ABSTRACT: Ticks are external parasites, which pose a significant economic burden to domestic animal agriculture. The effects of ticks on grazing animals may be exacerbated during periods of low nutrition, such as those encountered during drought. It is not completely understood how plane of nutrition and tick burden interact to affect metabolism in cattle. The objective of the current research was to examine the plane of nutrition by tick-burden interaction in cattle and determine the effects of this interaction on physiological indicators of growth and metabolism. Eight-month-old Angus cross steers (n = 28, 194 ± 3.0 kg) were stratified by pretrial BW and DMI into 1 of 4 groups (n = 7/group) in a 2 × 2 factorial arrangement. Categories were: moderate (14.0 ± 1.0% CP, 60 ± 1.5% TDN) vs. low (9.0 ± 1.0% CP, 58 ± 1.5% TDN) plane of nutrition and control (no tick) vs. tick treatment (300 pair of adult Amblyomma americanum per treated animal). Steers were individually fed their respective experimental diets ad libitum and feed intake was monitored for 35 d before and 21 d after the start of tick infestation (d 0). Blood samples were harvested via coccygeal venipuncture on d –7, 0, 7, 8, 9, 10, 11, 13, 17, and 21. Plasma cortisol and IGF-I were determined by RIA. Metabolic indicators were determined by colorimetric assay. Steers weighed 195 ± 6 kg on d –35, but on d –7 and d 21, the moderate steers weighed more than the low steers (244.1 ± 8.7 vs. 227.7 ± 8.4 kg, P < 0.07; and 283.4 ± 8.0 vs. 244.0 ± 7.9 kg, P < 0.001, respectively). Cortisol was affected by plane of nutrition and treatment (P < 0.08). Insulin-like growth factor-I was greater (P < 0.01) in moderate than in low and control animals (P < 0.02), compared with tick-treated animals. Tick treatment had no effect (P > 0.05) on any of the metabolites measured in this study. Plane of nutrition affected (P < 0.02) albumin, blood urea nitrogen, and glucose in that values from the moderate group animals were greater than those from the low group. Although cortisol was related to both tick treatment and nutritional status in the current study, with respect to the combination of parasitism and suboptimal nutrition, IGF-I was the most highly indicative constituent measured. Tick burden affected various characteristics of growth and metabolism in these growing cattle and the effects were exacerbated by a low plane of nutrition.

Key words: Amblyomma americanum, cattle, growth, insulin-like growth factor-I, metabolism, plane of nutrition

INTRODUCTION

Ticks are external parasites, which pose a significant economic burden to animal agriculture (Drummond, 1987; Kivaria, 2006). Combating a parasite burden may be considered a “cost of fitness,” which incurs a drain on available energy (Lochmiller and Deerenberg, 2000; Demas, 2004). Malnutrition has metabolic, endocrine, and immune consequences, especially with respect to parasitism (Hughes and Kelly, 2006). Thus, the effects of ticks may be exacerbated during periods of low nutrition, such as those encountered during drought.


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drought. Many grazing animals worldwide face periods of drought as a common occurrence.

Diet quality and quantity interact to provide the nutritional environment for grazing animals. Within a given plane of nutrition, energetically costly events, such as lactation (Bell, 1995) or infection (Elsasser et al., 2008), affect the profile of metabolic indicators, such as glucose, ketones, or fatty acids of an individual. These profiles can be used to monitor the extent or duration of such events. It is not completely understood how plane of nutrition and tick burden interact to affect metabolism in cattle. Ticks, such as *Dermacentor albipictus*, infest cattle during winter and may be confounded with a low nutritional state. Similarly, adult Lone Star ticks (*Amblyomma americanum*) feed in late spring and summer, a time period often corresponding to drought in the southern Great Plains of the United States and thus reduced forage quantity and quality.

Physiological effects of ticks on cattle have been investigated previously and the work produced varied results (Riley et al., 1995; Willis et al., 1995). The observed variation could be due to differences in the species and number of ticks used in each study, or to differences in individual animal responses to the ticks. The objective of the current research was to examine the plane of nutrition by tick-burden interaction in cattle and determine the effects of this interaction on physiological indicators of growth and metabolism.

**MATERIALS AND METHODS**

All animal procedures were approved by the Texas A&M University Institutional Animal Care and Use Committee. The experiment was conducted at the Texas A&M University Animal Science Teaching, Research, and Extension Center.

**Animal Procedures and Experimental Design**

Eight-month-old Angus cross steers (n = 28, 194 ± 3.0 kg) obtained from the Texas Department of Criminal Justice commercial cow herd were stratified by pretrial BW and DMI into 1 of 4 groups (n = 7 per group) in a 2 × 2 factorial arrangement. Categories were: moderate (14.0 ± 1.0% CP, 60 ± 1.5% TDN) vs. low (9.0 ± 1.0% CP, 58 ± 1.5% TDN) plane of nutrition, and control (no tick) vs. tick treatment (300 pair of adult *A. americanum* per treated animal). Both the moderate and low diets were cottonseed hull based with various proportions of cottonseed meal, corn, sorghum, and a vitamin-mineral premix to achieve the desired plane of nutrition (Table 1). All animals were fed their respective experimental diets ad libitum and intake was monitored for 35 d before and 21 d after the start of tick infestation (d 0). Nonshrunk BW and BCS (1 = thin, 9 = fat) were obtained on d −35, −7, and 21. Animals were housed outside in concrete-floored pens (6.0 m × 10.0 m) and individually fed from d −35 to −7. At this point, the animals were moved inside where they were housed and fed in 1.0-m × 2.5-m stanchions through the end of the experiment. Due to the configuration of the stanchions in the room, 7 replicates of 4 animals each, 1 per tick treatment by plane of nutrition group were stratified across the stanchion room. Water was provided ad libitum. Stanchions were cleaned daily.

**Tick Procedures**

Ticks used in this study originated from research and teaching colonies maintained at the Texas A&M University Department of Entomology Tick Research Laboratory. Experimental populations of *A. americanum* were originally established and periodically supplemented with progeny of gravid female ticks collected from livestock residing at the Texas Agriculture Experiment Station in Sutton County, TX, and at the Hill Ranch in Edwards County, TX. While being reared for the study, tick colonies were maintained within separate sealed glass chambers where environmental conditions approximated 20°C, 90% relative humidity, and 14:10 light:dark photoperiod. The feeding cycle for this species consists of infestation followed by 7 d of location and attachment by female ticks, then intense feeding beginning at about d 10 until engorgement and dropoff at ~14 d. A period of predominately male feeding occurs from d 14 to 17. All feeding is complete by d 21. Environmental conditions within the stanchion room were maintained at 21 ± 1.0°C, ~50% relative humidity, and a 14:10 light:dark photoperiod.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Percentage as fed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Cottonseed hull pellet</td>
<td></td>
</tr>
<tr>
<td>Cottonseed hulls (loose)</td>
<td>25</td>
</tr>
<tr>
<td>Cottonseed meal</td>
<td>25</td>
</tr>
<tr>
<td>Corn (dry rolled)</td>
<td>23</td>
</tr>
<tr>
<td>Sorghum (cracked)</td>
<td>23</td>
</tr>
<tr>
<td>Vitamin-mineral premix</td>
<td>4</td>
</tr>
<tr>
<td>Pellet total</td>
<td>100</td>
</tr>
<tr>
<td>Total mixed ration</td>
<td></td>
</tr>
<tr>
<td>Cottonseed hull pellets</td>
<td>60</td>
</tr>
<tr>
<td>Cottonseed hulls</td>
<td>35</td>
</tr>
<tr>
<td>Molasses</td>
<td>5</td>
</tr>
<tr>
<td>Ration total</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1. Composition of rations used to create moderate and low planes of nutrition for growing beef steers.
Tick exposure was accomplished as described by Tolleson et al. (2007). Briefly, ticks were confined within a series of 6 surgical cotton stockinettes secured along the top midline from withers to hips of each animal, using a commercially available adhesive (Nasco Livestock ID Tag Cement, Fort Atkinson, WI) and fastened by twisting the open end of the fabric tightly into a pigtail, held in place with rubber bands. Tick attachment and feeding was monitored by daily inspection of each stockinet cell. During these inspections, the number of engorging (i.e., “nonflat”) female ticks was recorded.

**Blood Sampling and Analysis**

Blood samples (~8 mL) were harvested via coccygeal venipuncture on d −7, 0, 7, 8, 9, 10, 11, 13, 17, and 21 into EDTA coated vacutainers and placed on ice (~1 h) until centrifugation (1,500 × g for 30 min at 4°C). Plasma was subsequently aspirated and stored at −20°C until assayed. Cortisol concentrations were determined in a single RIA from duplicate samples using a single antibody RIA procedure (Carroll et al., 2006) and used: rabbit anticortisol antiserum (Pantex, Div. of Bio-Analysis Inc., Santa Monica, CA, Cat. #P44) diluted 1:2,500; standards made by serial dilution (8,000 pg/100 mL to 3.9 pg/100 mL) of 4-pregnen-11ß,17,21-triol-3,20-dione (Steraloids Inc., Newport, RI, Cat. #Q3880-000); and radio-labeled cortisol: $^3$H-Hydrocortisone (1,2-$^3$H, NEN, Boston, MA, Cat. #NET-185). Counts per minute obtained from a liquid scintillation spectrophotometric beta counter (Beckman Coulter LS 6500, Beckman Coulter, Brea, CA) and unknown cortisol concentrations were calculated using Assay Zap software (Biosoft, Cambridge, UK). Cortisol antiserum cross reactivity was: corticosterone, 60%; deoxycorticosterone, 48%; progesterone, 0.01%; and estradiol, 0.01%, (determined by Pantex). Intra-assay CV was 8.0%. Aliquots were assayed in duplicate to determine the concentration of IGF-I by RIA (Strauch et al., 2003). The final dilution of the primary antibody was: 1:120,000 and the goat antirabbit secondary antibody was used at a dilution of 1:60. The IGF-I antibody used was A FP4892898 anti-hIGF-I (A. F. Parlow, National Hormone Labs (San Carlos, CA). All samples were assayed in a single assay with an intra-assay CV of 7.8%. Urea nitrogen (BUN), glucose (GLU), NEFA, beta-hydroxybutyrate (BHBA), albumin (ALB), hemoglobin (HGB), gamma-glutamyl transpeptidase (GGT), and aspartate aminotransferase (AST) were determined by colorimetric assays at the Texas A&M Veterinary Medical Diagnostic Laboratory.

**Statistical Procedures**

Differences in metabolic and performance characteristics among groups were detected, using MIXED model procedures (SAS Inst. Inc., Cary, NC) for repeated measures. Animal was the experimental unit and fixed effects were plane of nutrition, treatment, and day, as well as the 2- and 3-way interactions. Day was the repeated variable. Random effects were replicate and animal within replicate by treatment. The Tukey-Kramer statistic was used for least squares mean separation (Kuehl, 1999). Differences among planes of nutrition for adult female tick drop were determined by ANOVA procedures (Steel and Torrie, 1980). Stepwise multiple regression (Steel and Torrie, 1980) was used to determine relationships between growth and endocrine or metabolic constituents. The Pearson $\chi^2$ procedure (Steel and Torrie, 1980) was applied to detect differences in the proportion of samples from treatment groups belonging to specified categories. Simple linear regression (Steel and Torrie, 1980) identified relationships among metabolic constituents.

**RESULTS**

**Tick and Animal Performance**

The tick feeding cycle progressed normally with engorged ticks commencing dropoff on d 9, peaking at d 12, and terminating by d 17 (Table 2). The pattern of tick feeding was not affected by host plane of nutrition, but there were more ($P < 0.05$) adult female ticks that fed and dropped off of the moderate (290.0 ± 4.3) than the low (272.8 ± 5.8) cattle by the end of the feeding cycle. Tick treatment did not affect animal performance measures ($P > 0.1$; not shown). All cattle gained BW throughout the trial (Figure 1). Pretreatment BW and DMI were not different ($P > 0.1$) among groups. Steers weighed 195 ± 6 kg on d −35, but on d −7 and d 21, the moderate steers weighed more than the low steers (244.1 ± 8.7 vs. 227.7 ± 8.4 kg, $P < 0.07$; and 283.4 ± 8.0 vs. 244.0 ± 7.9 kg, $P < 0.001$, respectively). On d −35, BCS averaged 4.5 ± 0.1 for both nutrition groups, but by d 21, BCS was 5.5 ± 0.1 and 5.0 ± 0.2 for moderate and low groups, respectively ($P < 0.05$). Values for ADG (kg/d) between d −7 and d 21 were greater ($P < 0.001$) for moderate (1.31 ± 0.15) vs. low (0.54 ± 0.06) steers. Dry matter intake as a percentage of BW was slightly greater ($P = 0.08$) in moderate (3.79 ± 0.17) than low (3.36 ± 0.17) steers, but not ($P > 0.1$) for the control (3.69 ± 0.17) compared with the tick-treated (3.46 ± 0.17) group. Day significantly ($P < 0.01$) affected DMI as a percentage of BW, with values reaching a maximum of 3.78 ± 0.14 on d 4 and a minimum of 3.42 ± 0.14 on d 14, before trending upward to 3.70 ± 0.20 by d 20.
**Endocrine and Metabolic Indicators**

All blood constituents are reported in least squares means (Table 3). Cortisol was affected by plane of nutrition and treatment ($P < 0.08$; Figure 2). There was also a significant day effect in that d 21 ($12.65 ± 1.01$ ng/mL) was greater ($P < 0.05$) than d 0 through d 17 ($~7.8$ ng/mL) but not d –7 ($10.36 ± 1.01$ ng/mL). Within the moderate plane of nutrition, tick-treated steers had greater ($P < 0.05$) plasma cortisol concentrations than nontreated steers. Day 21 samples ($12.31 ± 1.43$ ng/mL) within the moderate group also exhibited greater ($P < 0.05$) cortisol concentrations than any other day (all $<8.8$ ng/mL). There was no treatment effect ($P > 0.05$) within the low plane of nutrition, but d –17 cortisol concentration ($6.76 ± 1.43$ ng/mL) was less ($P < 0.05$) than d 21 ($12.31 ± 1.43$ ng/mL). Insulin-like growth factor-I concentration was greater ($P < 0.01$) in moderate than low steers, and in control compared with tick-treated steers ($P < 0.02$; Figure 3). Within the moderate group, there was no difference ($P > 0.1$) in IGF-I among treatments. However, within the low group, IGF-I concentration was greater in control ($P < 0.01$) than in treated steers. There was a significant plane of nutrition by day interaction ($P < 0.02$). During peak tick feeding, IGF-I concentration was greater in controls than tick-treated steers.

Tick treatment had little effect on the metabolites measured in this study (Table 3). Only GGT approached significance ($P < 0.1$), with approximately twice the concentration observed in treated vs. control steers. Within the low plane of nutrition, tick burden resulted in greater ($P < 0.04$) AST values compared with controls ($66.95 ± 2.39$ and $58.8 ± 2.39$ U/L, respectively). Plane of nutrition affected ALB ($P < 0.02$), BUN ($P < 0.01$), and GLU ($P < 0.01$), in that values from moderate-group steers were greater than those from the low group. There was a plane of nutrition by treatment interaction ($P < 0.04$) for HGB; the magnitude of difference between treated and control groups was greater in the moderate plane of nutrition group. The effect of day was highly significant ($P < 0.01$) for all metabolites, except GLU ($P < 0.1$) and GGT ($P = 0.08$). A model containing BUN, GLU, and NEFA at d 12 and 21 described $54.9\%$, $66.4\%$, and $75.5\%$ of the variation in d 21 BCS, d 21 BW, and d 0 to 21 ADG ($P < 0.01$), respectively.

### DISCUSSION

The ticks used in this study were able to successfully complete a normal feeding cycle (Drummond, 1971), the pattern and duration of which was not affected by plane of nutrition. By the end of the feeding cycle, there was, however, a lower yield of engorged ticks recorded in the low plane of nutrition group. Cattle in both groups visibly experienced some degree of irritation, as evidenced by periodic attempts to groom the ticks from their backs. The low plane of nutrition cattle were physically smaller than the moderate group as the experiment progressed and appeared to be more successful at contorting their torso within the stanchions to reach the tick stockinettes

**Table 2.** Effect of plane of nutrition and day of the tick feeding cycle on total daily and cumulative engorged female Lone Star tick dropoff from growing steers

<table>
<thead>
<tr>
<th>Day</th>
<th>Moderate Daily Mean</th>
<th>Moderate Daily SE</th>
<th>Moderate Cumulative Mean</th>
<th>Moderate Cumulative SE</th>
<th>Moderate Cumulative %</th>
<th>Low Daily Mean</th>
<th>Low Daily SE</th>
<th>Low Cumulative Mean</th>
<th>Low Cumulative SE</th>
<th>Low Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>9</td>
<td>2.7</td>
<td>2.1</td>
<td>2.7</td>
<td>2.1</td>
<td>2.0</td>
<td>0.7</td>
<td>0.4</td>
<td>0.7</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>10</td>
<td>19.7</td>
<td>9.7</td>
<td>22.4</td>
<td>11.7</td>
<td>7.5</td>
<td>13.9</td>
<td>4.6</td>
<td>14.6</td>
<td>4.8</td>
<td>4.9</td>
</tr>
<tr>
<td>11</td>
<td>71.1</td>
<td>14.7</td>
<td>93.6</td>
<td>23.9</td>
<td>31.2</td>
<td>50.6</td>
<td>6.1</td>
<td>65.1</td>
<td>8.7</td>
<td>21.7</td>
</tr>
<tr>
<td>12</td>
<td>105.6</td>
<td>8.2</td>
<td>199.1</td>
<td>21.0</td>
<td>66.4</td>
<td>105.1</td>
<td>8.3</td>
<td>170.3</td>
<td>6.5</td>
<td>56.8</td>
</tr>
<tr>
<td>13</td>
<td>56.0</td>
<td>8.6</td>
<td>254.7</td>
<td>13.0</td>
<td>84.9</td>
<td>62.0</td>
<td>8.8</td>
<td>232.3</td>
<td>8.2</td>
<td>77.4</td>
</tr>
<tr>
<td>14</td>
<td>22.4</td>
<td>6.1</td>
<td>276.6</td>
<td>7.4</td>
<td>92.2</td>
<td>27.3</td>
<td>2.7</td>
<td>259.6</td>
<td>7.9</td>
<td>86.5</td>
</tr>
<tr>
<td>15</td>
<td>12.4</td>
<td>3.9</td>
<td>288.6</td>
<td>4.9</td>
<td>96.2</td>
<td>11.4</td>
<td>2.4</td>
<td>270.1</td>
<td>6.3</td>
<td>90.0</td>
</tr>
<tr>
<td>16 to 21</td>
<td>2.3</td>
<td>0.2</td>
<td>290.0</td>
<td>4.3</td>
<td>96.7</td>
<td>3.1</td>
<td>0.3</td>
<td>272.8</td>
<td>5.8</td>
<td>90.9</td>
</tr>
</tbody>
</table>
Tolleson et al. (authors’ personal observations). So, we cannot attribute our observed difference in cumulative tick drop to only nutritional differences among the groups. In a review of the relationships between ectoparasites and herbivore nutrition, Sutherst (1987) reported that an effect of host nutrition on ticks has been observed by several authors. For instance, Sutherst (1987) cites a study in which “lean” sheep had a 50% greater number of ticks than “fat” sheep. Additionally, growing steers fed lucerne exhibited greater resistance to Boophilus microplus than did steers grazing autumn and winter pasture in Queensland (Sutherst et al., 1983). The cattle fed lucerne were heavier than the pastured group at the end of the feeding trial (~ 400 vs. 300 kg, respectively) and maintained a greater tick resistance than the original pastured cattle after returning to pasture the following year. Perhaps, our study was not of sufficient duration or magnitude between planes of nutrition to allow expression of an effect of host nutritional status on tick viability of a single cohort.

**Animal Performance**

When expressed as a proportion of pretreatment (d 0) DMI, overall DMI was depressed during the peak tick feeding and blood sampling periods (Figure 4). In a study using Holstein-Friesian cows exposed to gradually increasing burdens of *Boophilus microplus*, control cows produced 2.86 L more milk and 0.14 kg more butterfat per day and gained 10.6 kg more BW than infested cows over a 15-wk period (Jonsson et al., 1998). The daily DMI of control cows in Jonsson et al. (1988) was 0.83 kg greater than that for infested cows by wk 12. Seebeck et al. (1971) reported that daily feed intake was decreased ~15% and BW gain ~50% in cattle infested with *B. microplus* vs. tick-free cattle. Also in Seebeck et al. (1971) was a tick-free group of cattle that were pair fed to the same level of intake as the tick group. Both of these groups gained less BW than the tick-free group with ad libitum intake. Dry matter intake was numerically affected by treatment in our study, but this observance could also have been due to the coincident frequent blood sampling procedures because a numerical depression in DMI was observed in the control cattle.

### Table 3. The effect of plane of nutrition and tick treatment on metabolic and endocrine constituents in growing beef steers across all sampling days

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Moderate LSMean¹</th>
<th>Moderate SE</th>
<th>Low LSMean</th>
<th>Low SE</th>
<th>Control LSMean</th>
<th>Control SE</th>
<th>Tick LSMean</th>
<th>Tick SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALB</td>
<td>3.51ᵃ</td>
<td>0.05</td>
<td>3.35ᵃ</td>
<td>0.05</td>
<td>3.40ᵇ</td>
<td>0.05</td>
<td>3.45ᵃ</td>
<td>0.05</td>
</tr>
<tr>
<td>BUN</td>
<td>7.01ᵃ</td>
<td>0.22</td>
<td>2.89ᵇ</td>
<td>0.22</td>
<td>5.01ᵃ</td>
<td>0.22</td>
<td>4.90ᵇ</td>
<td>0.22</td>
</tr>
<tr>
<td>GLU</td>
<td>101.47ᵃ</td>
<td>2.12</td>
<td>90.44ᵇ</td>
<td>2.13</td>
<td>96.66ᵇ</td>
<td>2.12</td>
<td>95.26ᵇ</td>
<td>2.12</td>
</tr>
<tr>
<td>BHBA</td>
<td>453.31ᵃ</td>
<td>32.01</td>
<td>444.30ᵃ</td>
<td>32.06</td>
<td>428.13ᵃ</td>
<td>32.03</td>
<td>469.48ᵃ</td>
<td>32.04</td>
</tr>
<tr>
<td>NEFA</td>
<td>0.25ᵃ</td>
<td>0.02</td>
<td>0.26ᵃ</td>
<td>0.02</td>
<td>0.24ᵇ</td>
<td>0.02</td>
<td>0.27ᵇ</td>
<td>0.02</td>
</tr>
<tr>
<td>AST</td>
<td>62.98ᵃ</td>
<td>2.04</td>
<td>62.89ᵇ</td>
<td>2.05</td>
<td>61.01ᵇ</td>
<td>2.04</td>
<td>64.86ᵇ</td>
<td>2.05</td>
</tr>
<tr>
<td>GGT</td>
<td>30.07ᶜ</td>
<td>7.75</td>
<td>20.92ᶜ</td>
<td>7.76</td>
<td>16.12ᶜ</td>
<td>7.75</td>
<td>34.87ᵈ</td>
<td>7.75</td>
</tr>
<tr>
<td>HGB</td>
<td>27.64ᵃ</td>
<td>2.11</td>
<td>26.56ᵃ</td>
<td>2.13</td>
<td>27.75ᵃ</td>
<td>2.12</td>
<td>26.45ᵃ</td>
<td>2.12</td>
</tr>
<tr>
<td>IGF-I</td>
<td>191.26ᵃ</td>
<td>6.38</td>
<td>125.06ᵇ</td>
<td>6.41</td>
<td>169.74ᵃ</td>
<td>6.39</td>
<td>146.58ᵇ</td>
<td>6.39</td>
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<tr>
<td>Cort</td>
<td>7.35ᶜ</td>
<td>0.87</td>
<td>9.61ᵈ</td>
<td>0.87</td>
<td>7.32ᶜ</td>
<td>0.87</td>
<td>9.64ᵈ</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Within plane of nutrition or treatment comparisons, means within a row without a common superscript differ (P < 0.05).

Within plane of nutrition or treatment comparisons, means within a row without a common superscript differ (P < 0.1).

¹LSMean = least squares mean; ALB = Albumin, g/dL; BUN = urea nitrogen, mg/dL; GLU = glucose, mg/dL; BHBA = beta-hydroxybutyrate, μmol/L; NEFA, mg/L; AST = aspartate aminotransferase, U/L; GGT = gamma-glutamyl transpeptidase, U/L; HGB = hemoglobin, g/dL; IGF-I, ng/mL; Cort = cortisol, ng/mL.
as well. Daily DMI in pen-fed animals appears to cycle normally (Cooper et al., 1999; Schwartzkopf-Genswein et al., 2004; Caldeira et al., 2007), but the decrease observed here is similar to that observed in previous tick-burden research done by our laboratory (Tolleson et al., 2010). In this previous study, intake of tick-treated and control cattle increased to ~20% above pretick infestation values through d 9. Dry matter intake for the tick-treated group declined 12 percentage points by d 12, whereas the control group maintained intake above the pretreatment values. It seems unlikely that in both studies a decrease in DMI of similar magnitude would have occurred at the same time period relative to tick treatment if this was just part of a normal cycle.

All cattle in our study gained BW, even those in the low plane of nutrition, tick-treated group. As expected, moderate plane of nutrition steers gained more BW and were in better condition at the end of the trial than the low group. We did not monitor feed intake or BW gain in the current study past d 21. We also did not have a nonstick-treated, nonblood-sampled experimental group. Anecdotally, however, there were 6 extra steers from the original herd that were not used in the current study. These animals were maintained in a dry lot and fed (ad libitum) a combination of the moderate experimental diet, plus any orts from cattle on both experimental diets during the trial. These nonexperimental animals weighed 171.5 ± 9.7 kg on d ~35 (vs. 197.8 ± 3.7 kg for the moderate control steers) but were 265.0 ± 10.8 kg by d 21 of the experiment. Corresponding d 21 BW for the moderate control steers was 283.4 ± 8.0 kg. Thus, proportionally, the 6 extra steers gained numerically more BW than did the moderate control treatment group (56 vs. 45% increase in BW). At the other extreme, the low plane of nutrition, tick-treated group achieved a 22% increase in BW.

Endocrine Indicators of Stress and Metabolism

Although less than values we reported in previous research (Tolleson et al., 2010), the cortisol concentrations observed in this study would indicate that these animals were indeed under stress. Grandin (1997) reported in a summary of several studies that baseline cortisol concentration for cattle is <9 ng/mL. Our individual values ranged from 1.43 to 28.73 ng/mL. Both low plane of nutrition and tick burden increased plasma cortisol concentration. Increased cortisol concentrations have been associated with malnutrition (Douyon and Schteingart, 2002). Dairy cows fed straw had greater cortisol concentrations than those fed straw and silage (Odensten et al., 2007). Willis et al. (1995), using Ambystoma maculatum, and Riley et al. (1995), using A. americanum, reported no effect of ticks on cortisol in cattle. A review of Byford et al. (1992) reported an increase in cortisol coincident with increasing numbers of horn flies (Haematobia irritans). In our study, moderate control cattle possessed the least cortisol concentrations (6.0 ± 0.5 ng/mL) and these lie within the baseline values reported by Grandin (1997). Conversely, low plane of nutrition, tick-treated steers had the numerically greatest cortisol values (10.6 ± 0.5 ng/mL) in the experiment and these values are similar to that reported by Grandin (1997) for animals in the “restraint in headgate” category. All steers in this study were restrained in a headgate within their individual feed stanchions during blood sampling.

Our observed magnitude of ranges in cortisol values is similar to that observed before (~ 5 ± 1.0 ng/mL) and
after (~12 ± 2.0 ng/mL) jugular catheterization in cattle (Stewart et al., 2007). Cortisol concentration was similar between the low control and moderate tick groups. Of the greatest quartile of plasma cortisol values (15.78 ± 0.53 ng/mL, n = 60) obtained between d 0 and d 21 in this study, 61% were from low plane of nutrition cattle, 64% from the tick groups, and 41% from peak tick-feeding and blood-sampling days (d 10 to d 14), as compared with 32%, 43%, and 42%, respectively, from the least quartile (2.80 ± 0.13 ng/mL, n = 60). It is interesting to note that although the proportion of samples belonging to the upper and lower quartiles differed with respect to plane of nutrition and treatment, the proportion of samples with respect to day did not differ.

Our observation that the low nutritional plane steers had decreased IGF-I concentrations compared with their better-nourished counterparts is not surprising. When beef heifers fed to either maintain BCS or lose condition until becoming anovulatory were compared, the group fed to maintain BCS had greater plasma IGF-I concentrations than the heifers that lost body condition (Bossis et al., 1999). Mean concentration of IGF-I sequentially increased from low to moderate and tick to control in the current study. These values closely mirror those reported by Caldeira et al. (2007) in groups of sheep with BCS (1 = thin; 5 = fat) of 1.25, 2.0, 3.0, or 4.0. Corresponding IGF-I (ng/mL) values were 70.0 ± 13.5, 156.8 ± 27.6, 173.9 ± 27.7, and 209.0 ± 14.7 for each BCS group, respectively.

Disruption to homeostasis is also related to IGF-I concentrations. Disease-induced IGF-I reduction in bull calves (125 kg BW) was highly correlated to magnitude of infection and decreased BW gain (Elsasser et al., 1998). These authors also observed that hepatic mRNA for GH receptor and IGF-I was decreased in infected calves. In our earlier research, expression of hepatic GH receptor was greater in control than in tick-treated steers (Tolleson et al., 2010), and on d 0 than d 10 and 35 of the A. americanum-feeding cycle. In this same study, no differences in plasma IGF-I were observed among days of the feeding cycle, but IGF-I was greater in control than treated animals. Plasma IGF-I was considered the best indicator of short-term metabolic status and body composition in humans undergoing intense physical exertion and caloric restriction (Nindl et al., 2007). Although cortisol was related to both tick treatment and nutritional status in the current study, with respect to the combination of parasitism and suboptimal nutrition, IGF-I concentration was the most highly indicative constituent measured.

**Metabolic Indicators**

The metabolites measured in this study were largely not affected by tick treatment. Perhaps, the immunosuppressive capabilities of the ticks (Nuttall, 1998) attenuated the normal host proinflammatory response. Cattle infested with B. microplus possessed less serum ALB than noninfested animals (O’Kelly and Kennedy, 1981). These authors found no effect of ticks on either NEFA or GLU. O’Kelly et al. (1971) observed reduced HGB but not NEFA or GLU in B. microplus-treated compared with nontreated steers. In A. americanum-infested cattle, Willis et al. (1995) reported no effects of tick feeding on cortisol, total blood protein, BUN, or GLU. It should be noted that in their study, a lighter tick burden (20 to 120 adult pairs per animal) was used than in our study (300 adult pairs per animal).

Plane of nutrition caused expected differences in ALB, BUN, and GLU, but surprisingly not in NEFA or BHBA. We also did not observe the negative relationship between GLU and NEFA often reported for nutritionally stressed animals (Yelich et al., 1996; Bossis et al., 1999; Kida, 2002; van Knegsel et al., 2005). A nutritional balance analysis (Nuthal Pro, Stuth et al., 1999) indicates that the low plane of nutrition steers would have been just slightly positive for energy and these steers did gain BW throughout the experiment. There were some interesting relationships observed between metabolic and endocrine constituents measured. For instance, BHBA was negatively correlated with GLU within both the moderate and low groups. Concentrations of IGF-I and GLU were positively correlated in both planes of nutrition. Lastly, the NEFA vs. cortisol relationship was positive in both the moderate and low groups. These relationships are to be expected within the context of energy metabolism as affected by level of nutrition and hypothalamic-pituitary-adrenal axis activity. Restraint and isolation for 2 to 6 h increased cortisol and GLU but not NEFA in treated steers vs. controls (Apple et al., 2005). Kushibiki et al. (2003) observed that NEFA and cortisol increased in response to tumor necrosis factor α (TNF-α) vs. saline in lactating cows. The increase in NEFA...
occurred even though these early lactation cows (i.e., in negative energy balance) already exhibited increased NEFA. These same authors report that IGF-I decreased in the TNF-α-challenged cows.

In an attempt to elucidate the relationships among tick burden, plane of nutrition, and animal performance, multiple stepwise-regression models were developed. The most notable of these contained BUN, GLU, and NEFA at d 12 and 21. This model described ~50 to 75% of the variation in BCS, BW, and ADG at the end of the trial. Individual animal metabolic responses within the treatment groups were as important as were treatment differences.

**Conclusions**

Tick burden affected various characteristics of growth and metabolism in these growing steers and the effects were exacerbated by a low plane of nutrition. Grazing cattle experience spatial and temporal variation in both diet quality and quantity in many rangeland or pasture management scenarios. Lone Star ticks occur primarily in the Southeast and South Central United States, and they tend to infest animals during summer when droughts are more common. Barnard (1985) reported lower BW gain in *A. americanum*-infested beef calves compared with controls. This BW difference was greater in a drought year than in the previous, or average, year. Drought in the short term and climate in the long term, if current projections hold true, will result in an overall reduced plane of nutrition for cattle (Craine et al., 2010). The effects of chronic tick exposure on nutritionally compromised cattle may be more severe than reported in this study.

In addition to the individuality observed, experimental day had a large effect in this study. It would appear that both tick burden and the combined stress of the experiment had an effect on animal performance, though it would be difficult to distinguish the effects of ticks vs. those of confinement and blood sampling from these data. Based on our results and those of previous workers, our hypothesis is that the stress of tick feeding was confounded with that of frequent blood sampling. Thus, our research not only provides insights concerning the interaction of ticks and host nutrition, but also illustrates the need for alternate methods of evaluating stress and metabolism in livestock. Fecal chemistry and/or near-infrared spectroscopy offer potential solutions for noninvasive monitoring of stress and nutrition in grazing animals.

**LITERATURE CITED**


