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PRODUCTION AND MANAGEMENT: *Original Research*

Supplemental monensin affects growth, physiology, and coccidiosis infestation of early-weaned beef calves consuming warm-season perennial or cool-season annual grasses

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ABSTRACT

Objective: Two experiments evaluated the effects of supplemental monensin on growth and physiology of early-weaned beef calves grazing ryegrass (Exp. 1) or bahiagrass (Exp. 2).

Materials and Methods: Brangus calves were weaned at 3 mo of age, stratified by sex and BW, and randomly assigned into 1 of 8 pastures (2 steers and 2 heifers per pasture per year) of ryegrass (Exp. 1; n = 2 yr) or bahiagrass (Exp. 2; n = 1 yr) from d 0 to 84. Treatments were assigned to pastures (4 pastures per treatment per year) and consisted of concentrate supplementation at 1 or 2% of BW (DM basis) in Exp. 1 and 2, respectively, with or without 20 mg of monensin/kg of DMI.

Results and Discussion: Herbage nutritive value and allowance did not differ ($P \geq 0.23$) between treatments in Exp. 1 and 2, but herbage mass tended ($P = 0.10$) to increase by 5% for monensin versus control calves in Exp. 1. Calf overall ADG increased ($P \leq 0.005$), whereas fecal coccidia egg count on d 84 decreased ($P \leq 0.0004$), for monensin versus control calves in Exp. 1 and 2. Monensin supplementation tended ($P \leq 0.08$) to increase plasma insulin concentrations in Exp. 1 and 2 and increased ($P \leq 0.03$) plasma IGF-1 concentrations on d 56 in Exp. 1 and plasma urea nitrogen concentrations on d 84 in Exp. 2.

Implications and Applications: Supplemental monensin led to subtle changes to physiological parameters associated with energy metabolism, reduced coccidiosis infestation, and promoted the growth performance of early-weaned calves grazing ryegrass and bahiagrass pastures.

Key words: bahiagrass, beef cattle, early weaning, monensin, ryegrass

INTRODUCTION

Early weaning (**EW**) beef calves at 2 to 3 mo of age is an effective management practice to enhance reproductive performance of primiparous cows (Arthington and Kalmbacher, 2003). Favorable climatic conditions during the winter season in the southern United States provide an opportunity to raise EW calves on annual cool-season (Vendramini et al., 2006) and perennial warm-season grasses (Vendramini et al., 2015). However, regardless of forage type, EW calves have a relatively small rumen capacity and consequently require concentrate supplementation (i.e., 1 or 2% of BW; DM basis) to achieve growth performance similar to or greater than calves normally weaned at 8 mo of age (Vendramini et al., 2007; Moriel et al., 2014a,b). For example, concentrate DM supplementation at 1 and 2% of BW linearly increased the ADG of EW steers grazing Tifton 85 bermudagrass (*Cynodon* spp.; Vendramini et al., 2007) and annual ryegrass (*Lolium multiflorum*; Vendramini et al., 2006) compared with no concentrate supplementation.

Ionophores should be provided to EW calves as a strategy to further increase their growth performance by changing physiological parameters while controlling coccidiosis, as these calves are highly susceptible to this disease until 8 mo of age (Vendramini and Moriel, 2018). Coccidiosis is detrimental to young cattle and is caused by a protozoan present in forage and water sources (Keeton and Navarre, 2018). Although forage DMI is limited in EW calves receiving large amounts of concentrate DM supplementation (Vendramini et al., 2006, 2007, 2018), EW calves may get infected in areas of high animal and feces agglomeration (Keeton and Navarre, 2018), limiting their growth performance. Limited information about the potential benefits

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of monensin to the performance of EW beef calves grazing cool- and warm-season grass pastures and offered high concentrate DM supplementation is available in the literature (Vendramini et al., 2006; Vendramini and Moriel, 2018). The hypothesis of the study was that monensin supplementation would reduce coccidia infestation and increase growth performance of EW beef calves grazing annual cool-season or perennial warm-season forages. The objective of this study was to test the effects of monensin supplementation on fecal coccidia egg counts, BW gain, and physiological indicators of energy and protein metabolism of EW calves grazing ryegrass (Exp. 1) and bahiagrass (*Paspalum notatum*; Exp. 2) pastures.

MATERIALS AND METHODS

Animals were cared for following procedures approved by the University of Florida Institute of Food and Agriculture Sciences Animal Research Committee (protocol #201709703). Experiments 1 and 2 were conducted at the University of Florida Institute of Food and Agricultural Sciences Range Cattle Research and Education Center, Ona, Florida (27°26′N and 82°55′W). Experiment 1 was conducted from January to April 2015 and repeated from January to April 2016 (grazing phase only), whereas Exp. 2 was conducted from January to March 2018 (grazing phase) and April to May 2018 (drylot phase).

Animals and Diets

Exp. 1—Grazing Phase (d 0 to 84). Approximately 10 d before the start of the experiment, 64 Angus × Brahman crossbred calves (n = 16 steers and 16 heifers per year; n = 2 yr) were early weaned on average at 107 ± 18 d of age and 84.6 ± 14 kg of BW. Calves were held in a drylot with access to long-stem stargrass (*Cynodon nlemfuensis*) hay ad libitum and 1 kg/d of preconditioning concentrate (guaranteed analysis, as fed: 14% CP, 1.0% fat, 18% fiber, 0.75% Ca, 0.40% P, and 0.40% NaCl, Land O'Lakes Purina Feed LLC, Gray Summit, MO) for 10 d until the start of the experiment (d 0). On d 0 of each year, EW calves were stratified by sex, initial BW, and age and randomly allocated into 1 of 8 ryegrass pastures (2 steers and 2 heifers per pasture; 0.30 ha/pasture). All calves remained in their respective pasture assignment for 84 d. Treatments were randomly assigned to pastures (4 pastures per treatment per year) and consisted of concentrate DM supplementation at 1% of BW with or without 20 mg of monensin (Rumensin 90; Elanco Animal Health, Greenfield, IN) per kilogram of an estimated total DMI of 2.5% of BW (NASEM, 2016). The supplement DM amount was selected based on previous results from Vendramini et al. (2006) demonstrating that optimal growth and economic feasibility occurred when EW calves grazing annual rye–ryegrass mixtures were supplemented with concentrate DM at 1 versus 0 and 2% of BW. The proposed monensin amount was added daily to the concentrate immediately before feeding (0800 h). Concentrate consisted of (DM basis) 21.0% soybean hulls, 15.7% cottonseed meal, 15.0% cottonseed hulls, 8.8% wheat middlings, 8.0% dried distillers grains, 8.0% citrus pulp pellets, 7.8% cracked corn, 7.8% corn meal, 5.4% soybean meal, 2.0% sugarcane molasses, 0.50% Ca carbonate, 0.05% trace mineral premix, and 0.02% vitamin E (94% DM, 78% TDN, 16% CP). All calves received daily free-choice access to a commercial vitamin–mineral mix (Lakeland Animal Nutrition, Lakeland, FL; 14, 0.3, 24, and 9.0% of Ca, Mg, NaCl, and P, respectively, and 50, 1,500, 20, 40, and 3,000 mg/kg of Co, Cu, I, Se, and Zn, respectively).

Exp. 2—Grazing Phase (d 0 to 84). Forty-eight Angus × Brahman crossbred calves (24 steers and 24 heifers) were weaned on January 9, 2018 (initial age = 92 ± 14 d; initial BW = 97 ± 12 kg). Calves were held in a drylot with access to long-stem stargrass hay ad libitum and 1 kg/d of preconditioning concentrate (same concentrate as described in Exp. 1) for 10 d. On d 0, calves were stratified by sex, initial BW, and age and randomly allocated into 1 of 8 bahiagrass pastures (3 steers and 3 heifers per pasture; 0.4 ha/pasture). All calves remained in their respective pasture assignment for 84 d. Treatments were randomly assigned to pastures (4 pastures per treatment) and consisted of concentrate DM supplementation at 2% of BW with or without 20 mg of monensin (Rumensin 90; Elanco Animal Health) per kilogram of an estimated total DMI of 2.5% of BW (NASEM, 2016). The supplement DM amount was selected based on previous results from Vendramini et al. (2007) demonstrating that optimal growth and economic feasibility occurred when EW calves grazing perennial bermudagrass were supplemented with concentrate DM at 2 versus 0 and 1% of BW. The proposed monensin amount was added daily to the concentrate immediately before feeding (0800 h). Concentrate consisted of (DM basis) 21.0% soybean hulls, 15.7% cottonseed meal, 15.0% cottonseed hulls, 8.8% wheat middlings, 8.0% dried distillers grains, 8.0% citrus pulp pellets, 7.8% cracked corn, 7.8% corn meal, 5.4% soybean meal, 2.0% sugarcane molasses, 0.50% Ca carbonate, 0.05% trace mineral premix, 0.04% Bovatec 90 (Alpharma Inc., Fort Lee, NJ), and 0.02% vitamin E (94.1% DM, 75% TDN, 28.4% CP, 23.2% ADF, 1.78 Mcal/kg NE_m, 1.17 Mcal/kg NE_g, 1.57% Ca, 0.58% P, 0.44% S, 0.28% Mg, 1.32% K, 0.067% Na, 185 mg/kg Fe, 53 mg/kg Zn, 9 mg/kg Cu, 30 mg/kg Mn, and 1.9 mg/kg Mo). All calves received daily free-choice access to a commercial vitamin–mineral mix (University of Florida Cattle Research Winter Mineral; Vigortone, Brookville, OH; 16.8, 1.0, 20.7, and 4.0% of Ca, Mg, NaCl, and P, respectively, and 60, 1,750, 350, 60, and 5,000 mg/kg of Co, Cu, I, Se, and Zn, respectively).

Exp. 2—Drylot Phase (d 85 to 101). On d 85, 12 calves per treatment (6 steers and 6 heifers) were randomly assigned to 1 of 24 individual concrete floor pens (18 m^2/pen) in a fully covered drylot facility for a 17-d evaluation period (adaptation from d 85 to 94, daily for-

age intake data collection from d 95 to 101, and daily fecal sample collection from d 99 to 101) to evaluate forage and total DMI, and apparent DM digestibility. From d 85 to 101, calves remained on their respective treatment previously assigned on d 0 (same supplement type and amount as offered during the grazing phase) and were provided daily free-choice access to ground stargrass hay (11.2% CP, 43.9% ADF, 75.8% NDF, 53% TDN; DM basis).

Sample and Data Collection

Grazing Phase. In Exp. 1 and 2, each pasture was sampled for herbage mass (**HM**) and nutritive value [CP and in vitro digestible OM (**IVDOM**)] every 14 d but reported at 28-d intervals from d 0 to 84. The double sampling technique was used to determine HM according to Gonzalez et al. (1990). Briefly, the indirect measure was the settling height of a 0.25-m^2 aluminum disk, and the direct measure involved hand clipping all herbage to a 2-cm stubble from the same area using an electric clipper. Every 28 d, 1 or 2 double samples were taken from each experimental unit for a total of 20 samples per pasture that represented the HM range present on pastures. At each site, the disk settling height was measured and the forage clipped. Clipped forage was dried for 72 h at 60°C and weighed. The herbage mass from the clipped sample and the corresponding disk height were used to develop a regression equation, which was later used to estimate HM. Herbage allowance (**HA**) was calculated as the average HM divided by the average total BW of calves in each pasture (Sollenberger et al., 2005). Hand-plucked forage samples were collected from each pasture every 14 d, dried at 55°C for 72 h in a forced-air oven, ground to pass a 1-mm screen (Model 4, Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ), and analyzed for IVDOM as described by Moore and Mott (1974). Nitrogen concentration was determined using a micro-Kjeldahl method, a modification of the aluminum block digestion technique described by Gallaher et al. (1975). Crude protein was determined by multiplying N concentration by 6.25. Individual samples of the concentrate were collected every 28 d, pooled across months, and then sent in duplicate to a commercial laboratory (Dairy One Forage Laboratory, Ithaca, NY) for wet chemistry analysis of all nutrients.

Calf BW were assessed immediately before concentrate feeding at 0800 h on d 0, 28, 56, and 84 (Exp. 1) and on d 0, 56, and 84 (Exp. 2). Blood samples (10 mL) were collected via jugular venipuncture into tubes containing sodium heparin (Vacutainer, Becton Dickinson, Franklin Lakes, NJ) for plasma harvest on d 0, 28, 56, and 84 (Exp. 1) and d 0, 56, and 84 (Exp. 2). Blood was centrifuged at 2,000 × *g* at 4°C for 30 min, and plasma was harvested and kept frozen at −80°C until further analysis to determine the plasma concentrations of insulin, glucose, plasma urea nitrogen (**PUN**), and IGF-1. Plasma concentrations of insulin were determined using Coat-A-Count solid-phase 125I RIA kits (Siemens Healthcare Diagnostics, Los Angeles, CA) previously validated for bovine samples (Moriel et al., 2008). Plasma concentrations of glucose and PUN were determined using quantitative colorimetric kits (#G7521 and B7551, respectively; Pointe Scientific Inc., Canton, MI). Concentrations of IGF-1 were determined using a human-specific commercial ELISA kit (SG100; R&D Systems Inc., Minneapolis, MN) with 100% cross-reactivity with bovine IGF-1 and previously validated for bovine samples (Moriel et al., 2012). The intra- and inter-assay CV were 2.9 and 4.8% for insulin, 3.2 and 4.5% for glucose, 3.9 and 4.9% for PUN, and 6.2 and 5.0% for IGF-1. The minimum detectable concentration was 0.01 μIU/mL for insulin and 0.056 ng/mL for IGF-1.

Rectal fecal samples were collected from all calves on d 0 and 84 (Exp. 1 and 2). All fecal samples were stored in plastic bags, placed in an insulated container with ice, and then sent to a commercial laboratory (Myers Parasitology Services, Magnolia, KY) for analysis of fecal coccidia egg count using the modified Wisconsin sugar flotation technique (Cox and Todd, 1962). Total fecal coccidia egg counts (observed egg count + 1) of each calf were log-transformed before statistical analyses and reported as $\log_{10}$ (Martins et al., 2017). In Exp. 1, all calves were negative for the fecal coccidia eggs on d 0.

Drylot Phase. In Exp. 2, BW of all calves were also assessed immediately before concentrate feeding at 0800 h on d 84 and 101. Hay and concentrate samples were collected daily, dried at 55°C for 72 h in a forced-air oven, and ground to pass a 1-mm screen to determine the forage and concentrate DM concentration and, consequently, calculate forage and total daily DMI from d 95 to 101. Rectal fecal samples from all calves in drylot were collected twice daily (0800 and 1500 h) from d 99 to 101 to determine in vivo apparent DM digestibility using the indigestible NDF procedure. Fecal samples were pooled across all fecal collection days for each calf. Concentrations of indigestible NDF in the forage, concentrate, and feces were determined as described by Cole et al. (2011) with modifications proposed by Krizsan and Huhtanen (2013). Four grams of forage was placed in 20 × 10-cm N-free polyester bags with pore sizes ranging from 50 to 60 μm. The bags were heat sealed and incubated for 288 h in one ruminally fistulated Braford steer. The steers were housed in a pen with ad libitum access to stargrass hay. All the bags representing all experimental units were incubated and removed from the steers simultaneously. The bags removed from the rumen were rinsed repeatedly until the rinsing water was colorless. Finally, bags were dried at 60°C for 48 h and weighed. Dried samples were analyzed for NDF concentration using the method of Van Soest et al. (1991) adapted for an Ankom 200 Fiber Analyzer (Ankom Technology Corp., Macedon, NY). Heat-stable α-amylase and sodium sulfite were used in the NDF assay, and the results are presented inclusive of residual ash. Total feces output and apparent DM digestibility were calculated as described by Vendramini et al. (2018).

Statistical Analyses

All data analyses included Satterthwaite approximation to determine the denominator df for the test of fixed effects using MIXED procedure (SAS Institute Inc., Cary, NC, version 9.4). Pasture and calf were considered the experimental units for the grazing (Exp. 1 and 2) and drylot phases (Exp. 2 only), respectively. In Exp. 1, pasture(treatment × year), calf sex, and calf(pasture) were included as random effects in all analyses of animal responses. In Exp. 2, pasture(treatment), calf sex, and calf(pasture) were included as random effects in all analyses of grazing phase, whereas calf(treatment) and calf sex were included as random effects in all analyses during the drylot phase. Pasture evaluation, growth performance, plasma parameters, and fecal egg counts (Exp. 2. only) during the grazing phase were analyzed as repeated measures and tested for fixed effects of treatment, day, year, and all resulting interactions (Exp. 1), and treatment, day, and treatment × day (Exp. 2). Pasture(treatment) was considered the subject for analyses of forage evaluation, whereas calf(treatment) was the subject in the analyses of growth and plasma measurements. In Exp. 1, all calves were negative for coccidia fecal egg count on d 0, and hence, fecal egg count on d 84 was tested for the fixed effects of treatment, year, and treatment × year using pasture(treatment) and calf(pasture) as random effects. Compound symmetry covariance structure was used for analyses of repeated measures. Plasma measurements and calf BW obtained on d 0 were used as covariates if $P \leq 0.05$. In Exp. 2, calf growth and forage and total DMI during drylot phase were tested for fixed effects of treatment. All results were reported as least squares means. Significance was set at $P \leq 0.05$, and tendencies were declared if $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Growth Performance

In Exp. 1 and 2, calf age did not differ between treatments ($P \geq 0.67$) but was included as a covariate ($P \leq 0.05$) in the analyses of calf BW and ADG. Effects of treatment × day × year and treatment × year were not detected ($P \geq 0.42$) for calf BW in Exp. 1. In agreement with our hypothesis, effects of treatment × day were detected ($P \leq 0.0007$) for calf BW in Exp. 1 and 2 (Table 1). In Exp. 1, calf BW on d 0 and 28 did not differ ($P \geq 0.28$) between treatments but increased ($P \leq 0.001$) for monensin versus control calves on d 56 and 84. In Exp. 2, calf BW did not differ ($P = 0.61$) between treatments on d 0 but increased ($P \leq 0.0006$) for monensin versus control calves on d 56 and 84. Calf ADG from d 0 to 28, 28 to 56, and 56 to 84 and overall ADG from d 0 to 84 in Exp. 1 were always greater ($P \leq 0.04$) for monensin versus control calves (Table 1), whereas in Exp. 2, calf ADG from d 0 to 56 and 0 to 84 were greater ($P \leq 0.008$) for monensin versus control calves and tended ($P = 0.07$) to increase for monensin versus control calves from d 56 to 84 (Table 1). Overall, monensin supplementation increased the ADG of EW calves by 0.17 and 0.14 kg/d in ryegrass (Exp. 1) and bahiagrass pastures (Exp. 2), respectively, which is in agreement with previous studies (Rouquette et al., 1980; Vendramini et al., 2018). Beef calves grazing bermudagrass (*Cynodon dactylon*) and receiving 0.90 kg/d concentrate added with 200 mg/d monensin had greater ADG (0.54 vs. 0.40 kg/d) compared with beef calves receiving concentrate without monensin (Rouquette et al., 1980). Average daily gain of EW calves offered stargrass hay increased from 0.36 to 0.44 kg/d when monensin (20 mg/kg of total DMI) was added to the supplement (Vendramini et al., 2018). In contrast, supplementation of 200 mg/d monensin did not affect the overall ADG of beef heifers grazing bahiagrass pastures and offered a soybean hulls–based supplement at 0.40 kg/d (Vendramini et al., 2015) or 2 kg/d sugarcane molasses + 0.50 kg/d cottonseed meal (Moriel et al., 2019). The monensin-induced mechanisms leading to greater growth performance will be discussed below, but plausible explanations for the discrepancy on growth performance of calves supplemented or not with monensin among the studies described above may include the supplement amount, composition, forage type, and level of coccidia infestation.

Forage Responses

Growth performance of cattle is regulated by intake (50–70%), digestibility (24–40%), and metabolism (5–15%, Mertens, 2009). Effects of treatment × day and treatment × year × day were not detected ($P \geq 0.23$) for HM, HA, IVDOM, and CP in Exp. 1 and 2. Herbage CP and IVDOM concentrations did not differ between treatments in Exp. 1 and 2 ($P \geq 0.23$) but changed monthly similarly to our previous study (Vendramini et al., 2006). In Exp. 1, the growth period was longer for herbage on d 0 (approximately 80 d from planting) relative to subsequent forage regrowth periods (28 d), and this may have reduced CP concentration on d 0 versus 28 and 56. Also, herbage CP concentration was less on d 84 compared with d 28 and 56 due to the greater presence of reproductive tillers on d 84. Similarly, bahiagrass CP and IVDOM in Exp. 2 decreased with maturity from d 0 to 84. The reduced leaf:stem ratio caused by the onset of reproductive-stem elongation is usually the main factor decreasing the nutritive value of warm-season grasses (Sollenberger et al., 1988). Despite the monthly changes to forage CP and IVDOM, forage nutritive value in both experiments remained at adequate levels to meet the energy and protein requirements of EW calves during the entire study (NASEM, 2016).

Herbage mass and HA in Exp. 1 and 2 gradually decreased ($P < 0.0001$) from d 0 to 84 (Table 2) due to the consumption of calves being greater than the forage accumulated during winter. The levels of ryegrass HA observed in Exp. 1 were greater during the first 56 d but almost half of the minimum threshold that limits forage intake

Table 1. Body weight and ADG of early-weaned calves grazing ryegrass pastures and offered concentrate DM supplementation at 1% of BW (Exp. 1) or bahiagrass pastures and offered concentrate DM supplementation at 2% of BW (Exp. 2) with or without monensin (20 mg of monensin/kg of an estimated total DMI of 2.5% of BW) from d 0 to 84

	Treatment				*P*-value		
Item	Control	Monensin	SEM	*P*-value[1]	Treatment × day	Treatment	Day
Exp. 1							
BW,[2] kg							
d 0	85	85	1.8	0.90	<0.0001	0.009	<0.0001
d 28	107	110	1.8	0.29			
d 56	115	124	1.8	0.001			
d 84	130	145	1.8	<0.0001			
ADG,[2] kg							
d 0 to 28	0.78	0.88	0.034	—	—	0.04	—
d 28 to 56	0.30	0.52	0.057	—	—	0.02	—
d 56 to 84	0.54	0.73	0.042	—	—	0.002	—
d 0 to 84	0.54	0.71	0.036	—	—	0.005	—
Exp. 2							
BW,[2] kg							
d 0	96	97	1.4	0.61	<0.0001	0.004	<0.0001
d 56	143	151	1.4	0.0006			
d 84	164	175	1.4	<0.0001			
ADG,[2] kg							
d 0 to 56	0.83	0.99	0.027	—	—	0.008	—
d 56 to 84	0.72	0.84	0.039	—	—	0.07	—
d 0 to 84	0.80	0.94	0.021	—	—	0.003	—

[1]*P*-value for the comparison of treatment within day.

[2]Covariate adjusted for calf age ($P \leq 0.05$).

of EW calves (0.5 kg of DM/kg of BW; Vendramini and Arthington, 2008). Although ryegrass HM tended ($P = 0.10$) to increase for calves supplemented with monensin versus control (958 vs. 1,006 ± 15.0 kg of DM/ha, respectively), calves supplemented with monensin were heavier compared with control calves, and, consequently, overall ryegrass HA did not differ ($P = 0.91$) between treatments (1.09 vs. 1.08 ± 0.262 kg of DM/kg of BW, respectively). In Exp. 2, despite the gradual decrease in HA over time, the levels of bahiagrass HA were significantly greater during the entire grazing phase compared with the minimum threshold of 0.5 kg of DM/kg of BW described by Vendramini and Arthington (2008). Therefore, growth performance of EW calves in both experiments was not limited by herbage mass during most (Exp. 1) and all (Exp. 2) of the grazing phase, and the greater growth performance of calves supplemented with monensin reported in both experiments was associated with factors beyond herbage mass, allowance, and nutritive value.

Physiological Parameters

Additional factors that may explain the greater growth performance of monensin-fed calves compared with those not supplemented with monensin are differences in total diet digestibility and metabolism. Although forage intake and digestibility were not estimated during the grazing phase, forage and total DM consumption and apparent DM digestibility did not differ ($P \geq 0.17$) between calves supplemented or not with monensin during the drylot phase of Exp. 2 (Table 3) and in previous studies (Vendramini et al., 2018; Moriel et al., 2019). Therefore, we evaluated the plasma concentrations of hormones and metabolites associated with energy and protein metabolism that could potentially explain the differences in calf growth performance observed in the current study.

Effects of treatment × day and treatment were not detected ($P \geq 0.27$) for plasma concentrations of glucose in Exp. 1 and 2 (Table 4). Effects of treatment × day were not detected ($P \geq 0.30$) for plasma concentrations of IGF-1 in Exp. 2 but tended to be detected ($P = 0.009$) in Exp. 1. Effects of treatment × day were not detected ($P \geq 0.43$), but overall plasma concentrations of insulin tended to be greater for monensin versus control calves in Exp. 1 ($P = 0.08$) and 2 ($P = 0.07$; Table 4). Effects of treatment × day were not detected for plasma concentrations of PUN in Exp. 1 ($P \geq 0.43$) but tended to be detected ($P = 0.07$) in Exp. 2 (Table 4).

Monensin supplementation to cattle can enhance plasma concentrations of IGF-1 indirectly by stimulating the synthesis of glucose, leading to the release of insulin and

Table 2. Herbage mass (HM), herbage allowance (HA), in vitro digestible OM (IVDOM), and CP of ryegrass (Exp. 1) and bahiagrass (Exp. 2) pastures grazed by early-weaned calves offered concentrate supplementation with or without monensin (20 mg of monensin/kg of an estimated total DMI of 2.5% of BW) from d 0 to 84

	Day of the study					
Item[1]	0	28	56	84	SEM	*P*-value, day
Exp. 1						
HM, kg of DM/ha	1,393[a]	1,039[b]	955[c]	540[d]	22.5	<0.0001
HA, kg of DM/kg of BW	2.43[a]	0.95[b]	0.68[c]	0.28[d]	0.04	<0.0001
IVDOM, g/kg of DM	796[a]	798[a]	725[b]	708[c]	4.57	<0.0001
CP, g/kg of DM	195[a]	301[c]	237[b]	205[a]	5.5	<0.0001
Exp. 2						
HM, kg of DM/ha	6,071[a]	5,192[b]	3,302[c]	2,570[d]	152.7	<0.0001
HA, kg of DM/kg of BW	10.5[a]	6.9[b]	3.3[c]	2.4[d]	0.20	<0.0001
IVDOM, g/kg of DM	477[a]	430[bc]	411[c]	444[b]	13.0	<0.01
CP, g/kg of DM	177[c]	127[b]	105[d]	138[a]	5.0	<0.01

[a–d]Within a row, means without a common superscript differ ($P \leq 0.05$).

[1]Pastures were sampled for HM and nutritive value (CP and IVDOM) every 14 d but reported at 28-d intervals from d 0 to 84. The double sampling technique was used to determine HM according to Gonzalez et al. (1990). Herbage allowance was calculated as the average HM divided by the average total BW of calves in each pasture (Sollenberger et al., 2005).

IGF-1. In both experiments, effects of treatment × day and treatment were not detected ($P \geq 0.27$) for plasma concentrations of glucose, whereas plasma concentrations of insulin tended ($P = 0.08$ and 0.07 in Exp. 1 and 2, respectively) to increase following monensin supplementation (Table 4; treatment × day effects for plasma insulin concentrations were not detected; $P \geq 0.43$). Effects of treatment × day were not detected ($P = 0.30$) for plasma concentrations of IGF-1 in Exp. 2 but tended to be detected ($P = 0.009$) in Exp. 1, when plasma concentrations of IGF-1 were greater on d 56 (and numerically greater on d 28 and 84) after monensin was added to the concentrate supplement. The increases in plasma concentrations of glucose, insulin, and IGF-1 were expected (Cappellozza et al., 2014a,b). Vendramini et al. (2018) reported no differences in plasma concentrations of glucose and insulin but increased plasma concentrations of IGF-1 when monensin was offered to EW calves grazing bahiagrass and supplemented with concentrate DM at 1 and 2% of BW. Moriel et al. (2019) reported no differences in plasma concentrations of glucose, insulin, and IGF-1 between heifers supplemented with molasses + cottonseed meal with or without monensin. Although supplement composition may have played a role, the discrepancy among these studies on

Table 3. Drylot growth performance, DMI, and apparent DM digestibility of calves offered daily free-choice access to ground stargrass and offered concentrate DM supplementation at 2% of BW with or without monensin (20 mg of monensin/kg of an estimated total DMI of 2.5% of BW) from d 85 to 101 (Exp. 2)

	Treatment			
Item	Control	Monensin	SEM	*P*-value, treatment
BW,[1] kg				
d 84	176	185	4.7	0.21
d 101	197	207	5.2	0.17
Forage DMI,[2] % of BW	0.73	0.72	0.05	0.86
Total DMI,[2] % of BW	2.83	2.81	0.05	0.73
Apparent DM digestibility, g/kg of DM	781	773	16.7	0.63

[1]Full BW obtained on d 84 and 101 of calves randomly selected and assigned to the drylot phase from d 85 to 101.

[2]Forage and total DMI calculated as percentage of the average calf BW obtained on d 84 and 101.

Table 4. Plasma concentrations of glucose, IGF-1, insulin, and urea nitrogen (PUN) of early-weaned calves grazing ryegrass pastures and offered concentrate DM supplementation at 1% of BW (Exp. 1) or bahiagrass pastures and offered concentrate DM supplementation at 2% of BW (Exp. 2) with or without monensin (20 mg of monensin/kg of an estimated total DMI of 2.5% of BW) from d 0 to 84

	Treatment				*P*-value	
Plasma variable	Control	Monensin	SEM	*P*-value[1]	Treatment × day	Treatment
Exp. 1[2]						
Glucose, mg/dL	78.3	81.4	1.87	—	0.42	0.28
IGF-1, ng/mL						
d 0	105.4	109.7	18.32	0.87	0.09	0.51
d 28	77.1	112.1	18.32	0.19		
d 56	26.8	89.5	18.32	0.03		
d 84	45.7	58.4	18.32	0.63		
Insulin, μIU/mL	1.92	2.75	0.30	—	0.92	0.08
PUN, mg/dL	27.1	25.7	1.08	—	0.83	0.43
Exp. 2[3]						
Glucose, mg/dL	95.4	97.0	1.66	—	0.85	0.49
IGF-1, ng/mL	59.8	62.5	1.88	—	0.40	0.30
Insulin, μIU/mL	11.2	12.6	0.52	—	0.17	0.07
PUN, mg/dL						
d 0	5.73	7.81	2.63	0.58	0.07	0.12
d 56	12.0	9.91	2.63	0.58		
d 84	20.8	31.0	2.63	0.007		

[1]*P*-value for the comparison of treatment within day.

[2]Concentrations of glucose, PUN, and insulin on d 0 of Exp. 1 were not included as a covariate ($P \geq 0.19$). Plasma concentrations of IGF-1 on d 0 of Exp. 1 did not differ ($P \geq 0.59$) between treatments but were included as a covariate ($P = 0.03$).

[3]Plasma concentrations of glucose, insulin, and IGF-1 on d 0 of Exp. 2 did not differ ($P \geq 0.59$) between treatments but were included as a covariate ($P < 0.0001$). Concentrations of PUN on d 0 of Exp. 2 were not included as a covariate ($P = 0.65$).

plasma concentrations of glucose, insulin, and IGF-1 may be attributed to the timing of blood collection relative to time of day when supplements were offered. Plasma concentrations of glucose and insulin usually peak after 1 to 2 h after concentrate feeding (Moriel et al., 2008), whereas blood samples were collected immediately before feeding in both experiments. Hence, peak concentrations of plasma glucose, insulin, and IGF-1 were likely missed. Despite the mismatch between timing of blood collection and peak of plasma concentrations of these hormones and metabolites, the observed differences in plasma concentrations of insulin in Exp. 1 and 2 and IGF-1 in Exp. 1 support the rationale that the energy metabolism of EW calves was positively affected by monensin supplementation.

Concentrations of PUN are positively associated with intake of RDP, ruminal ammonia concentration, and ruminal protein:energy ratio (Hammond, 1997). Protein metabolism can also be affected by monensin, but variable responses have been reported for concentrations of PUN following monensin fortification of supplements. Monensin supplementation did not increase the PUN concentrations in some studies (Vendramini et al., 2018; Moriel et al., 2019). However, it significantly increased the PUN concentrations in other studies (Poos et al., 1979; Muntifering et al., 1980; Vendramini et al., 2015) likely due to an improved utilization of N associated with decreased proteolysis of dietary protein and altered site of protein digestion (Poos et al., 1979). Effects of treatment × day were not detected for concentrations of PUN in Exp. 1 ($P \geq 0.43$) but tended to be detected ($P = 0.07$) in Exp. 2, which did not differ between treatments on d 0 and 56 ($P = 0.58$; Table 4) and were below the optimal concentrations for growing animals (11 to 15 mg/dL; Byers and Moxon, 1980). However, concentrations of PUN in Exp. 2 increased on d 84 ($P = 0.007$; Table 4) for monensin versus control calves and were above the optimal concentration range. Despite the lack of treatment effects, concentrations of PUN in Exp. 1 were also above the 11 to 15 mg/dL range (Byers and Moxon, 1980). These results on PUN concentrations reflect the fluctuations in forage CP concentrations observed in both experiments. They also indicate that RDP and CP were consumed in excess from

Table 5. Rectal fecal coccidia egg counts of early-weaned calves grazing ryegrass pastures and offered concentrate DM supplementation at 1% of BW (Exp. 1) or bahiagrass pastures and offered concentrate DM supplementation at 2% of BW (Exp. 2) with or without monensin (20 mg of monensin/kg of an estimated total DMI of 2.5% of BW) from d 0 to 84

	Treatment				*P*-value	
Coccidia egg count,[1] log_{10} of eggs/g of feces	Control	Monensin	SEM	*P*-value[2]	Treatment × day	Treatment
Exp. 1						
d 0	0	0	—		—	<0.0001
d 84	1.15	0.40	0.086	<0.0001		
Exp. 2						
d 0	0.16	0.06	0.111	0.51	0.007	0.004
d 84	1.14	0.33	0.111	0.0004		

[1]Coccidia egg counts (observed egg count + 1) of each calf were log-transformed before statistical analyses and reported as log_{10} (Martins et al., 2017). Fecal coccidia egg count on d 0 was not detected in Exp. 1, did not differ ($P = 0.51$) between treatments in Exp. 2, and was not included as a covariate ($P = 0.12$).

[2]*P*-value for the comparison of treatment within day.

d 0 to 84 in Exp. 1 but in limited amounts until d 56 and in excess from d 56 to 84 in Exp. 1.

Coccidiosis Infestation

In addition to the subtle changes to protein and energy metabolism, monensin fortification of supplements may also improve calf performance by controlling coccidiosis (Stromberg et al., 1986; Hurst et al., 2018). Coccidiosis is a parasitic disease caused by the protozoan parasite of the genus *Eimeria* that can lead to either clinical disease or subclinical losses to growth performance of young cattle (Keeton and Navarre, 2018). High concentrations of this protozoa can accumulate in areas where animals often congregate and feces accumulate, such as a drylot, heavily stocked pastures, and watering and feeding areas (Keeton and Navarre, 2018). Cattle become immune to coccidia at around 1 yr of age but afterward may continue to serve as a reservoir to younger animals (Keeton and Navarre, 2018). Hence, coccidiosis is an important clinical and subclinical disease with negative effects on performance of EW calves. Intact ionophore residues are excreted by treated animals, and the manure produced by these animals may be applied to croplands as fertilizers, leach into the groundwater, or enter surface water through runoff (Hurst et al., 2018). Fecal coccidia eggs on d 0 were not detected in Exp. 1, whereas in Exp. 2, fecal coccidia egg counts on d 0 were minimal and did not differ between treatments ($P = 0.51$; Table 5). However, on d 84 of both experiments, fecal coccidia egg counts were 2.8- and 3.5-fold greater ($P < 0.001$) for control versus monensin calves in Exp. 1 and 2, respectively. These results are in agreement with other studies providing monensin to EW calves (Vendramini et al., 2018) and are likely a result of ionophore controlling levels of coccidia in the body as well as decreasing ground level contamination. Therefore, regardless of forage type, the lower coccidia contamination of monensin-fed calves was likely the main factor contributing to their greater growth performance compared with calves not offered monensin supplementation in both experiments.

APPLICATIONS

Supplement fortification with monensin in annual cool-season and perennial warm-season forage systems led to similar positive responses on performance of early-weaned beef calves. Supplemental monensin positively affected the plasma concentrations of energy metabolism–related hormones and metabolites, reduced the coccidia infestation, and increased the growth performance of early-weaned calves grazing annual ryegrass and perennial bahiagrass pastures.

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