RESEARCH ARTICLE

Monensin supplementation increases weight gain in stocker steers, but higher doses reduce essential mineral intake

Monensin in mineral supplements increases steer weight, but higher doses lead to reduced mineral intake.

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Abstract

Monensin is known to improve feed efficiency in cattle. At higher doses, however, monensin reduces the palatability of mineral supplements, which may reduce consumption of essential minerals such as selenium. The main objective of this study was to compare weight gain, while evaluating the impact on blood selenium concentrations, among treatment and control groups of stocker calves supplemented with a self-fed mineral supplement designed to deliver different amounts of monensin, while the control group received the same mineral without monensin. A secondary objective was to compare the presence of pathogenic and total coccidia oocysts. At study end, all monensin treatment groups weighed more than the control group but were not different from each other. No effect was detected on coccidia oocysts. In sum, there is a production gain from providing monensin in a mineral supplement to weaned calves on pasture. However, too high a dose may lead to insufficient trace mineral consumption. This is a concern in areas where forage is deficient in these nutrients.

Stocker calves between 6 and 9 months of age, weighing 450 to 650 pounds (lb) at the onset of the season, graze California rangelands from November through June while green feed is available, after which cattle are marketed to feedlots. Stocker operators face threats to their profit margins, including market price fluctuations and weight gain differences between years, caused by drought and limited forage availability (Forero et al. 2021) and coccidiosis (a parasitic gastrointestinal disease).

Stocker cattle are at risk of coccidiosis due to close contact while congregating on pastures. The disease is caused by one-celled parasites belonging to the genus *Eimeria*, with *E. bovis*, *E. zuernii* and *E. alabamensis* being the most important pathogenic species (Bangoura and Daugschies 2020). Coccidiosis can negatively impact the productivity of stocker cattle due to reduced feed efficiency, poor growth performance, and mortality from diarrhea and damage to the intestinal mucosa (Daugschies and Najdrowski 2005). Calves 3

A group of steers in a holding pen during weigh day. Results of the study suggest that adding monensin in a mineral mix can increase weight gain in stocker steers. However, maximum doses reduce palatability of the mix and may result in mineral deficiencies. *Photo*: Gabriele Maier.

to 6 months old are highly susceptible to coccidiosis; however, its prevalence can still be problematic for yearlings (Daugschies and Najdrowski 2005).

To improve productivity, feed additives are widely used in the cattle industry to increase feed efficiency and to provide essential nutrients to maintain health. Monensin is a type of compound called an ionophore; it has gained popularity among cattle operators since its approval in feedlot diets in 1975 to improve feed efficiency (Goodrich et al. 1984). Monensin acts as a methane inhibitor and propionate enhancer by shifting the ruminal flora toward propionate-producing ruminal bacteria (Guan et al. 2006). Because ionophores are not used in human medicine and have a distinctly different mode of action from therapeutic antibiotics, their use in livestock production has raised little concern about transfer of antimicrobial resistance to humans (Russell and Houlihan 2003).

Ionophores can significantly improve feed efficiency and weight gain. A meta-analysis of the effects of monensin on growth and bloat of cattle on pasture showed an estimated monensin response of a 23.4-lb increase in average ending body weight (BW) during a mean supplementation period of 112.6 days at a mean supplementation dose of 150 milligrams (mg) of monensin per day (Gadberry et al. 2022).

In addition, monensin can reduce growth and transmission of coccidia. The effectiveness of monensin in controlling pathogenic coccidia species has been shown in dairy calves (Stromberg et al. 1986) and more recently in early weaned beef calves (Vendramini et al. 2018).

One drawback of monensin is its low palatability. Many areas in California have soils that are low in copper, zinc, and selenium concentrations, which are important trace minerals in cattle diets. This can result in forage that is deficient in these minerals, thus requiring mineral supplementation for cattle (Davy et al. 2019). Mineral supplements are commonly supplied through a loose salt mineral.

Selenium is a particular concern in California. This mineral plays an important role in immune function and prevents oxidative damage to tissues caused by free radicals — for example, as part of glutathione peroxidase, which is a metalloenzyme. Cattle requirements for selenium can be met through a diet containing 0.1 parts per million (ppm) selenium. Deficiencies are seen when cattle consume forage at levels below 0.05 ppm (National Academy of Sciences 2016). Selenium content in forage samples from Northern California has historically been categorized as very low, with the majority of samples containing 0.05 ppm or less (Carter et al. 1968).

Apparently, cattle do not like the taste of monensin. Previous work on providing monensin through a free-choice loose salt supplement has been documented only once on California rangelands (Forero et al. 2019), at a single dose of 800 grams/ton. Even at this low dose, supplement consumption was lessened. The degree of reduced consumption under local conditions is not known at rates higher than 800 grams/ton in a supplement. Determining the optimal dose per ton of supplement is important to both supplement formulators and those providing the supplement to cattle.

We hypothesized that monensin supplementation would lead to weight gain in stocker cattle, with more weight gain at higher doses. We further hypothesized that it would lead to a reduction of pathogenic and total coccidia shedding. The main objective of the study was to compare weight gain and blood selenium concentrations between a control group and groups of stocker calves grazing on rangeland supplemented with a self-fed mineral supplement at different amounts of monensin. The study delivered various levels of monensin spanning the range of doses for which Rumensin 90 (Elanco Animal Health, Greenfield, Ind.) is approved (50 mg–200 mg per head per day) (U.S. Food and Drug Administration 2012) in growing cattle on pasture. A secondary objective was to compare the shedding of pathogenic and total coccidia oocysts (a stage of the parasite) among groups.

Grazing, weights, and sampling

The study procedures were approved by the Institutional Animal Care and Use Committee at the University of California, Davis (protocol #21524). Cattle were housed at the Sierra Foothill Research and Extension Center in Browns Valley, California. In each of three consecutive years starting in 2019, 148 British breed crossbred steers were stratified by body weight and randomly assigned to one of four groups of 37 steers receiving a self-fed custom mineral supplement (A. L. Gilbert Co., Oakdale, Calif.) with either no monensin (Control), 50 mg (Low), 125 mg (Medium), or 200 mg (High) monensin and 2.86 mg selenium if consumed

Modified creep feeder used to deliver mineral supplement to study steers. The setup protected the mineral mix from wind and rain to reduce waste and ensure accurate measurements of consumption. *Photo*: Gabriele Maier.

Leftover mineral supplement collected at pasture rotation to determine consumption during the period. The researchers found that higher doses of monensin result in less consumption of a mineral mix by stocker steers. *Photo*: Gabriele Maier.

at 2 ounces (oz) per head per day (table 1). A nutrient analysis of the four mineral mixes is provided in table 2. Total enrollment in the study was 444 animals. Study personnel were blinded to group assignments. Between December and May, cattle grazed winter annual rangeland consisting primarily of slender oat (*Avena barbata*), soft brome (*Bromus hordeaceus*), annual ryegrass (*Lolium multiflorum*), and filaree (*Erodium* ssp.).

Steers were provided in all three years from the same Northern California stocker operation. Steers were vaccinated with an injectable modified live vaccine for bovine rhinotracheitis and bovine virus diarrhea type 1 and 2 (Express 3, Boehringer Ingelheim, St. Joseph, Mo.), an intranasal modified live vaccine for bovine rhinotracheitis, parainfluenza 3 and bovine respiratory syncytial virus (Inforce 3, Zoetis, Kalamazoo, Mich.), and an 8-way clostridial bacterin (Bar-Vac 8, Boehringer Ingelheim, St. Joseph, Mo.). They were dewormed with injectable doramectin (Dectomax, Zoetis, Kalamzoo, Mich.) and received a trenbolone acetate and estradiol-containing implant (Revalor-G, Merck Animal Health, Madison, N.J.) on arrival, approximately 1 to 2 weeks prior to study start. All animals appeared healthy at enrollment.

Steers were weighed the day before study start and their weights stratified into four quartiles. Within each quartile, the order of group assignments was determined through a random number generator within Excel (Microsoft, Redmond, Wash.) so that each of the four treatment groups was composed of approximately equal numbers of steers from each weight quartile. After being held off feed and water overnight, the BW of individual steers was measured on five occasions approximately 40 days apart as follows: day 0; between day 36 and day 42; between day 71 and day 82; between day 106 and day 117; and between day 146 and day 156. The accuracy of the scale was verified by placing sixteen 50-lb weights for a total of 800 lb on the empty scale after every group on weigh days. In addition, on the first and last day of the study period in each year, 5 to 10 milliliter (ml) whole blood samples were collected from the tail from a random sample of 13 steers in each group into vacutainers containing 0.1 milliliter of the anti-coagulant EDTA (Covidien, Minneapolis, Minn.). Blood samples were kept on ice and submitted the same day to the California Animal Health and Food Safety Laboratory in Davis, California, for evaluation of blood selenium concentrations. From a random sample of 20 steers on the first four weight collection days in each group

TABLE 1. Mineral mix formula (as fed) for each treatment group in a trial with stocker steers on pasture supplemented with different doses of monensin

Ingredients	High*	Medium*	Low*	Control*
	Percentage			
Corn oil	1.00	1.00	1.00	1.00
Wheat, millrun	43.24	43.90	44.56	45.00
Limestone, coarse	15.00	15.00	15.00	15.00
Limestone, ground	14.25	14.25	14.25	14.25
Magnesium oxide, 55%	0.90	0.90	0.90	0.90
Copper sulfate, 25.2%	0.89	0.89	0.89	0.89
Trace mineral salt with iodine, 79.5%	0.11	0.11	0.11	0.11
Sodium selenite 1.5%	0.34	0.34	0.34	0.34
Zinc sulfate, 36%	1.26	1.26	1.26	1.26
Rumensin 90	1.77	1.11	0.44	0.00
Sodium chloride	21.25	21.25	21.25	21.25
Total	100.00	100.00	100.00	100.00

* Control = no monensin, Low = 800 g monensin, Medium = 2,000 g monensin, High = 3,200 g monensin, per ton of mineral mix.

TABLE 2. Nutrient analysis of mineral mix formulas for each group in a trial with stocker steers on pasture supplemented with different doses of monensin

Nutrient	Unit	High*	Medium*	Low*	Control*
Dry matter	%	94.20	94.20	94.20	94.20
Total digestible nutrients	%	33.50	34.00	34.50	34.80
Crude protein	%	7.20	7.30	7.40	7.50
Undegradable intake protein	%	1.40	1.40	1.5	1.50
Crude fat	%	2.80	2.90	2.9	2.90
Crude fiber	%	3.70	3.80	3.90	3.90
Acid detergent fiber	%	6.10	6.10	6.20	6.30
Neutral detergent fiber	%	19.90	20.20	20.50	20.70
Non-structural carbohydrate	lb	0.08	0.08	0.08	0.08
Ash	%	54.30	54.30	54.30	54.30
Additional mineral	%	32.40	32.40	32.40	32.400
Calcium	%	10.60	10.60	10.60	10.60
Phosphorus	%	0.40	0.40	0.40	0.40
Sodium	%	8.50	8.50	8.50	8.50
Chloride	%	12.90	12.90	12.90	12.90
Salt	%	21.30	21.30	21.30	21.30
Magnesium	%	1.40	1.40	1.40	1.40
Potassium	%	0.50	0.50	0.50	0.50
Sulfur	%	0.50	0.50	0.50	0.50
DCAD	meq/lb	−56.20	−55.60	−55.00	−54.60
Cobalt	mg/lb	0.04	0.04	0.05	0.05
Copper	mg/lb	1,028.20	1,028.30	1,028.40	1,028.40
Iodine	mg/lb	405.70	405.70	405.70	405.70
EDDI	mg/lb	505.20	505.20	505.20	505.20
Iron	mg/lb	19.80	20.10	20.40	20.60
Manganese	mg/lb	0.52	0.50	0.50	0.50
Selenium	mg/lb	23.00	23.00	23.00	23.00
Zinc	mg/lb	2,061.70	2,061.70	2,061.70	2,061.70
Lysine	%	0.30	0.30	0.30	0.30
Methionine	%	0.09	0.09	0.10	0.09
Monensin	g/ton	3,201.70	2,004.50	802.70	0.00

* Control = no monensin, Low = 800 g monensin, Medium = 2,000 g monensin, High = 3,200 g monensin, per ton of mineral mix.
DCAD = dietary cation-anion difference; EDDI = ethylenediamine dihydriodide.

during years 2 and 3 of the study, approximately 2 ounces (oz) of feces were collected from the rectum, placed in sterile plastic bags (Nasco, Fort Atkinson, Wis.), and kept on ice until further analysis in the lab. Given the lifecycle of coccidia, follow-up over the entire study period was not deemed to result in additional information.

Groups were kept on separate pastures and rotated to the next pasture each time they were weighed so that every group grazed each pasture. The same four pastures were used during all three years of the trial. Initial pasture assignment was random each year. The pasture assignment order for the three study years is shown in table 3. The mineral supplement was weighed and delivered to one covered feed trough per pasture away from moisture. Mineral feeders were inspected every five days to ensure that the product was always available. At pasture rotation, leftover mineral was removed and was dried at 140° Fahrenheit until a constant weight was attained. Dried weight was used to estimate daily consumption on a group basis for each period.

Coccidia count and type

A modified McMaster's technique was used to quantify coccidia in individual fecal samples. Briefly, four grams of fecal material were mixed with saturated saline solution for a total of 60 milliliters, strained through a sieve, and stirred with a magnetic stir bar. Both chambers of a McMaster gridded slide were filled with the mix and set aside for two minutes to let oocysts float to the surface. Oocysts were counted using 100×

TABLE 3. Pasture rotation assignments for treatment groups (n = 37) in a trial with 444 stocker steers on pasture supplemented with different doses of monensin during each of 3 years

Group*	Pasture assignment period 1	Pasture assignment period 2	Pasture assignment period 3	Pasture assignment period 4
Year 1				
Control	4	3	2	1
Low	3	4	1	2
Medium	1	2	4	3
High	2	1	3	4
Years 2 and 3				
Control	1	2	4	3
Low	3	4	2	1
Medium	2	1	3	4
High	4	3	1	2

* Control = no monensin, Low = 800 g monensin, Medium = 2,000 g monensin, High = 3,200 g monensin, per ton of mineral mix.

magnification and species identified using 200× magnification based on size and morphology (Joachim et al. 2018). Oocysts were distinguished into pathogenic (*E. bovis*, *E. zuernii*, *E. alabamensis*), or non-pathogenic species for cattle.

Data on BW, mineral consumption, average daily gain (ADG), and blood selenium were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, N.C.). Linear mixed models with the subject as the random effect, nested within study year, were used to compare outcomes. For mineral consumption, the random effect was the study year, because individual consumption was unknown and consumption was measured at the group level. Treatment group, time, and their interaction were main predictors for BW, blood selenium, and mineral consumption, while group was the predictor for ADG. Residuals were visually assessed for normality. The SLICE statement was used to compare outcomes at all time points for BW and mineral consumption and for study start and end for blood selenium. The PDIFF statement was used to compare ADG. Unstructured was the covariance structure with the best model fit compared with compound symmetry and autoregressive.

Oocyst count data were analyzed in a generalized linear mixed model with a negative binomial distribution with the subject as the random effect, nested within year, using the GLIMMIX procedure in SAS. The difference in oocysts among treatment groups was examined using the SLICE statement.

All pairwise comparisons were adjusted according to the Tukey Honestly Significant Difference method. Significance was set at $P < 0.05$ and tendencies at $P < 0.10$ for all statistical analyses.

Data on minimum and maximum air temperatures and precipitation during the trial periods at the trial site are provided in table 4 (University of California Integrated Pest Management n.d.).

TABLE 4. Weather data during the trial periods from December through May for a trial with stocker steers on pasture supplemented with different doses of monensin

Trial start year*	2019	2020	2021
December			
Mean daily minimum air temperature, °F (SD†)	41.4 (3.8)	38.7 (2.5)	39.2 (5.0)
Mean daily maximum air temperature, °F (SD)	52.0(12.9)	55.0 (1.8)	49.6 (4.1)
Total precipitation, inches	1.9	2.7	4.2
January			
Mean daily minimum air temperature, °F (SD)	41.1 (3.3)	40.7 (4.1)	40.3 (2.6)
Mean daily maximum air temperature, °F (SD)	56.0 (4.1)	57.5 (5.7)	59.4 (4.1)
Total precipitation, inches	2.2	1.4	0.45
February			
Mean daily minimum air temperature, °F (SD)	41.5 (4.5)	41.4 (4.8)	40.4 (5.0)
Mean daily maximum air temperature, °F (SD)	64.4 (5.0)	61.4 (4.6)	64.3 (5.8)
Total precipitation, inches	0.4	1.3	0.0
March			
Mean daily minimum air temperature, °F (SD)	45.4 (2.6)	41.3 (4.0)	45.1 (4.5)
Mean daily maximum air temperature, °F (SD)	65.8 (6.8)	63.0 (6.3)	67.6 (5.0)
Total precipitation, inches	3.9	2.7	1.37
April			
Mean daily minimum air temperature, °F (SD)	47.8 (4.2)	46.5 (4.0)	45.0 (4.8)
Mean daily maximum air temperature, °F (SD)	70.2 (8.1)	73.6 (5.7)	69.6 (7.0)
Total precipitation, inches	1.8	0.4	2.2
May			
Mean daily minimum air temperature, °F (SD)	51.4 (2.8)	52.9 (5.9)	51.1 (5.6)
Mean daily maximum air temperature, °F (SD)	76.0 (4.7)	81.2 (5.0)	78.7 (6.8)
Total precipitation, inches	1.0	0.2	0.3
Entire trial period			
Mean daily minimum air temperature, °F (SD)	44.7 (5.2)	42.9 (5.7)	43.5 (5.8)
Mean daily maximum air temperature, °F (SD)	64.9 (9.0)	64.4 (9.5)	65.8 (9.2)
Total precipitation, inches	11.3	8.7	8.5

* Trial periods were 12/17/2019–05/22/2020, 12/17/2020–05/12/2021, and 12/21/2021–05/19/2022, respectively, for the three years. Data for December and May cover trial days only.

† SD = standard deviation.

Mineral supplement consumption

Average daily group mineral consumption divided by number of animals per group for the three study years is shown in figure 1 for the four intervals evaluated. The average consumption for Control fluctuated the most between time points and ranged between 1.4 and 3.7 oz/animal/day, with an overall average of 2.9 oz/animal/day, providing 4.1 mg selenium. For Low, average consumption varied between 1.8 and 2.6 oz/animal/day, with an overall average of 2.1 oz/animal/day, which translates to an average intake of 3.1 mg selenium and 53 mg monensin/animal/day, close to the target of 3 mg selenium and 50 mg monensin/animal/day. For Medium, consumption ranged from 1.0 to 1.6 oz/animal/day, with an overall average of 1.3 oz/animal/day, representing an average intake of 1.9 mg selenium and 82 mg monensin/animal/day. Finally, for High, intake was the most consistent, ranging between 0.7 and 1.1 oz/animal/day, with an average of 0.9 oz/animal/day, for an average intake of 1.3 mg selenium and 91 mg monensin/animal/day. Consumption was significantly higher in the Control group compared to the High group during the first and third study periods. During the second and fourth study periods, consumption was higher in the Control group compared to all other groups.

Weight and average daily gain

There was a significant interaction between group and time ($P < 0.001$), indicating a difference in weight gain over time among groups. BW was not different among groups at study start or at the first three pasture rotations ($P > 0.05$). However, it tended to be higher in Low versus Control ($P = 0.06$) at the second pasture rotation between days 71 and 82, with the Low group weighing 707.2 lb ± 5.9 lb and Control weighing 689.9 lb ± 5.9 lb. At study end, all groups receiving monensin weighed more than Control ($P < 0.05$) but did not statistically significantly differ from each other. While the Control group weighed 872.8 lb ± 5.9 lb, steers in the Low group weighed 897.3 lb ± 5.9 lb, in the Medium group 900.2 lb ± 5.9 lb, and in the High group 898.2 lb ± 5.9 lb (table 5). ADG over the entire study period was improved in all groups receiving monensin compared with Control, but there were no differences among monensin-supplemented groups. Estimates for ADG were 1.91 lb ± 0.24 lb for Control compared with 2.04 lb ± 0.24 lb in the Low ($P = 0.002$), 2.08 lb ± 0.24 lb in the Medium ($P < 0.001$), and 2.05 lb ± 0.24 lb in the High ($P = 0.001$) group (table 5).

Blood selenium levels

Blood selenium concentration in all groups was similar at study start: between 0.106 and 0.112 ± 0.013 ppm, $P = 0.83$. At study end, blood selenium was highest in Control (0.173 ± 0.013 ppm) and Low (0.165 ± 0.013 ppm), which were not significantly statistically different from each other ($P = 0.73$). In the Medium treatment group, blood selenium was 0.124 ± 0.013 ppm, which was significantly different from both Control ($P < 0.001$) and Low ($P < 0.001$), as well as from High (0.092 ± 0.013 ppm, $P < 0.001$) (fig. 2).

Coccidia oocyst shedding

No effect of monensin supplementation on pathogenic coccidia oocyst shedding was detected among any of the groups at the $P < 0.05$ significance level for oocyst numbers shed at any of the four time points evaluated.

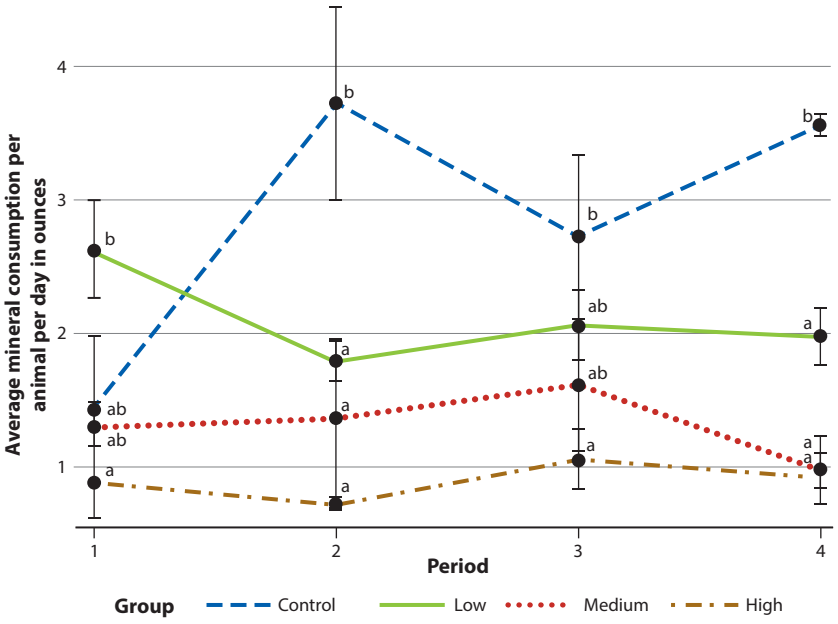

FIG. 1. Daily mineral consumption averaged over three years divided by group size in a trial with 444 (148 per year) stocker steers on pasture supplemented with different doses of monensin supplied in a mineral supplement in a 3-year trial (2019–2021) between December and May of each year. Average period length was approximately 40 days. Control = no monensin, Low = 800 g monensin, Medium = 2,000 g monensin, High = 3,200 g monensin per ton of mineral supplement. Different lowercase letters indicate statistically significant differences between groups within each time period.

TABLE 5. Least square means of body weight and average daily gain (lb) in stocker steers on pasture supplemented with different doses of monensin

	Control*	Low*	Medium*	High*	SE	*P*
	lb					
Study start	587.9	591.5	588.8	591.5	5.9	0.94
36–42 days	635.2	626.4	629.3	626.5	5.9	0.55
71–82 days	689.9[a]†	707.2[b]‡	705.8[a,b]	695.1[a,b]	5.9	0.03
106–117 days	783.0	788.9	795.7	788.1	5.9	0.33
146–156 days	872.8[a]	897.2[b]	900.2[b]	898.2[b]	5.9	0.00
ADG	1.91 (0.24)[a]	2.04 (0.24)[b]	2.08 (0.24)[b]	2.05 (0.24)[b]	0.24	< 0.001

* Control = no monensin, Low = 800 g monensin, Medium = 2,000 g monensin, High = 3,200 g monensin, per ton of mineral mix.

† Values within a row without a superscript in common differ at $P < 0.05$ or ($0.05 < P < 0.10$) if marked with a double dagger (‡) after Tukey adjustment for multiple comparisons.

ADG = average daily gain.

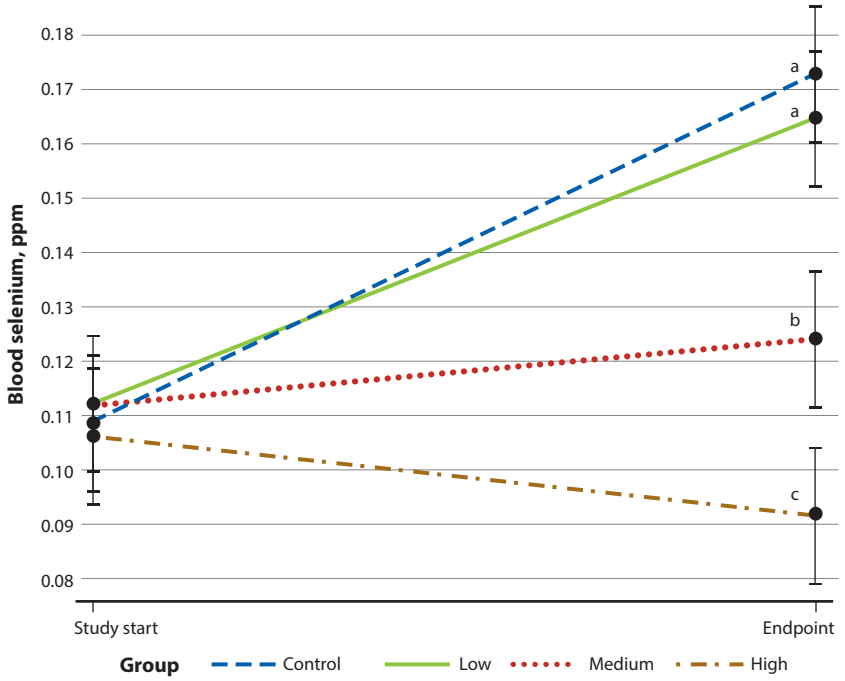

FIG. 2. Mean blood selenium concentration per study group at study start and end after approximately 150 days in a trial with 444 (148 per year) stocker steers on pasture supplemented with different doses of monensin supplied in a mineral supplement in a 3-year trial (2019–2021) between December and May of each year. Control = no monensin, Low = 800 g monensin, Medium = 2,000 g monensin, High = 3,200 g monensin per ton of mineral supplement. Different lowercase letters indicate statistically significant differences between groups.

The Medium and High groups tended to shed fewer pathogenic coccidia oocysts on the third sampling day (day 82 for year 2 and day 71 for year 3) than Control ($P = 0.09$ for Medium and $P = 0.10$ for High). The High group shed fewer total coccidia oocysts than Control ($P = 0.02$) and the Medium group tended to shed fewer total coccidia oocysts than Control ($P = 0.05$) on the third sampling day. Mean pathogenic and total coccidia oocyst counts per time point are described in table 6.

Cost of supplements

The cost of mineral supplementation per animal per season was calculated based on the cost of the mineral supplement, consumption by each group over the study period, and number of animals per group. In addition, the cost of each treatment per additional pound of weight gain compared with the control group was calculated.

Although adding monensin increased the price per ton of supplement, the variability in intake affected cost per treatment. On a per-ton basis, supplement costs were $361 (Control), $445 (Low), $570 (Medium), and $697 (High). Based on the observed average consumption, the Control supplement ($5.80) cost less than the Low supplements ($6.62), but more than the Medium ($4.18) and High supplements ($3.60) per animal for the season. While the Low supplement decreased daily mineral consumption by 0.8 oz/day compared to Control, the added cost of monensin in the supplement resulted in an overall higher cost. The Medium and High supplements decreased mineral consumption by

TABLE 6. Least square means of pathogenic and total coccidia oocyst counts (standard error of mean) in stocker steers on pasture supplemented with different doses of monensin

	Control*	Low*	Medium*	High*	*P*
Pathogenic coccidia oocyst† count (SEM)					
Study start	285.1 (100.2)	372.1 (157.8)	552.4 (234.6)	221.2 (77.8)	0.41
36–42 days	314.0 (109.0)	123.1 (45.3)	212.9 (78.7)	118.5 (41.8)	0.16
71–82 days	247.6 (87.2)[a]‡	154.1 (58.3)[a,b]	76.9 (26.8)[b]§	78.5 (27.5)[b]§	0.05
106–117 days	188.1 (66.1)	110.7 (40.1)	220.6 (82.3)	223.6 (78.9)	0.48
Total coccidia oocyst count (SEM)					
Study start	393.3 (121.5)	429.5 (148.5)	647.1 (222.3)	361.5 (110.1)	0.61
36–42 days	366.8 (110.6)	141.7 (45.6)	298.3 (101.8)	161.7 (49.6)	0.09
71–82 days	359.9 (109.7)[a]	183.0 (59.1)[a,b]	120.1 (36.2)[b]§	103.8 (31.6)[b]	0.02
106–117 days	296.5 (90.4)	149.0 (47.0)	264.8 (85.4)	370.7 (114.6)	0.20

* Control = no monensin, Low = 800 g monensin, Medium = 2,000 g monensin, High = 3,200 g monensin, per ton of mineral mix.

† *Eimeria bovis, E. zuernii, E. alabamensis.*

‡ Values within a row without a superscript in common differ at $P < 0.05$ or ($0.05 < P < 0.10$) if marked with a section symbol (§) after Tukey adjustment for multiple comparisons.

1.6 oz and 2 oz/day, respectively, when compared with Control, which reduced their cost compared with the Low and Control supplements, regardless of the increased cost of higher monensin content.

In addition to the actual cost of supplementation due to intake, increased weight gain led to differences in cost per pound of gain by supplement. While all three monensin supplements yielded equal additional gain economically, the Low supplement ($0.02/lb) was approximately twice the cost of the Medium ($0.01/lb) and High ($0.01/lb) per pound of added gain, due to higher mineral consumption. At current market prices for live cattle at $1.81/lb, the net potential gain per steer of approximately 27 lb in the Medium group compared to Control would result in a $48.87 higher profit. However, these numbers depend on the current market prices for live cattle.

Intake varies with free feeding

The results of this study confirm the effect of monensin supplementation on weight gain and increased ADG in grazing cattle seen in previous studies. A recent meta-analysis of the effects of monensin on growth and bloat of cattle on pasture reported that stockers supplemented with monensin gained an additional 23 lb versus controls at an initial BW of 518 lb and an average trial duration of 112 days (Gadberry et al. 2022). In the present study, average initial BW was 591 lb, with additional estimated weight gains between 13 lb and 18 lb at about 117 days for the three treatment groups.

ADG increased between 0.13 lb and 0.17 lb for steers in the monensin treated groups over the control group in our study, which is similar to the 0.17-lb increase in ADG that was found to be the average monensin response in the meta-analysis (Gadberry et al. 2022). An earlier literature review found that differences in ADG in monensin-supplemented grazing cattle depend on on forage quality (Bretschneider et al. 2008). In regression models, higher ADG, representing increased forage quality, led to an attenuated monensin response. The proposed mechanism is that cattle grazing high-quality forage may reach their genetic growth potential with forage alone, so that the effect of monensin is reduced. In our study, differences in BW only became apparent during the last grazing period, when forage quality may have deteriorated compared to earlier in the season. Other factors, such as genetics or trace mineral status, may also contribute to outcomes in performance.

Delivering monensin in a free-choice mineral supplement comes with the challenge of ensuring adequate intake of other ingredients in the mineral supplement that may benefit animal health. In our study, the mineral supplement was designed to provide adequate trace mineral supplementation at 2 oz/animal/day. A study performed in the same location compared weight gains for stocker cattle supplemented with salt alone, a mineral supplement, monensin in salt, or monensin in a mineral supplement (Forero et al. 2019). The results showed synergy between mineral supplement and monensin, where the groups receiving either mineral supplement or monensin in salt gained more weight than the salt-only group, but less than the group receiving monensin in mineral supplement, which gained the most weight. In our study, we observed reduced intake of mineral supplement at higher doses of monensin, in line with previous studies (Fitzgerald and Mansfield 1973), which may have prevented the weight gain expected at the full dose. The effect of mineral supplementation on weight gain has been observed by others as well (Dias et al. 2013; Gunter and Combs 2019; Mattioli et al. 2018).

We found that the High group decreased in blood selenium concentrations over the study period on average. The reduced consumption of the High monensin mineral supplement may have been too low to provide adequate supplementation with selenium in areas where forage is deficient in selenium. However, it should be noted that we gave steers free choice access to the mineral supplement, so that we could assess differences in consumption that may be due to reduced palatability through the addition of monensin. In a commercial setting, mineral supplementation is likely restricted to a target level — for example, through increased salt levels — because supplementation beyond the target may be unnecessary and raise production costs. The cost of supplementation calculated in the present study for Control may be exaggerated due to the low salt levels in the supplement that we provided. The effect of mineral supplementation on weight gain is likely dependent on mineral status at study start and on local forage and water mineral status; for these reasons, the effects may differ from the results seen in our study.

Pathogenic coccidia

Pathogenic coccidia oocyst shedding was highest in the Control group and was numerically lower in all monensin groups, except at the last time point when fecal samples were monitored for oocysts. Overall, there were few animals that shed 500 oocysts or more belonging to any of the pathogenic species (*E. bovis*, *E. zuernii*, or *E. alabamensis*), the cutoff for clinically relevant shedding (Mundt et al. 2005), and pathogenic coccidia burden may not have contributed significantly to the results seen in this study. There was an increase in oocyst shedding in the Medium and High groups observed during the last time point of sampling. The Medium and High groups switched pastures before the last fecal sample was taken. The Control or Low groups had occupied those pastures previously. Although we tried to minimize pasture effects by exposing each group to each pasture, the sequence of pasture assignments may have had some confounding effect on the outcomes, which was unavoidable. The main objective of the study was to evaluate the effect of monensin on weight gain and trace mineral status, and the rotation

A group of mixed breed steers grazing at sunset. *Photo*: Fernando Lurie, Shutterstock.com.

of pastures may have exposed some steers to coccidia shed by a previous group. Development of *Eimeria* inside the host takes between 1 and 3 weeks (Bangoura et al. 2022; Bangoura and Bardsley 2020) and we may have missed the most important shedding events with the chosen sampling time points. Furthermore, anticoccidial effects of the monensin treatment may have been confounded by the hormone implant used during this study. As shown previously, estradiol-containing implants may exhibit some level of protective effects against *Eimeria* infections in calves (Heath et al. 1997). Thus, the effect of monensin as a coccidiostat may have been masked due to the study design. A monensin intake of about 0.5 milligram (mg)/kilogram (kg)/day body weight to 4.0 mg/kg/day has been shown to efficiently suppress *E. bovis* oocyst excretion (Fitzgerald and Mansfield 1973), while the lower doses that were consumed during this study might be the cause of lower efficacy. One study found reduced coccidia oocyst counts in feces on day 84 of supplementation with concentrate containing 20 mg monensin/kg of total dry matter intake in early-weaned heifers on bahiagrass pastures, which was accompanied by increased growth performance (Vendramini et al. 2018).

In short, limitations of the current study are that the effect of monensin on pathogenic coccidia shedding may have been masked by both insufficient sampling time points and concurrent implanting.

Selecting the right dose

Monensin supplementation at any dose in the present study led to higher BW and ADG in the study population, although we did not find any differences in ADG among Low, Medium, or High monensin supplementation in the form of a mineral supplement. Blood selenium concentrations at the end of the study differed among monensin-fed groups in a manner that inversely corresponded with the amount of monensin in the mineral supplement. Under circumstances where cattle may become deficient of trace minerals if their intake of mineral supplement is reduced, producers should carefully evaluate whether providing monensin at the highest dose (3,200 g/ton) will provide any benefits over lower doses. CA

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References

Bangoura B, Bardsley KD. 2020. Ruminant coccidiosis. Vet Clin N Am–Food A 36(1):187–203. https://doi.org/10.1016/j.cvfa.2019.12.006

Bangoura B, Bhuiya MAI, Kilpatrick M. 2022. Eimeria infections in domestic and wild ruminants with reference to control options in domestic ruminants. Parasitol Res 121(8):2207–32. Epub 20220610. https://doi.org/10.1007/s00436-022-07564-x

Bangoura B, Daugschies A. 2020. Coccidiosis in cattle. In *Coccidiosis in Livestock, Poultry, Companion Animals, and Humans*. Dubey JP (ed.). Boca Raton, Florida: CRC Press.

Bretschneider G, Elizalde JC, Perez FA. 2008. The effect of feeding antibiotic growth promoters on the performance of beef cattle consuming forage-based diets: A review. Livest Sci 114(2-3):135–49. https://doi.org/10.1016/j.livsci.2007.12.017

Carter DL, Brown MJ, Allaway WH, Cary EE. 1968. Selenium content of forage and hay crops in the Pacific Northwest. Agron J 60(5):532–4. https://eprints.nwisrl.ars.usda.gov/id/eprint/4

Cazarotto CJ, Boito JP, Gebert RR, et al. 2018. Metaphylactic effect of minerals on immunological and antioxidant responses, weight gain and minimization of coccidiosis of newborn lambs. Res Vet Sci 121:46–52. Epub 20180928. https://doi.org/10.1016/j.rvsc.2018.09.003

Daugschies A, Najdrowski M. 2005. Eimeriosis in cattle: Current understanding. J Vet Med B 52(10):417–27. https://doi.org/10.1111/j.1439-0450.2005.00894.x

Davy JS, Forero LC, Shapero MWK, et al. 2019. Mineral status of California beef cattle. Transl Anim Sci 3(1):66–73. Epub 20181017. https://doi.org/10.1093/tas/txy114

Dias RS, Lopez S, Montanholi YR, et al. 2013. A meta-analysis of the effects of dietary copper, molybdenum, and sulfur on plasma and liver copper, weight gain, and feed conversion in growing-finishing cattle. J Anim Sci 91(12):5714–23. https://doi.org/10.2527/jas.2013-6195

Fitzgerald PR, Mansfield ME. 1973. Efficacy of monensin against bovine coccidiosis in young Holstein-Friesian calves. J Protozool 20(1):121–6. Epub 1973/02/01. https://doi.org/10.1111/j.1550-7408.1973.tb06014.x

Forero L, Barry S, Larson S. 2021. Beef Cattle on California Annual Grasslands: Production Cycle and Economics. UC ANR Publication 8687. https://escholarship.org/uc/item/0dm890zx

Forero LC, Davy JS, McMurry BE, Oltjen JW. 2019. Monensin and mineral supplementation economically increase yearling cattle weight gain on California annual rangeland. Transl Anim Sci 3(2):737–41. Epub 20190517. https://doi.org/10.1093/tas/txz041

Gadberry S, Lalman D, White F, et al. 2022. Meta-analysis of the effects of monensin on growth and bloat of cattle on pasture. Transl Anim Sci 6(2):txac031. Epub 20220304. https://doi.org/10.1093/tas/txac031

Goodrich RD, Garrett JE, Gast DR, et al. 1984. Influence of monensin on the performance of cattle. J Anim Sci 58(6):1484–98. https://doi.org/10.2527/jas1984.5861484x

Guan H, Wittenberg KM, Ominski KH, Krause DO. 2006. Efficacy of ionophores in cattle diets for mitigation of enteric methane. J Anim Sci 84(7):1896–906. https://doi.org/10.2527/jas.2005-652

Gunter SA, Combs Jr GF. 2019. Efficacy of mineral supplementation to growing cattle grazing winter-wheat pasture in northwestern Oklahoma. Transl Anim Sci 3(4):1119–32. Epub 20190406. https://doi.org/10.1093/tas/txz031

Heath HL, Blagburn BL, Elsasser TH, et al. 1997. Hormonal modulation of the physiologic responses of calves infected with Eimeria bovis. Am J Vet Res 58(8):891–6. https://doi.org/10.2460/ajvr.1997.58.08.891

Joachim A, Altreuther G, Bangoura B, et al. 2018. WAAVP guideline for evaluating the efficacy of anticoccidials in mammals (pigs, dogs, cattle, sheep). Vet Parasitol 253:102–19. Epub 20180215. https://doi.org/10.1016/j.vetpar.2018.02.029

Macon DK, Barry S, Becchetti T, et al. 2016. Coping with drought on California rangelands. Rangelands 38(4):222–8. https://doi.org/10.1016/J.RALA.2016.06.005

Mattioli GA, Rosa DE, Turic E, et al. 2018. Effects of copper and zinc supplementation on weight gain and hematological parameters in pre-weaning calves. Biol Trace Elem Res 185(2):327–31. Epub 20180205. https://doi.org/10.1007/s12011-017-1239-0

Mundt HC, Bangoura B, Mengel H, et al. 2005. Control of clinical coccidiosis of calves due to Eimeria bovis and Eimeria zuernii with toltrazuril under field conditions. Parasitol Res 97:S134–42. https://doi.org/10.1007/s00436-005-1457-9

National Academy of Sciences, Engineering and Medicine. 2016. *Nutrient Requirements of Beef Cattle* (8th revised ed.). Washington DC: The National Academies Press. https://doi.org/10.17226/19014

Russell JB, Houlihan AJ. 2003. Ionophore resistance of ruminal bacteria and its potential impact on human health. FEMS Microbiol Rev 27(1):65–74. https://doi.org/10.1016/S0168-6445(03)00019-6

Stromberg BE, Schlotthauer JC, Hamann KJ, et al. 1986. Experimental bovine coccidiosis: Control with monensin. Vet Parasitol 22(1-2):135-40. https://doi.org/10.1016/0304-4017(86)90015-4

University of California Integrated Pest Management. n.d. California Weather Database https://ipm.ucanr.edu/calludt.cgi/WXSTATIONDATA?STN=BRWNSVLY.A (accessed Sept. 7, 2023).

U.S. Food and Drug Administration. 2012. New Animal Drugs for Use in Animal Feeds; Monensin. Federal Register 77(18). www.federalregister.gov/documents/2012/01/27/2012-1755/new-animal-drugs-for-use-in-animal-feeds-monensin

Vendramini JMB, Moriel P, Cooke RF, et al. 2018. Effects of monensin inclusion into increasing amount of concentrate on growth and physiological parameters of early-weaned beef calves consuming warm-season grasses. J Anim Sci 96(12):5112–23. https://doi.org/10.1093/jas/sky374