2. Herbage mass, herbage allowance, and chemical composition of bahiagrass pastures (1.3 ha/pasture) grazed by pregnant beef heifers with or without access to artificial shade (11 × 7.3 m in length and 2.4 m high) during summer (47 d, July to September) in Florida

	Treatment		Week					P-value		
Item	SHADE	NO SHADE	1	3	5	7	SEM	Treat[a]	Week	Treat × week[b]
HM, kg DM/ha	5,816	6,296	5,651[b]	5,729[b]	5,429[b]	7,715[a]	227	0.09	<0.01	0.98
HA, kg DM/ kg of heifer BW	3.15	3.18	3.25[b]	3.04[b]	2.61[c]	3.77[a]	0.08	0.27	<0.01	0.97
CP[c], %	17.9	16.6	21.6	15.9	14.9	16.7	0.39	0.01	<0.01	0.81
IVOMD[d], %	48.9	48.0	50.9	49.6	45.2	47.9	1.87	0.57	0.17	0.74

[a-b]Within a row, means without a common superscript differ ($P \leq 0.05$) and tendencies were declared when $0.05 < P \leq 0.10$.

[a]P-value for the effect of treatment (Shade vs. No shade).

[b]P-value for the treatment × week interaction.

[c]Crude protein calculated based on total $N \times 6.25$ as proposed by the official method 992.15 of AOAC (1995).

[d]In vitro organic matter digestibility was determined using the two-stage technique described by Moore and Mott (1974).

treatment had lower vaginal temperatures between 1200 and 1600 h and between 1200 and 1800 h on weeks 1 and 3, respectively (Fig. 3A and B). The maximum vaginal temperature difference between heifers in the SHADE and NO SHADE treatments was 0.4 °C and was observed at 1500 and 1700 h on weeks 1 and 3, respectively ($P < 0.05$). During weeks 5 and 7, no ($P > 0.50$) interaction between treatment and hour was detected for vaginal temperature. There was ($P < 0.01$), however, an association between the

hour of the day and vaginal temperature during both weeks (Fig. 3C and D).

Activity and Behavior Assessment

The interaction between treatment and day affected ($P < 0.01$) lying time (Fig. 4A). Heifers in the SHADE treatment spent more minutes lying on days 20, 30, 34, 36, and 39 (difference in min/d between treatments: 153, 145, 90, 118, 110 ± 27 min/d, respectively) compared with heifers in the NO SHADE treatment. The shade treatment tended ($P = 0.10$) to
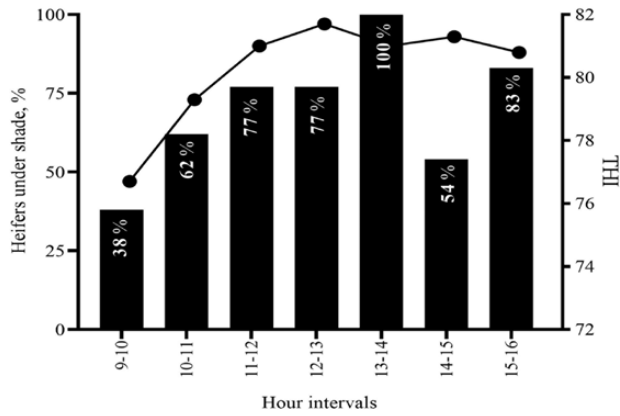
Figure 2. Evaluation of the use of shade structures by grazing heifers in summer. Pregnant beef heifers with access to artificial shade (11 × 7.3 m in length and 2.4 m high) during summer (47 days, July to September) in Florida were fitted with a GPS (Polar GPS, Cat. # M430) attached to a collar, which allowed to track the heifers for an 8-h period during weeks 1, 3, 5, and 7. Data are presented as the percentage of heifers using the shade at distinct times of the day (i.e., between 9000 and 1000 h or 1000 to 1100 h, and so on). The temperature–humidity index is plotted on the right y-axis.

affect lying bouts per day (SHADE = 27 ± 1.9 vs. NO SHADE = 22 ± 1.9 bouts/d; Fig. 4B). An interaction between treatment and day was ($P = 0.01$) detected for standing bout (Fig. 4C); however, there was no difference between treatments within days when individual mean comparisons were observed. Nevertheless, the standing bout duration for heifers with access to shade was ($P < 0.01$) shorter compared to heifers with no shade (62 vs. 83 ± 3 min/bouts). No ($P < 0.24$) effect of the interaction between treatment and day was detected for standing bouts, but overall standing bouts per day was ($P = 0.01$) greater for the SHADE treatment compared with the NO SHADE treatment (13 vs. 11 ± 0.4 bouts/day; Fig. 4D). There were no effects of treatment by day interaction ($P = 0.88$) and treatment ($P = 0.69$) on daily rumination time (510.9 vs. 500.4 ± 18.8 min/day for NO SHADE and SHADE, respectively). When rumination data was analyzed in 2-h intervals,
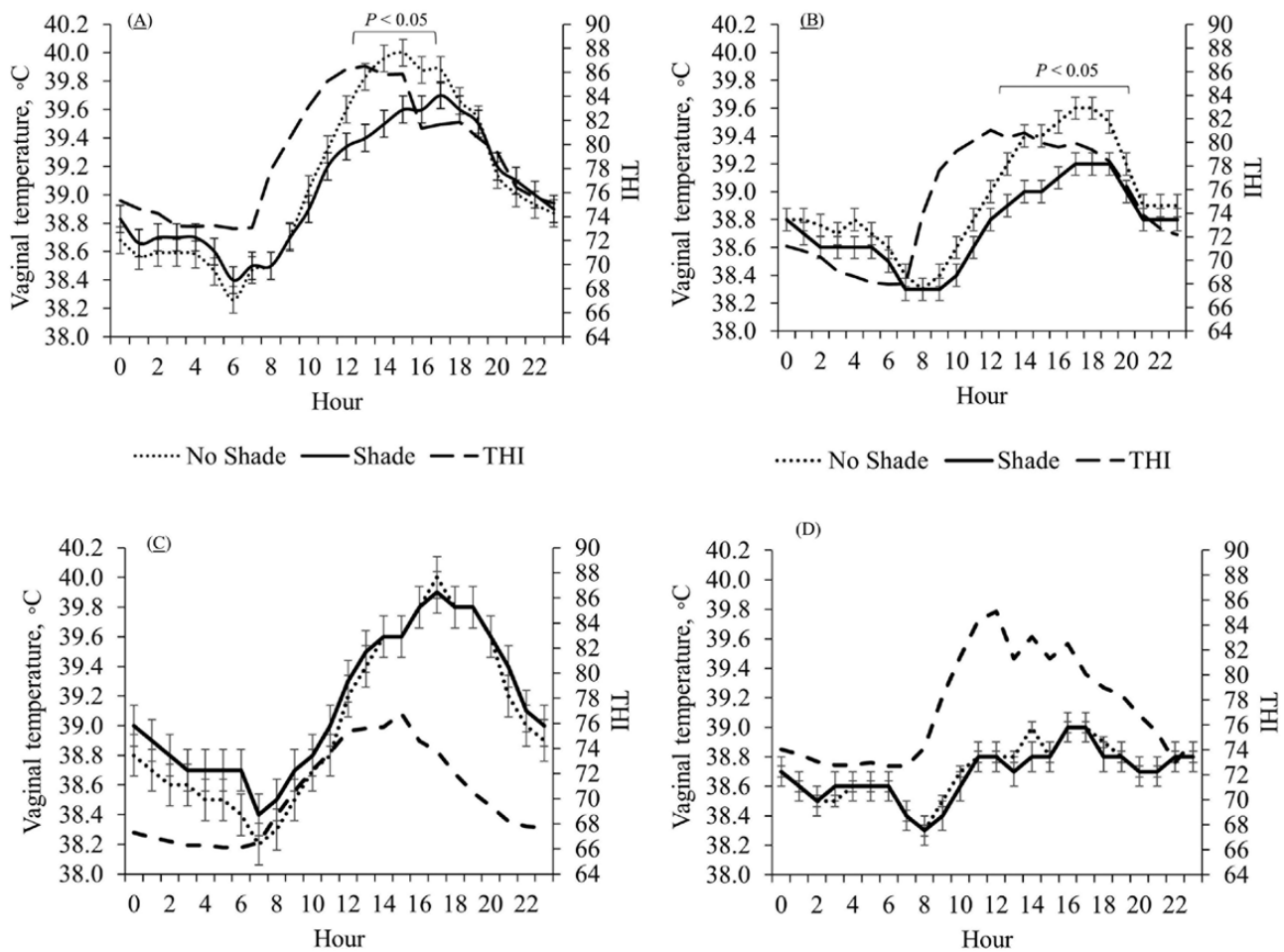

Figure 3. Effects of treatment × hour on vaginal temperature ($P \leq 0.004$; SEM ≤ 0.22) of pregnant beef heifers grazing bahiagrass pastures with ($n = 6$) or without access ($n = 6$) to artificial shade during summer on the first (A) and third (B) week of the experiment. Effects of hour on vaginal temperature ($P < 0.001$; SEM ≥ 0.10) were detected on the fifth (C) and seventh weeks (D). No effects of treatment ($P \geq 0.30$) or treatment × hour ($P \geq 0.50$) were detected on weeks 5 and 7 of the experiment. Data collected for 5 consecutive days during the first (July 17–21, 2017; A), third (31 July to 4 August 2017; B), fifth (August 14–18, 2017; C), and seventh (28 August to 1 September 2017; D) weeks of the experiment. Significance was set at $P \leq 0.05$, and tendencies declared when $0.05 < P \leq 0.10$.
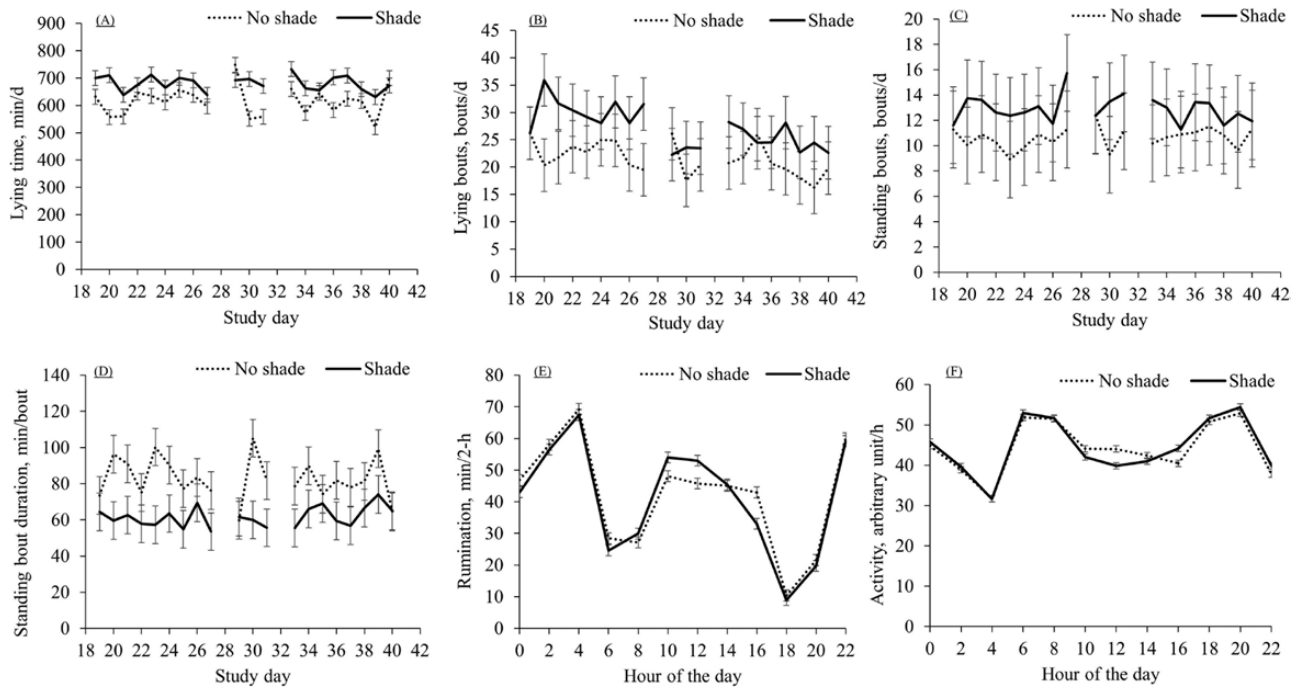
Figure 4. Effect of provision of shade on lying and standing behavior of beef heifers grazing bahiagrass pastures during summer in Florida. (A) Lying time: treatment × day of the experiment interaction ($P < 0.01$; SEM = 27.0); (B) lying bouts per day: effect of treatment ($P = 0.10$; SEM = 4.8); (C) standing bouts per day: treatment × day of the experiment interaction ($P = 0.01$; SEM = 3.0); (D) standing bout duration: effect of treatment ($P < 0.01$; SEM = 10.4); (E) rumination: treatment × hour of day interaction ($P < 0.01$; SEM = 1.7); and (F) activity: treatment × hour of day interaction ($P < 0.01$; SEM = 0.7). Significance was set at $P \leq 0.05$, and tendencies declared when $0.05 < P \leq 0.10$.

an interaction between treatment and hour of the day was observed ($P < 0.01$; Fig. 4E). Heifers in the SHADE treatment had greater rumination between 1000 and 1200 h (total of 13.1 min more compared with heifers in the NO SHADE treatment), whereas at 1600 h, their rumination was reduced compared with heifers in the NO SHADE treatment (33 vs. 43 ± 1.72 min/2 h). During these specific times (1000 to 1200 h), NO SHADE heifers had greater ($P < 0.01$) activity (2 and 4 arbitrary unit/h; Fig. 4F), whereas at 1600 h, NO SHADE treatment had decreased activity compared with the SHADE (40.4 vs. 44.2 ± 0.77 arbitrary unit/h, respectively).

Growth Parameters

The provision of artificial shade did not ($P = 0.79$) affect BW of the heifers throughout the experiment (Table 3). However, ADG from day 0 to 14 (0.82 vs. 0.44 ± 0.196 kg; $P = 0.10$) and from day 0 to 47 (0.20 vs. −0.02 ± 0.076 kg; $P = 0.08$) tended to be greater for heifers in the SHADE treatment compared with heifers in the NO SHADE treatment (Table 3).

DISCUSSION

Grazing beef cattle in subtropical and tropical regions, including the southeastern United States,

Table 3. Growth performance of pregnant beef heifers grazing bahiagrass pastures (1.3 ha/pasture) with ($n = 6$) or without ($n = 6$) access to artificial shade (11×7.3 m in length and 2.4 m high) during summer (47 days, July to September) in Florida

| | Treatment[a] | | | |
	SHADE	NO SHADE	SEM	*P*-value[b]
BW, kg				
Initial BW (day 0)[c]	414	422	8.9	0.41
day 14	425	427	7.9	0.82
day 28	444	443	7.6	0.85
day 42	437	436	7.9	0.97
Final BW (day 47)[2]	423	420	7.6	0.79
BW change from day 0 to 47, kg	9.22	−0.87	3.54	0.08
ADG, kg				
days 0–14	0.82	0.44	0.196	0.10
days 14–28	1.37	1.09	0.181	0.34
days 28–42	-0.57	-0.48	0.155	0.70
days 0–47	0.20	-0.02	0.076	0.08

[a]From day 0 to 47, pregnant beef heifers grazed bahiagrass pastures with or without access to artificial shade (11×7.3 m in length and 2.4 m high, which provided 26.8 m² of shade per heifer) during the summer of 2017.

[b]Significance was set at $P \leq 0.05$, and tendencies declared when $0.05 < P \leq 0.10$.

[c]Individual BW was measured on days 0 and 47, following 12 h of feed and water withdrawal, whereas full BW was obtained on days 14, 28, and 42.

are exposed to prolonged periods of extreme environmental conditions that can cause heat stress. Exposure of livestock to heat stress is associated with behavioral (Rovira, 2014) and physiological (Collier et al., 1982) alterations that can lead to decreased performance (Mitlöhner et al., 2001). This is particularly important given that beef production demand will increase to provide feed for the growing population and because 70% of the beef supply is expected to come from subtropical and tropical regions, including the southern United States (Cooke et al., 2020). Therefore, the implementation and development of strategies to mitigate heat stress in grazing livestock, such as the provision of artificial shade, to promote well-being and enhance animal performance are needed.

It is difficult to meet the desired shade amount of 2.8 m^2 per head for beef cows on pasture (Turner, 2000). In the present experiment, however, the shade structure provided 26.8 m^2 of shade per heifer, which surpassed the proposed recommendations of shade for beef cows (Turner, 2000) and prevented possible effects of limited shade availability on the response variables. When temperature and humidity are high, cattle tend to seek the cooler microclimate created by the shaded structure, which also protects animals from direct solar exposure (Polsky and von Keyserlingk, 2017). In the current experiment, heifers with access to shade spent 5.6 h out of the 8-h observation period under the shade. The use of shade was associated with the times of day when THI was highest. When environmental temperature, humidity, and solar radiation rise, the percentage of grazing beef cattle found resting on artificial shade also increases (Widowski, 2001). Tucker et al. (2008) reported that dairy cows with access to an artificial shade that provided 99% protection against solar radiation used the shade structure for 3.3 h out of 15.5 h day-time evaluation, with the greatest use when air temperature and solar radiation were higher. The preference of cattle for shade during times of high THI emphasizes the importance of providing shade as a mitigation strategy to HS.

Lying behavior can provide insight into how animals interact with the environment and it can be used as an indicator of animal comfort (Ledgerwood et al., 2010). In our experiment, shade availability increased lying time. Similarly, McDaniel and Roark (1956) observed that when artificial shade is not provided to beef cows, lying time was reduced by 62 min/d, whereas standing time was 69 min/d greater compared to beef cows with access to artificial shade. Metz (1985) reported that motivation to lay down is increased in dairy cows after 3 h of lying deprivation, which will further impact other activities, such as the time cows spend grazing, as they prioritize lay down instead of performing other activities. Even though artificial shade can be used as a strategy to ameliorate cattle well-being, it still may not completely offset the negative effects of HS. This would explain the greater number of standing bouts per day among heifers with access to shade, considering that standing is a behavioral mechanism used by cattle to enhance heat dissipation. When cattle stand, greater body surface area is exposed to airflow, maximizing heat loss (Schütz et al., 2008). It is important to note, however, that the standing bout duration was shorter for heifers with access to shade than for heifers without access to shade, resulting in greater lying time per day for the former. It is possible that heifers with access to shade sought the shade during the warmer periods of the day, for which they had to get up and lay down, resulting in a greater number of lying and standing bouts per day.

During HS, vasodilation in peripheral tissues is enhanced to increase heat dissipation, whereas blood flow is minimized in the digestive tract. As a result, the passage rate of digesta in the gastrointestinal tract is impaired, reducing ruminal activity and motility (Soriani et al., 2013). Reduction in rumination time (Moretti et al., 2017) and an increase in activity index (Abeni and Galli, 2017) of dairy cows in response to THI >70 have been observed. In our experiment, rumination time was the greatest (60 min/h) and activity was lowest (32 arbitrary unit/h) at 0400 h, when THI is typically low compared to other times of the day. Heifers with access to shade ruminated a total of 13 min more and had lower activity (40 vs. 44 arbitrary unit/h) at 1000 and 1200 h compared with heifers without access. In contrast, heifers without access to shade had an increase of 9 min/h in rumination and reduction in activity only at 1600 h when compared with heifers with shade. Alterations in rumination time during the hot season can occur as rumination activity is affected by factors, such as heat stress (Soriani et al., 2013). Heifers with access to shade had a more distributed rumination time throughout the day, which highlights the importance of shade to guarantee normal physiological behavior during summer. Rumination is the second-most time-consuming activity in cattle, grazing being the first, and the provision of shade ensures more appropriate distribution of this physiological behavior, as well as allowing for more rest (Blackshaw and Blackshaw, 1994).

Providing artificial shade to grazing beef heifers during summer reduced vaginal temperature. When ambient heat load increases above a certain threshold, specific within species and animal type (adult vs. young and pregnant vs. nonpregnant), heat accumulation exceeds heat loss, resulting in a rise in body temperature, which is an indicator of thermal stress (Lees et al., 2018). Access to artificial shade in beef and dairy cattle reduces body temperature (Roman-Ponce et al., 1977; Tucker et al., 2008; Fisher et al., 2010; Monn et al., 2018). Gebremedhin et al. (2011) observed that the rate of increase in body temperature was greater when heifers were lying under the sun compared with heifers lying on shade (0.61 vs. 0.25 °C/h), demonstrating that the use of shade can promote a slower increase in core body temperature (Brown-Brand et al., 2005). Herein, heifers with access to shade had lower vaginal temperatures, particularly in weeks 1 and 3. It is important to note that the combination of THI, wind speed, and solar radiation were more prone to cause HS in weeks 1 and 3 compared with weeks 5 and 7. An alternate explanation is that the acclimatization to the new environmental conditions (e.g., lack of shade) takes from several days to weeks to occur (Collier et al., 2019), which could justify similar vaginal temperatures between treatments in weeks 5 and 7 of the experiment. The maximum vaginal temperature difference between heifers with or without access to shade was 0.4 °C in weeks 1 and 3 and was achieved in the afternoon (1500 and 1700 h). In feedlot beef steers, the body temperature difference between those provided shade and those not provided shade ranged from 0.6 (THI ≥ 84; Brown-Brand et al., 2005) to 0.8 °C (air temperature > 30 °C for 8 h/day; Gaughan et al., 2010). Even though the energy intake and rates of gain of grazing beef heifers are lower than that of feedlot steers, the negative impact of HS can still be mitigated by the provision of shade regardless of energy demand and animal productivity.

The physiological and behavioral benefits of the use of shade by heifers (i.e., lying time and reduced body temperature) translated into improved ADG from enrollment to day 47. Monn et al. (2018) reported that grazing beef heifers provided with shade had an ADG of 0.5 kg/d, whereas those not provided with shade had an ADG of 0.3 kg/d. The difference in forage species grazed in both studies (high- vs. low-quality forages) likely explains differences in rates of gain. Nonetheless, the provision of shade to grazing beef heifers promoted an additional gain of approximately 0.2 kg/d in both experiments. Heat stress increases nutrient requirements for thermoregulation (Beede and Collier, 1986; Collier et al., 2019), which contributes to the negative association between exposure to HS and animal performance. Nutrients that could be used for growth are redirected toward maintaining euthermia when environmental temperatures are elevated (O'Brien et al., 2010), resulting in reduced performance. The provision of shade increases DMI (Gaughan et al., 2010). Even though we did not measure DMI in the current experiment, HA was similar between treatments; however, HM tended to be lower and CP was greater for heifers with access to shade compared with heifers without access.

In conclusion, the provision of heat stress abatement in the form of artificial shade during summer to pregnant grazing beef heifers was effective in reducing vaginal temperatures and increasing lying time. Furthermore, the use of artificial shade resulted in an additional 0.20 kg of BW per day, highlighting the positive effects of using artificial shaded structures on pasture-based systems during summer in subtropical climates.

Conflict of interest statement. The authors declare no conflict of interest.

LITERATURE CITED

Abeni, F., and A. Galli. 2017. Monitoring cow activity and rumination time for an early detection of heat stress in dairy cow. Int. J. Biometeorol. 61:417–425. doi:10.1007/s00484-016-1222-z.

AOAC. 1995. Official methods of analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Beede, D. K., and R. J. Collier. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. J. Anim. Sci. 62:543–554. doi:10.2527/jas1986.622543x.

Blackshaw, J. K., and A. W. Blackshaw. 1994. Heat stress in cattle and the effect of shade on production and behavior: a review. Aust. J. Exp. Agr. 34: 285–295. doi:10.1071/EA9940285.

Brown-Brand, T. M., R. A. Eigenberg, J. A. Nienaber, and G. L. Hahn. 2005. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, part 1: analyses of indicators. Biosyst. Eng. 90:451–462. doi:10.1016/j.biosystemseng.2004.12.006.

Brown-Brandl, T. M., J. A. Nienaber, R. A. Eigenberg, G. L. Hahn, and H. Freetly. 2003. Thermoregulatory responses of feeder cattle. J. Ther. Biol. 28:149–57. doi:10.1016/S0306-4565(02)00052-9.

Brown-Brandl, T. M., C. G. Chitko-McKown, R. A. Eigenberg, J. J. Mayer, T. H. Welsh, J. D. Davis, and J. L. Purswell. 2017. Physiological responses of feedlot heifers provided access to different levels of shade. Anim. 11:1344–1353. doi:10.1017/S1751731116002664.

Collier, R. J., L. H. Baumgard, R. B. Zimbelman, and Y. Xiao. 2019. Heat stress: physiology of acclimation and adaptation. Anim. Front. 9:12–19. doi:10.1093/af/vfy031.

Collier, R. J., D. K. Beede, W. W. Thatcher, L. A. Israel, and C. J. Wilcox. 1982. Influences of

environment and its modification on dairy animal health and production. J. Dairy Sci. 65:2213–2227. doi:10.3168/jds.S0022-0302(82)82484-3.

Collier, R. J., G. E. Dahl, and M. J. VanBaale. 2006. Major advances associated with environmental effects on dairy cattle. J. Dairy Sci. 89:1244–1253. doi:10.3168/jds.S0022-0302(06)72193-2.

Cooke, R. F., C. L. Daigle, P. Moriel, S. B. Smith, L. O. Tedeschi, and J. M. B. Vendramini. 2020. Cattle adapted to tropical and subtropical environments: social, nutritional, and carcass quality considerations. J. Anim. Sci. 98(2):1–20. doi:10.1093/jas/skaa014.

Dikmen, S., E. Alava, E. Pontes, J. M. Fear, B. Y. Dikmen, T. A. Olson, and P. J. Hansen. 2008. Differences in thermoregulatory ability between slick-haired and wild-type lactating Holstein cows in response to acute heat stress. J. Dairy Sci. 91:3395–3402. doi:10.3168/jds.2008-1072.

Ferreira, F. C., R. S. Gennari, G. E. Dahl, and A. De Vries. 2016. Economic feasibility of cooling dry cows across the United States. J. Dairy Sci. 99:9931–9941. doi:10.3168/jds.2016-11566.

Fisher, A. D., N. Roberts, S. J. Bluett, G. A. Verkerk, and L. R. Matthews. 2010. Effects on shade provision on the behavior, body temperature, and milk production of grazing dairy cows during a New Zealand summer. N. Zeal. J. Agric. Res. 51(2): 99–105. doi:10.1080/00288230809510439.

Gaughan, J. B., S. Bonner, I. Loxton, T. L. Mader, A. Lisle, and R. Lawrence. 2010. Effect of shade on body temperature and performance of feedlot steers. J. Anim. Sci. 88:4056–4067. doi:10.2527/jas.2010-2987.

Gebremedhin, K. G., C. N. Lee, P. E. Hillman, and T. M. Brown-Brandl. 2011. Body temperature and behavioral activities of four breeds of heifers in shade and full sun. Appl. Eng. Agric. 27(6):999–1006. doi:10.13031/2013.40620.

Hahn, G. L. 1999. Dynamic responses of cattle to thermal heat loads. J. Anim. Sci. 77(Suppl 2):10–20. doi:10.2527/1997.77suppl_210x.

Haydock, K. P., and M. H. Shaw. 1975. The comparative yield method for estimating dry matter yield of pasture. Aust. J. Exp. Agric. Anim. Husb. 15:663–670. doi:10.1071/EA9750663.

Lees, A. M., J. C. Lees, A. T. Lisle, M. L. Sullivan, and J. B. Gaughan. 2018. Effect of heat stress on rumen temperature of three breeds of cattle. Int. J. Biometeorol. 62:207–215. doi:10.1007/s00484-017-1442-x.

Ledgerwood, D. N., C. Winckler, and C. B. Tucker. 2010. Evaluation of data loggers, sampling intervals, and editing techniques for measuring the lying behavior of dairy cattle. J. Dairy Sci. 93:5129–5139. doi:10.3168/jds.2009-2945.

McDaniel, A. H., and C. B. Roark. 1956. Performance and grazing habits of hereford and aberdeen-angus cows and calves on improved pastures as related to types of shade. J. Anim. Sci. 15: 59–63. doi:10.2527/jas1956.15159x.

Merenda, V. R., O. Marques, E. K. Miller-Cushon, N. Dilorenzo, J. Laporta, and R. C. Chebel. 2019. Technical note: validation of a system for monitoring individual behavior in beef heifers. J. Anim. Sci. 97:4732–4736. doi:10.1093/jas/skz326.

Metz, J. H. M. 1985. The reaction of cows to a short-term deprivation of lying. Appl. Anim. Behav. Sci. 13:301–307. doi:10.1016/0168-1591(85)90010-3.

Mitlöhner, F. M., M. L. Galyean, and J. J. McGlone. 2002. Shade effects on performance, carcass traits, physiology, and behavior of heat-stressed feedlot heifers. J. Anim. Sci. 80:2043–2050. doi:10.2527/2002.8082043x.

Mitlöhner, F. M., J. L. Morrow, J. W. Dailey, S. C. Wilson, M. L. Galyean, M. F. Miller, and J. J. McGlone. 2001. Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. J. Anim. Sci. 79:2327–2335. doi:10.2527/2001.7992327x.

Moore, J. E., and G. O. Mott. 1974. Recovery of residual organic matter from in vitro digestion of forages. J. Dairy Sci. 57:1258–1259. doi:10.3168/jds.S0022-0302(74)85048-4.

Monn, R. E., Shea, T. P., Mayberry, K., Freeman, S. R., Poole, D. H., and M. H. Poore. 2018. Implementing shade and slick hair phenotypes improves heifer performance. J. Anim. Sci. 96(Suppl. 1):79–80. (Abstr.). doi:10.1093/jas/sky027.150.

Moretti, R., S. Biffani, S. Chessa, and R. Bozzi. 2017. Heat stress effects on Holstein dairy cows' rumination. Animal 11:2320–2325. doi:10.1017/S1751731117001173.

Mott, G. O., and H. L. Lucas. 1952. The design, conduct, and interpretation of grazing trials on cultivated and improved pastures. In: Wagner, R. E., editor. Proceedings of the 6th International Grassland Congress; August 17 to 23, 1952; State College Press, University Park, PA. p. 1380–1385.

Nardone, A., B. Ronchi, N. Lacetera, M. S. Ranieri, and U. Bernabucci. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livest. Sci. 130:57–69. doi:10.1016/j.livsci.2010.02.011.

O'Brien, M. D., R. P. Rhoads, S. R. Sanders, G. C. Duff, and L. H. Baumgard. 2010. Metabolic adaptations to heat stress in growing cattle. Domest. Anim. Endocrinol. 38:86–94. doi:10.1016/j.domaniend.2009.08.005.

Polsky, L., and M. A. G. von Keyserlingk. 2017. Invited review: effects of heat stress on dairy cattle welfare. J. Dairy Sci. 100:8645–8657. doi:10.3168/jds.2017-12651.

Rovira, P. 2014. The effect of type of shade on physiology, behavior and performance of grazing steers. Anim. 8:470–476. doi:10.1017/S1751731113002413.

Rovira, P., and J. Velazco. 2010. The effect of artificial or natural shade on respiration rate, behaviour and performance of grazing steers. New Zeal. J. Agr. Res. 53:347–353. doi:10.1080/00288233.2010.525785.

Roman-Ponce, H., W. W. Thatcher, D. E. Buffington, C. J. Wilcox, and H. H. Van Horn. 1977. Physiological and production responses of dairy cattle to a shade structure in a subtropical environment. J. Dairy Sci. 60:424–430.

Sejian, V., R. Bhatta, J. B. Gaughan, F. R. Dunshea, and N. Lacetera. 2018. Review: Adaptation of animals to heat stress. Animal 12(s2):s431–s444. doi:10.1017/S1751731118001945.

Soriani, N., G. Panella, and L. Calamari. 2013. Rumination time during the summer season and its relationships with metabolic conditions and milk production. J. Dairy Sci. 96:5082–5094. doi:10.3168/jds.2013-6620.

Sullivan, M. L., A. J. Cawdell-Smith, T. L. Mader, and J. B. Gaughan. 2011. Effect of shade area on performance and welfare of short-fed feedlot cattle. J. Anim. Sci. 89:2911–2925. doi:10.2527/jas.2010-3152.

Schütz, K. E., N. R. Cox, and L. R. Matthews. 2008. How important is shade to dairy cattle? Choice between shade or lying following different levels of lying deprivation.

Appl. Anim. Behav. Sci. 114:307–318. doi:10.1016/j.applanim.2008.04.001.

Schütz, K. E., A. R. Rogers, Y. A. Poulouin, N. R. Cox, and C. B. Tucker. 2010. The amount of shade influences the behavior and physiology of dairy cattle. J. Dairy Sci. 93:125–133. doi:10.3168/jds.2009-2416.

Tucker, C. B., A. R. Rogers, and K. E. Schütz. 2008. Effect of solar radiation on dairy cattle behavior, use of shade and body temperature in a pasture-based system. Appl. 109:141–154. doi:10.1016/j.applanim.2007.03.015.

Turner, L. W. 2000. Shade options for grazing cattle. Agricultural Engineering Update, AEU-91. University of Kentucky Cooperative Extension. http://www.bae.uky.edu/Publications/AEUs/aeu-91.pdf.

USDA Economic Research Service. 2019. Cattle inventory data: United States Department of Agriculture. Available from: http://www.ers.usda.gov [accessed May 12, 2021].

West, J. W. 2003. Effects of heat-stress on production in dairy cattle. J. Dairy Sci. 86:2131–2144. doi:10.3168/jds.S0022-0302(03)73803-X.

Widowski, T. 2001. Shade-seeking behavior of rotationally-grazed cows and calves in a moderate climate. In: Stowell, R. R., R. Bucklin, and R. W. Bottcher, editors. Proceedings of the 6th International Symposium; May 21 to 23, 2001; Louisville, KY; p. 632–639. doi:10.13031/2013.7126.