MINERAL SUPPLEMENTATION WITH OR WITHOUT IONOPHORES AND PHOSPHORUS ACCRETION IN GROWING BEEF CATTLE GRAZING WINTER WHEAT PASTURE

By

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CHAPTER I

INTRODUCTION

Feed cost is the primary cost associated with producing beef. An effective way to reduce production cost is to improve feed efficiency, which can be done by improving gain while not increasing intake, or maintaining daily gain while reducing DMI Carboxylic polyether ionophores, more commonly known as ionophores, including monensin and lasalocid are effective in achieving this goal. Monensin and lasalocid have been shown through multiple trials to improve feed efficiency.

Considerable research has been done to examine the effects of monensin on cattle performance, however comparatively less has been reported about the effects of lasalocid. Monensin was approved by the Food and Drug Administration in December 1975 for use in feedlot cattle (Goodrich et al., 1984). Lasalocid was approved for use in grazing cattle in December 1984 (Andersen and Horn, 1987). Both ionophores are now used in all phases of cattle feeding, including grazing wheat pasture or summer grazing of warm season grasses, as well as in high-concentrate finishing diets. When ionophores are administered in high-concentrate rations, DMI is depressed while ADG is maintained. Cattle fed high roughage diets in confinement experienced less reduction of DMI and experienced an increase in ADG (Bergen and Bates, 1984 and Schelling, 1984). The following is a review of literature that examines the effects of monensin and lasalocid on DMI and weight gain performance of cattle fed both high-concentrate and high-roughage diets.

CHAPTER II

REVIEW OF LITERATURE-IONOPHORES

Ionophore Effects and Mode of Action

Ionophores have long been known to influence animal performance. When cattle fed high-concentrate diets, composed of highly fermentable carbohydrates, are administered ionophores, DMI is reduced while weight gains are maintained, and consequently feed efficiency is improved. The effect on ADG and feed efficiency may vary between monensin and lasalocid. Lasalocid, when fed in high-concentrate diets maintains DMI and increases ADG, and monensin maintains ADG and decreases DMI in similar diets. In high-roughage diets, DMI is maintained and weight gains are increased (Bergen and Bates, 1984). This review examines the effect of different levels of monensin and lasalocid for cattle fed both high-concentrate and high-forage diets, along with the biological effects of both ionophores.

Cellular mode of action. Bergen and Bates (1984) reported that ionophores affect animal performance by altering the movement of ions across biological membranes. Lasalocid affects ADG and feed efficiency by influencing rumen microbial activity (Lasalocid Technical Manual, 1985). Bergen and Bates (1984) and Kirk et al. (1985) also reported that ionophores act as carriers to transport metal cations across cell membranes. For an ionophore to affect ionic transport, it must first be bound in an anionic form to the cell membrane. The anionic form is then capable of binding to a metal cation such as sodium or potassium, which will cause the formation of a lipophilic, cyclic cation-ionophore complex, which is able to diffuse across cell membranes. Once

Table 12. Composition of the bodies of 12 month old Ayrshire, Holstein, and Jersey dairy cattle

	DM	FFOM	Fat	Ash	Ratio	Calcium	Phosphorus	Fat-free dry matter Calcium	Fat-free dry matter Phosphorus
	%				Ca/P	%			
Whole Body	36.25	19.17	12.66	4.41	1.81	1.40	0.77	5.93	3.29
Skeleton	53.78	19.87	14.69	19.22	2.09	7.14	3.42	18.26	8.75
Soft tissue	32.06	19.00	12.17	0.89	0.22	0.03	0.14	0.16	0.73
Blood	18.68	17.11	0.07	0.74	0.77	0.02	0.02	0.11	0.13
Meat	30.65	19.52	10.00	0.94	0.16	0.03	0.18	0.13	0.85
Skin and hair	32.83	30.21	2.69	0.65	0.84	0.05	0.06	0.17	0.20
Horn and hoof	53.21		1.90		2.03	0.18	0.09	0.35	0.18
Internal organs	39.52	11.88	26.85	0.90	0.23	0.03	0.15	0.27	1.15
Digestive tract contents	11.28		0.19		0.65	0.05	0.08	0.44	0.69

From Ellenberger et al., (1950)

DM = dry matter, FFOM = fat free organic matter

Table 13. Percent phosphorus in the bodies of Ayrshire, Holstein, and Jersey dairy cattle

Animal (age)	Empty body	Skeleton	Empty body less skeleton	Blood	Lean tissue	Skin and hair	Internal organs
			% Phosphorus				
Birth	0.76	2.11	0.13	0.02	0.14	0.08	0.21
Calves (6 months)	0.77	2.91	0.17	0.02	0.20	0.07	0.18
Calves (12 months)	0.77	3.42	0.14	0.02	0.18	0.06	0.15
Cows (3 years)	0.93	4.71	0.13	0.02	0.16	0.05	0.12
Cows (8 years)	0.88	4.79	0.14	0.02	0.17	0.05	0.15

From Ellenberger et al. (1950)

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CHAPTER V

PHOSPHORUS ACCRETION IN STOCKER CATTLE GRAZING WINTER WHEAT PASTURE

ABSTRACT: Six Santa Cruz steers were harvested during 2000/2001 to determine phosphorus accretion of stocker cattle grazing winter wheat pasture. This experiment was part of a larger study to determine soil phosphorus removal by winter wheat pasture using various management techniques. Treatments included: 1) grazing during the winter, followed by grazing in the spring; 2) grazing during the winter, forage harvested as hay in the spring; 3) grazing during the winter, grain harvested in the spring; 4) no winter grazing, forage harvested as hay in the spring; and 5) no winter grazing, grain harvested in the spring. Three steers were harvested prior to grazing wheat pasture to determine initial phosphorus concentration in the whole body. Steers that remained grazed wheat pastures from January 10 until March 21 (fall/winter, 70 days) and from March 21 until April 11 (grazeout, 21 days). Three steers were harvested on April 16, following the grazing season to determine final phosphorus concentration. Composite samples of carcass and offal were collected and analyzed for concentration of DM, ash, fat, fat-free organic matter, nitrogen and phosphorus. Phosphorus accretion in carcass, empty body, and live weight, and carcass and empty body protein was determined by simple linear regression. Phosphorus accretion (g/kg) of carcass, empty body, and live weight was 7.5, 6.4, and 7.1, respectively. Phosphorus accretion in carcass and empty body protein was 32.6 and 26.7 g/kg, respectively. Phosphorus removal per steer

averaged 354 g, and phosphorus removal per ha averaged 1,014 g. Overall soil phosphorus removal by cattle was influenced by total cattle weight gained, and was substantially less than phosphorus removed by forage biomass.

Key Words: Steers, Phosphorus accretion, Carcass, Empty body, Live weight

Introduction

Application of livestock manure to agricultural land to increase soil fertility for growing crops is a common practice in the southern Great Plains. With the expansion of concentrated animal feeding operations and increased environmental concerns, additional questions arise relative to nutrient management. McCollum (2002) reported that the primary issue facing manure management is proper distribution. If manure can be transported away from the animal feeding operation, it can be land-applied without increasing nutrient levels in the soil. However, the cost associated with transport and application of manures may limit the economic efficiency of land-application in many areas (McCollum, 2002). The primary method of phosphorus removal is by harvesting grain or forage crops. Another way that phosphorus can be removed from the soil is by grazing cattle. In order to determine the amount of phosphorus removed by winter wheat, phosphorus removal by grain, hay, and grazing must be quantified. The data reported herein was obtained as part of a larger study that was conducted to determine the amount of soil phosphorus removed in grain, hay, and grazing. Treatments included: 1) grazing during the winter, followed by grazing in the spring; 2) grazing during the winter, forage harvested as hay in the spring; 3) grazing during the winter, grain harvested in the spring; 4) no winter grazing, forage harvested as hay in the spring; and 5) no winter grazing, grain harvested in the spring. The objective of this study was to quantify the amount of phosphorus removed as a result of the grazing of growing beef cattle on wheat pasture.

Materials and Methods

Animals. All experimental animal use has been reviewed and accepted by the Oklahoma State University Institutional Animal Care and Use Committee. Six fall-weaned Santa Cruz steer calves were randomly selected for this study from a group of 136 steers. Steers were harvested at the Oklahoma Food and Agricultural Products Research and Technology Center (FAPC). Three steers were harvested upon initiation of the experiment on January 15, 2001, prior to grazing wheat pasture, to determine initial phosphorus concentration in the whole body. Live weights of these steers were recorded on January 10, without being withheld from feed and water. This group of steers was transported from Marshall, OK to Stillwater, OK (approximately 58 km) the morning of harvest. Steers that remained were placed on wheat pastures on January 10 until March 21, 2001 (fall/winter), and from March 21 to April 11, 2001 (grazeout, 21 days). During the fall/winter period, eight to 12 steers were assigned to each of four pastures/treatment (1.15 steers/ha), and during the grazeout period, stocking density was adjusted to eight to 14 steers in each pasture (3.50 steers/ha). The steers that were grazed received no supplement except when bloat became a problem. They were then fed a mixture of 75% salt 25% Bloat Guard Medicated Premix (Pfizer Animal Health, Exton, PA) from February 16 until March 30 (42 days) with an average consumption of 10.5, 6.7, 3.8, and 10.6 g poloxalene daily. The final three steers were harvested following the completion of the grazing period on April 16. Live weights of this group were recorded on April 11 following an overnight shrink (approximately 16 hours) without feed or water. These steers were transported from Marshall to Stillwater the evening of April 15, at which time they were offered hay and water prior to harvest the following morning.

Harvest procedure. Steers were stunned by captive bolt. They were then bled, the head and hide were removed, and the visceral organs were removed. Once the steers were eviscerated, the visceral organs were removed, cleaned of their contents, and weighed. In addition to the organs, the head, hide, blood, mesenteric fat, and feet and ears were weighed. These weights were combined with the weight of the visceral organs to determine total offal weight for each steer.

Sample preparation and analysis. Offal was ground twice using a whole body grinder through a 12-mm screen on the day of harvest. Prior to grinding the hide, it was cut into pieces approximately six inches square. Carcasses were chilled for 24 hours, weighed, graded for carcass quality and yield grade, and the right side was ground through the same grinder using a 12 mm screen, and then reground using a 6-mm screen. Triplicate samples, about 4.5 kg each, were collected from carcass and offal. Three hundred to 450 g samples were collected from each of the triplicate samples, covered with cheesecloth and lyophilized until all moisture was removed. Dried samples were frozen in liquid nitrogen, and finely ground for approximately 30 to 45 seconds using a blender.

Dried, ground tissue samples were prepared for subsequent laboratory analysis to determine ash, nitrogen and phosphorus concentration. Concentration of fat and fat-free organic matter was also determined. Two to four gram samples were taken in triplicate, weighed into 100 mL beakers and placed into a drying oven at 100°C for 4 h to determine

DM, and then placed in a muffle furnace for five hours at 600°C to determine ash content. Samples were then hot plate digested in 40 mL of 25% HCl and one ml HNO_3 as described by Hoover (1976). The digested solution was then filtered into 200 mL volumetric flasks, and brought to volume with distilled water. Sub samples of the filtered solution were placed into 100 mL volumetric flasks. These sub samples were 2.5 and 5 mL for four and two grams of carcass, respectively, and 4 and 8 mL for four and two grams of offal respectively. Twenty ml of ammonium metavanadate was added to the sub samples, and the solution was brought to volume with distilled water.

Samples were analyzed on a spectrophotometer (AOAC, 1990) using the photometric molybdovanadate method described by Heckman (1965) to determine phosphorus concentration (mg/mL) in solution. This measurement was used to calculate the amount of phosphorus as a percent of DM in carcass and offal. Nitrogen analysis was determined using a total combustion technique (NS-2000[a]; LECO, St. Joseph, MI). Nitrogen concentration was used to compute percent crude protein in carcass and offal, by multiplying percent nitrogen x 6.25. Phosphorus accretion (g/kg) of carcass (entire chilled carcass, kg), empty body, and live weight was determined using simple linear regression. Empty body weight was calculated by adding total carcass to total offal weight. Phosphorus accretion (g/kg) of protein in carcass, offal, and total empty body was determined by regression of total phosphorus (g) against total protein (kg) in carcass, and empty body. Body composition data were analyzed using the PROC GLM procedure of SAS (SAS Inst. Inc., Cary NC). Means were separated by harvest date.

Results and Discussion

Carcass characteristics of steers are shown in Table 14. Live weight, empty body weight, and carcass weight of the initial harvest steers averaged 230, 181, and 113 kg, respectively. Dressing percent averaged 49% in the initial harvest steers. Rib eye area (REA) of the initial harvest steers averaged 18.3 cm^2, marbling score was practically devoid, and kidney pelvic and heart fat (KPH) averaged 0.67%. These measurements were low due to the age and live weights of the steers. Live weight, empty body weight, and chilled carcass weight for the final harvest steers averaged 317, 276, and 178 kg, respectively. Dressing percent of the final harvest steers averaged 56.1%, and REA averaged 22.3 cm^2. Marbling score ranged from PD^{70} to TR^{10} and KPH averaged 1.3% in the final harvest steers.

Table 15 shows mean composition of steer carcass, offal, and empty body. Composition of individual steer carcass, offal and empty body is shown in appendix Table 1. In the initial harvest steers, DM in carcass, offal, and empty body averaged 36.1, 34.3, and 35.2%, respectively. Ash content ranged from 122 to 141 g/kg, organic matter (OM) and protein content ranged from 822 to 856, and 553 to 658, g/kg, respectively. Fat and fat-free organic matter (FFOM) ranged from 217 to 227, and 668 to 828 g/kg, respectively. In the final harvest steers, DM in carcass, offal, and empty body averaged 35.7, 34.8, and 35.2%, respectively. Concentration of ash, OM, and protein, in the final harvest steers ranged from 114 to 134, 850 to 854, and 594 to 656, g/kg, respectively. Fat and fat-free organic matter concentration ranged from 179 to 269, and 802 to 832 g/kg, respectively. Table 16 shows comparisons between initial and final harvest steers. Phosphorus concentration of offal and empty body in the initial harvest inside the cell, the complex is subjected to polar conditions that cause the release of the metal cation, and the ionophore is freed to return to the exterior of the cell to bind to another cation. The rate of ion transport across the microbial cell membrane is dependent on the binding affinity of each ionophore and the concentration gradient of the individual cation. Each ionophore is specific in its affinity for a certain cation. Monensin has higher affinities for sodium and hydrogen, while lasalocid has a higher affinity for potassium, and equal affinities for calcium and sodium. According to Kirk et al. (1985), 39 kg lambs fed 67 mg of monensin tended ($P > 0.10$) to have increased apparent sodium absorption and increased ($P < 0.05$) potassium absorption. Bergen and Bates (1984) concluded that the changes in growth performance caused by ionophores are the result of secondary effects, such as a shift in VFA proportions, caused by altering ion transport and cation and protein gradients.

Schelling (1984) examined the possible modes of action of monensin. This researcher proposed that animal responses result from system modes of action rather than the basic mode of action of altering normal ionic transport across biological membranes. Shelling (1984) defined basic mode of action as the modification of ion transport across biological membranes. System mode of action was defined more broadly as the altering of normal metabolic functions. This study suggested that there are seven possible system modes of action responsible for an animal response to monensin. These included: 1) modification of VFA production; 2) modification of feed intake; 3) changes in gas production (CH_3 and H); 4) modification of DM digestibility; 5) changes in protein utilization; 6) modification of rumen fill and rate of passage; and 7) other indirect effects.

group was greater ($P < 0.01$) than the final group. Organic matter ($P = 0.07$) and FFOM ($P = 0.12$) tended to be greater in the final harvest group than the initial harvest group.

Table 17 shows steer performance and phosphorus removal. Steer performance and phosphorus removal per pasture is shown in appendix Table 2. Mean daily gain of the three steers harvested on April 16, was 0.42, 2.54, and 0.69 kg for fall/winter, grazeout, and the overall trial (91 days), respectively. Mean daily gain of the remaining steers that were not harvested was 0.28, 1.43, and 0.55 kg for fall/winter, grazeout, and the overall trial, respectively. Total gain per steer averaged 50 kg over the entire trial, and total gain per ha averaged 129 kg. Phosphorus removal per steer and per ha averaged 354 and 918 g, respectively.

Phosphorus accretion in carcass, empty body weight, and live weight was 7.5, 6.4, and 7.1 g/kg, and is shown in Figures 9, 10, and 11, respectively. Phosphorus accretion in this study is greater than that reported by Ternouth et al. (1996), who reported that phosphorus accretion rate in 200 to 400 kg growing cattle was 5.8 g/kg of live weight. This is within the range of 5 to 8 g P/kg live weight in pigs reported by Jongbloed (1987). Phosphorus concentrations in beef and swine tissues are similar (Anderson and Hoke, 1990; Anderson et al., 1992), and therefore, phosphorus accretion rates in cattle should be similar to that of the pig.

Phosphorus accretion rates in this study were 32.6 and 26.7 g/kg of protein in carcass and empty body, and are shown in Figures 12 and 13, respectively. The 1996 Beef Cattle NRC reported that phosphorus requirement above maintenance is 39 g P/kg of protein in empty body, which is greater than phosphorus accretion (g/kg of protein in empty body) in the current experiment.

The winter of 2000/2001 was poor for steer gains with low standing crop and a short grazing season, which limited steer performance, and consequently reduced phosphorus removal. When calculated to an equivalent total weight gain, the rate of phosphorus accretion in this study is similar to that reported by McCollum (2002), who reported that cattle gaining 0.68 kg daily should retain 5 g P daily. In this study, phosphorus accretion was limited by low steer gains, and phosphorus removal by grazing cattle was substantially less than phosphorus removed by biomass. At the Marshall location, 16,285 g P/ha was removed by harvesting the forage as hay, and 12,163 g P/ha was removed by harvesting grain.

Implications

Quantification of soil phosphorus removal from various sources is important in determining the amount of phosphorus that can be applied to the soil over a specific area in the form of animal manure. In the current study, the greatest amount of soil phosphorus was removed by forage biomass, which is substantially greater than the amount of phosphorus removed by grazing cattle (918 g/ha). Therefore, when designing manure management strategies, it is important to be aware of the amount of biomass produced.

Table 14. Carcass characteristics of steers[a].

Steer	Live Wt. (kg)	EBW (kg)	CCW (kg)	Dressing percent	REA (cm^2)	Marbling score	% KPH
Initial harvest[b]							
R23	222	170	107	48.2	18.0	PD^{0}	0.5
R25	220	174	107	48.6	16.8	PD^{0}	0.5
R98	249	196	125	50.2	20.1	PD^{0}	1.0
Mean:	230 ± 16	181 ± 14	113 ± 10	49.0 ± 1.0	18.3 ± 1.7		0.7 ± 0.3
Final harvest[c]							
W23	320	280	185	57.8	23.9	PD^{70}	1.5
W3	318	274	178	56.0	22.4	TR^{10}	1.5
Y41	313	274	171	54.6	20.6	PD^{80}	1.0
Mean:	317 ± 4	276 ± 3	178 ± 7	56.1 ± 1.6	22.3 ± 1.7		1.3 ± 0.3

[a]EBW = empty body weight, CCW = chilled carcass weight, REA = rib eye area, KPH = kidney, pelvic and heart fat, marbling score represents the percent intramuscular fat

[b]Initial harvest steers harvested on 1/15/01

[c]Final harvest steers harvested on 4/16/01

Table 15. Steer carcass, offal and empty body composition

Steer	Mean composition (g/kg)[a]						
	% DM	Ash	OM	Protein	Fat	FFOM	P
Initial harvest[b]							
Carcass:	36.1	141	822	553	227	668	7.7
Offal:	34.3	122	856	658	217	828	6.3
Empty body:	35.2	134	838	592	226	732	7.2
Final harvest[c]							
Carcass:	35.7	134	851	594	269	802	7.7
Offal:	34.8	114	850	656	179	832	5.4
Empty body:	35.2	125	854	616	244	812	6.9

[a]DM = dry matter, OM = organic matter, FFOM = fat-free organic matter
[b]Initial harvest steers harvested on 1/15/01
[c]Final harvest steers harvested on 4/16/01

Table 16. Comparison of initial vs final steer carcass, offal and empty body composition[a]

	Initial[b]			Final[c]			
Item	Carcass	Offal	EB	Carcass	Offal	EB	SE
% DM	36.1	34.3	35.2	35.7	34.8	35.2	1.45
Ash, g/kg	141	122	134	134	114	125	12.0
OM, g/kg	822	856	838	851	850	854	8.3
Protein, g/kg	553	658	592	594	656	616	27.7
Fat, g/kg	227	217	226	269	179	244	29.4
FFOM, g/kg	668	828	732	802	832	812	52.6
P[d], g/kg	7.7	6.3	7.2	7.7	5.4	6.9	0.25

[a]DM = dry matter, OM = organic matter, FFOM = fat-free organic matter, EB = empty body;

[b]Initial harvest steers harvested on 1/15/01

[c]Final harvest steers harvested on 4/16/01

[d]Initial P was different ($P < 0.001$) from final, OM ($P = 0.07$) and FFOM ($P = 0.12$) tended to be different between initial and final.

Table 17. Mean steer performance and phosphorus removal

	Means of four replications		
	F/W[a]	GO[b]	Total
Number of steers	10.5	11	
Hectares	9.11	3.14	
Stocking rate, steers/ha	1.15	3.5	
ADG, kg	0.28 ± 0.16	1.43 ± 0.08	0.55 ± 0.11
Gain/steer, kg	20 ± 11	30 ± 1.8	50 ± 10
Gain/hectare, kg	23 ± 15	106 ± 7	129 ± 10
P removal/kg of gain, g	7.08	7.08	7.08
P removal/steer, g	139 ± 81	213 ± 13	354 ± 71
P removal/hectare, g	168 ± 102	751 ± 43	916 ± 75

[a]F/W = Fall/winter grazing (1/10/01 to 3/21/01; 70 days)

[b]GO = Grazeout (3/22/01 to 4/11/01; 21 days)

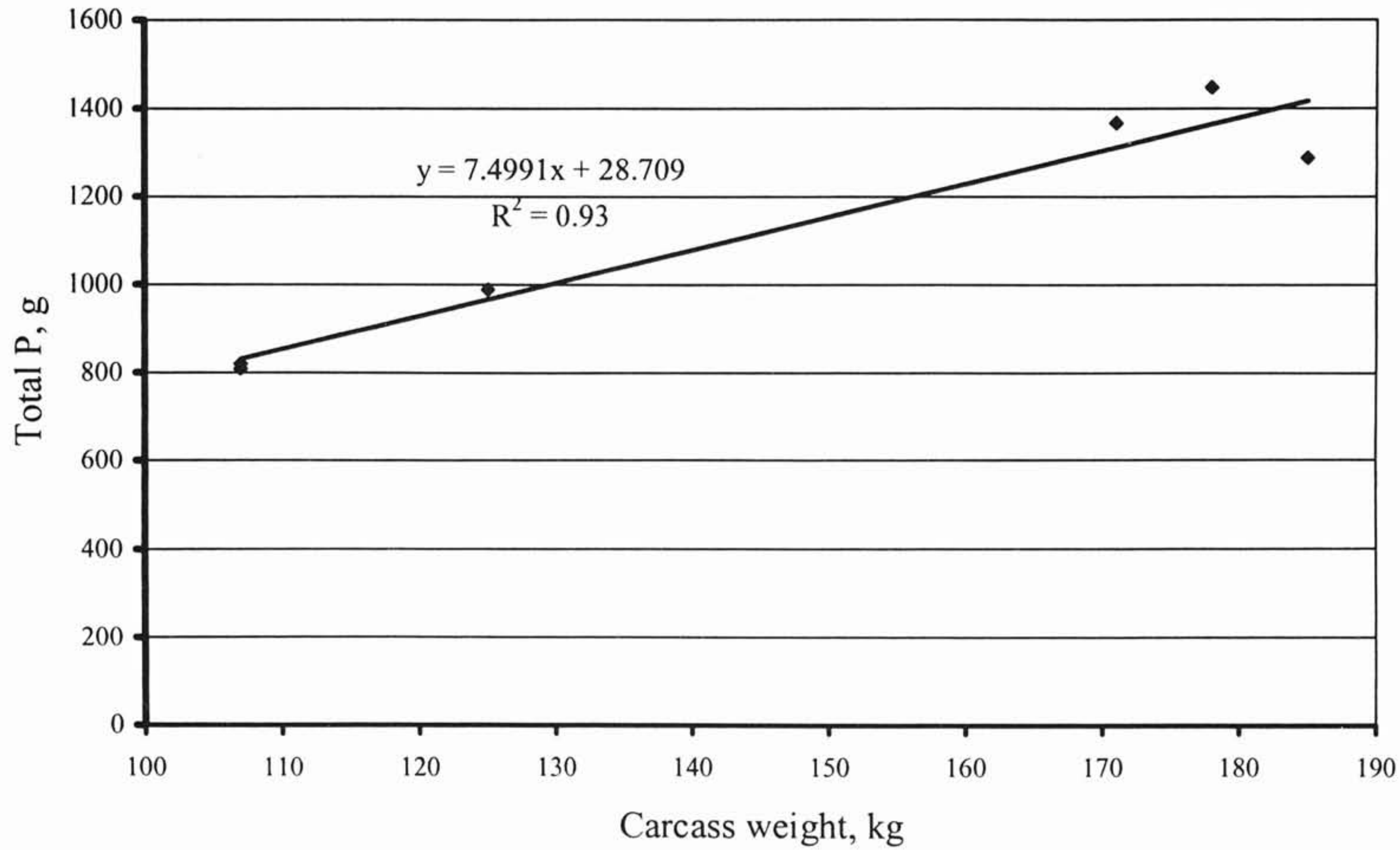

Figure 9. Relationship of total phosphorus content to carcass weight of growing beef steers grazed on winter wheat pasture.

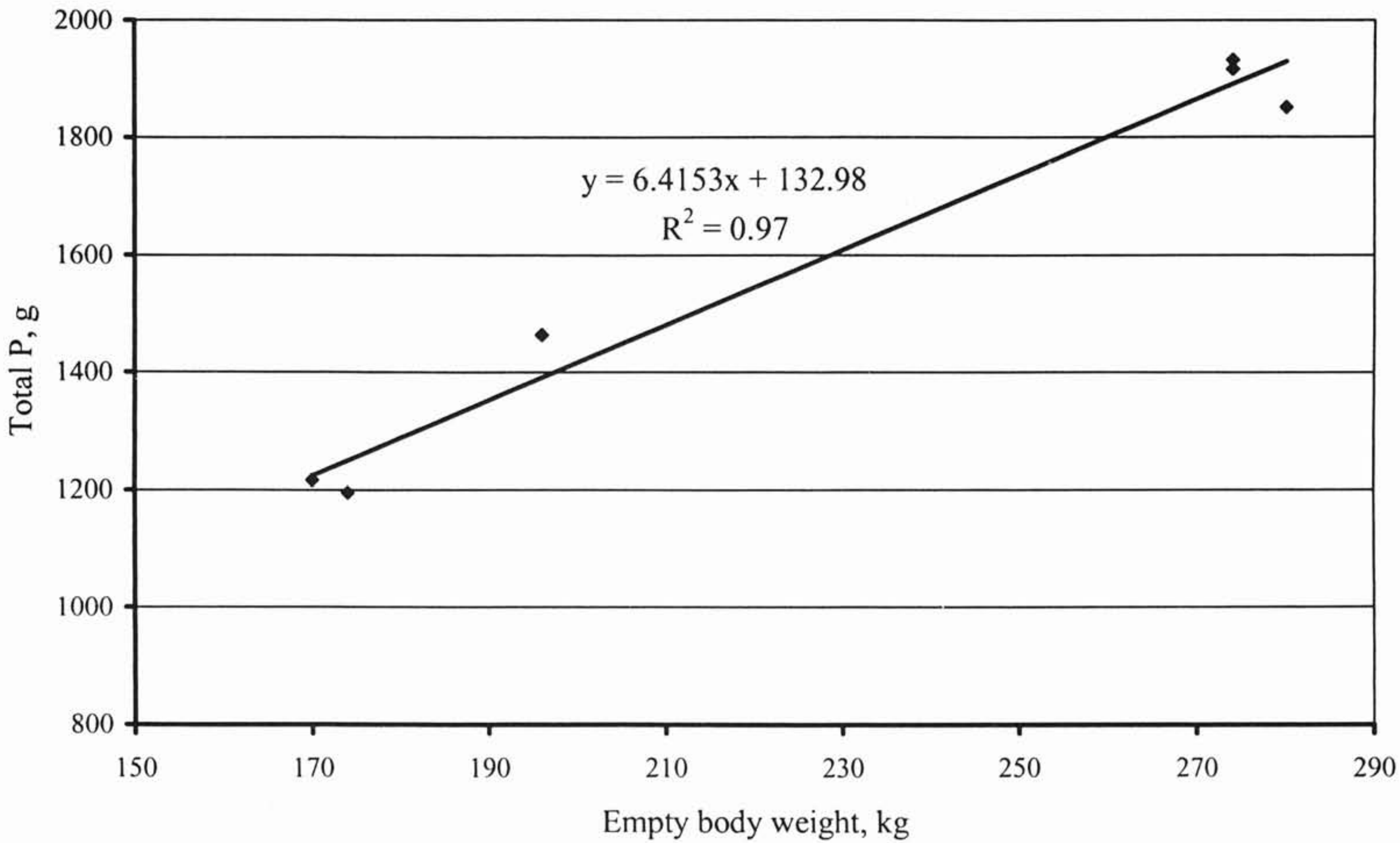

Figure 10. Relationship of total phosphorus content to empty body weight of growing beef steers grazed on winter wheat pasture.

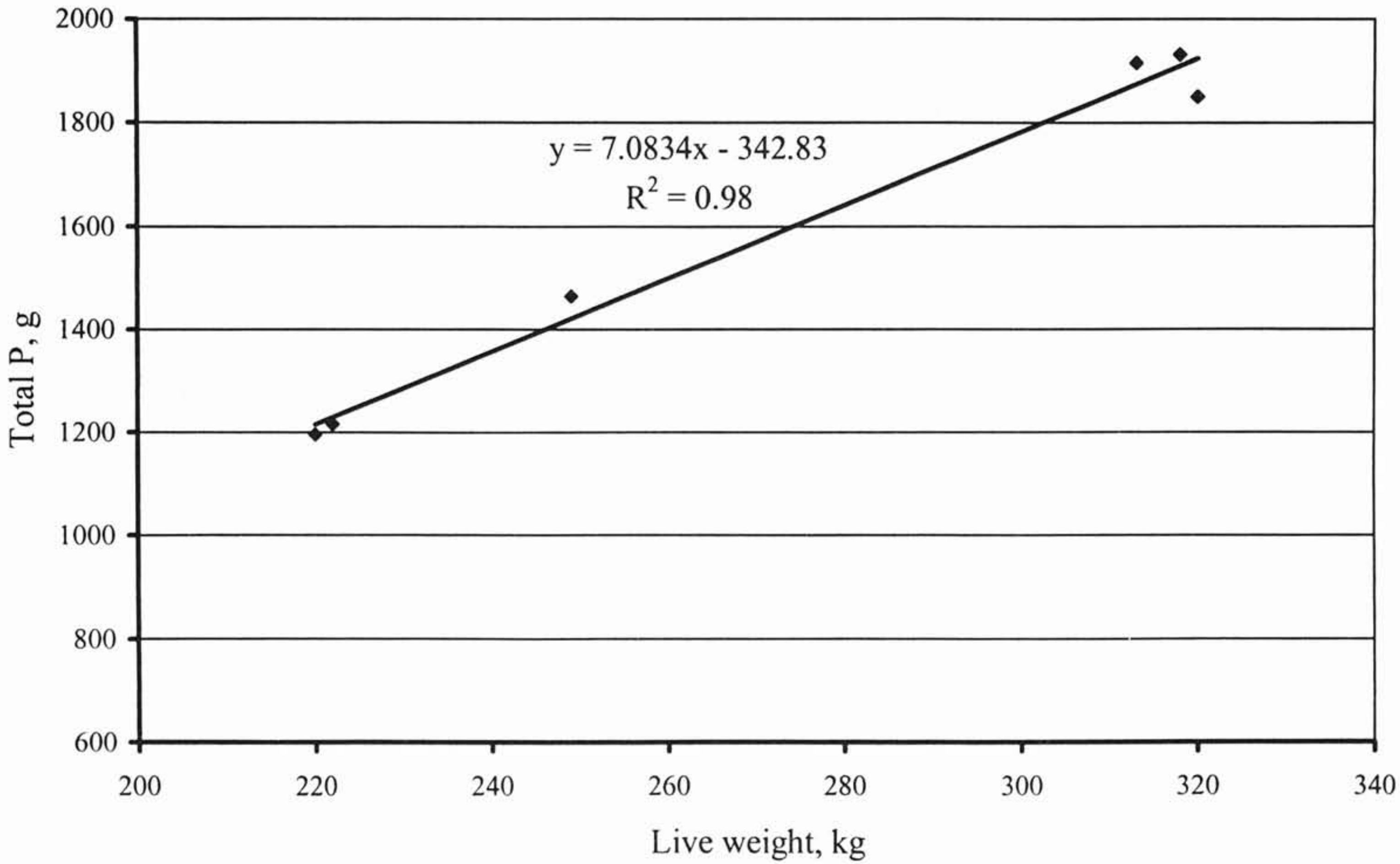

Figure 11. Relationship of total phosphorus content to live weight of growing beef steers grazed on winter wheat pasture.

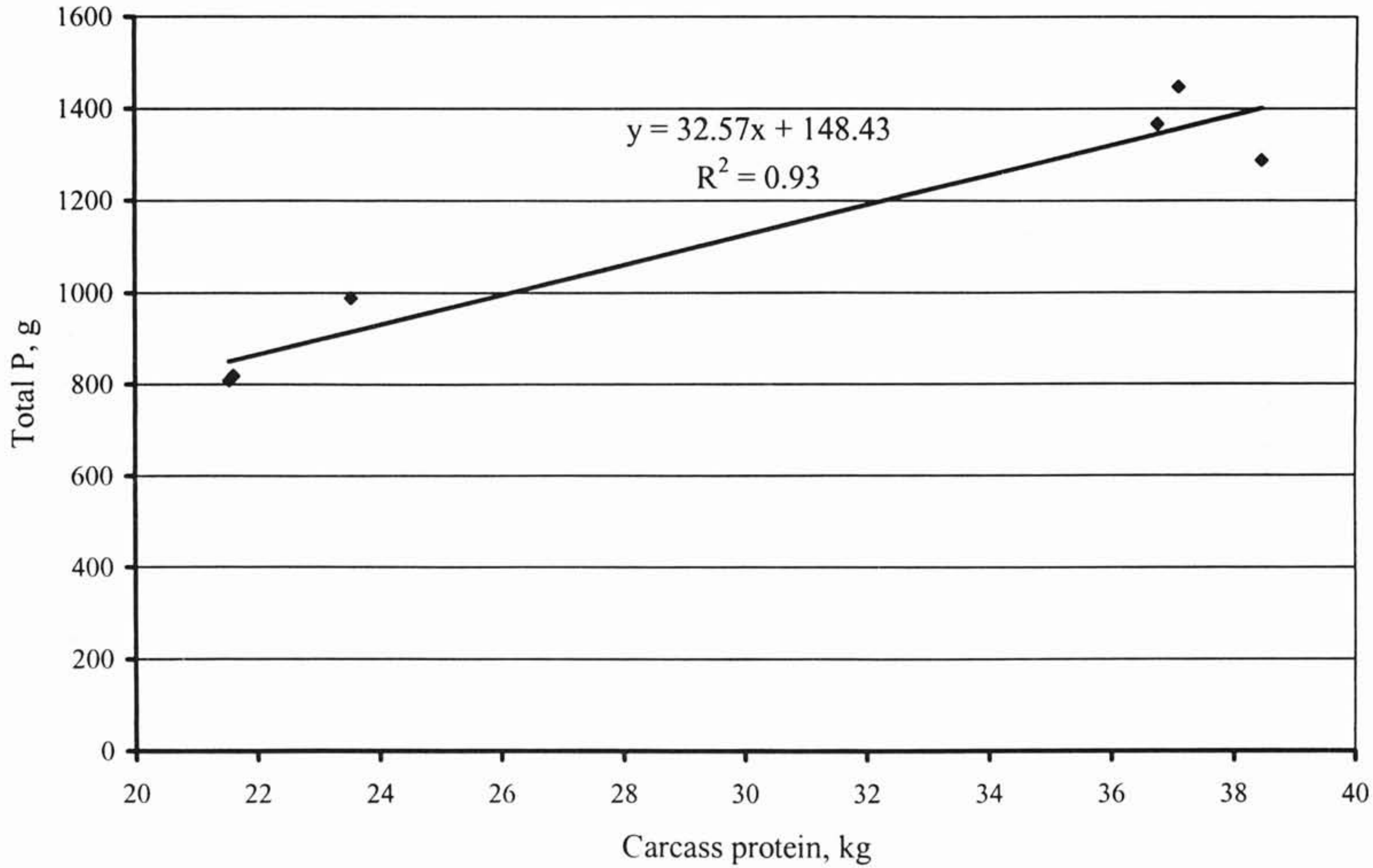

Figure 12. Relationship of total phosphorus content to carcass protein of growing beef steers grazed on winter wheat pasture.

VFA concentration. Many experiments have shown that monensin alters individual VFA concentrations in the rumen. The most common result of monensin and lasalocid on individual VFA concentrations is increased propionate, and decreased acetate and butyrate concentration. Although individual VFA concentrations are affected, total VFA concentration is not changed. Chalupa et al. (1980) conducted a study that examined 0, 0.1, 0.2, 0.5, 1, 2, and 4 ppm of monensin in 50 kg sheep. These researchers reported that 0.5 or 1 ppm monensin increased propionate production by 15 to 25%, and decreased ($P < 0.05$) acetate (2 to 18%) and butyrate production (4 to 25%). These researchers further suggested that the amount of energy captured as VFA was increased by increasing propionate production. Bartley et al. (1979) also reported that monensin and lasalocid increased propionate and decreased acetate concentration. Lemenager et al. (1978b) reported that 200 mg of monensin increased ($P < 0.10$) propionate and decreased ($P < 0.10$) acetate within four hours after administration. The change in VFA proportions does not account for the entire response shown by monensin; other factors such as alteration of DMI are important in increasing animal production.

Dry matter intake. It is also well documented in the literature that monensin is effective in modifying DMI. Monensin influences feed efficiency by reducing DMI while maintaining ADG. Lasalocid alters feed efficiency by increasing ADG and maintaining DMI in cattle fed high-concentrate diets (Lasalocid Technical Manual, 1985). Schelling (1984) reported trials that indicated an average 10.7% reduction in feed intake by monensin fed in high-concentrate diets. This average included severe reductions of as much as 16% experienced by cattle offered monensin with no adaptation period. However, cattle fed monensin over a 112-day feeding period experienced only

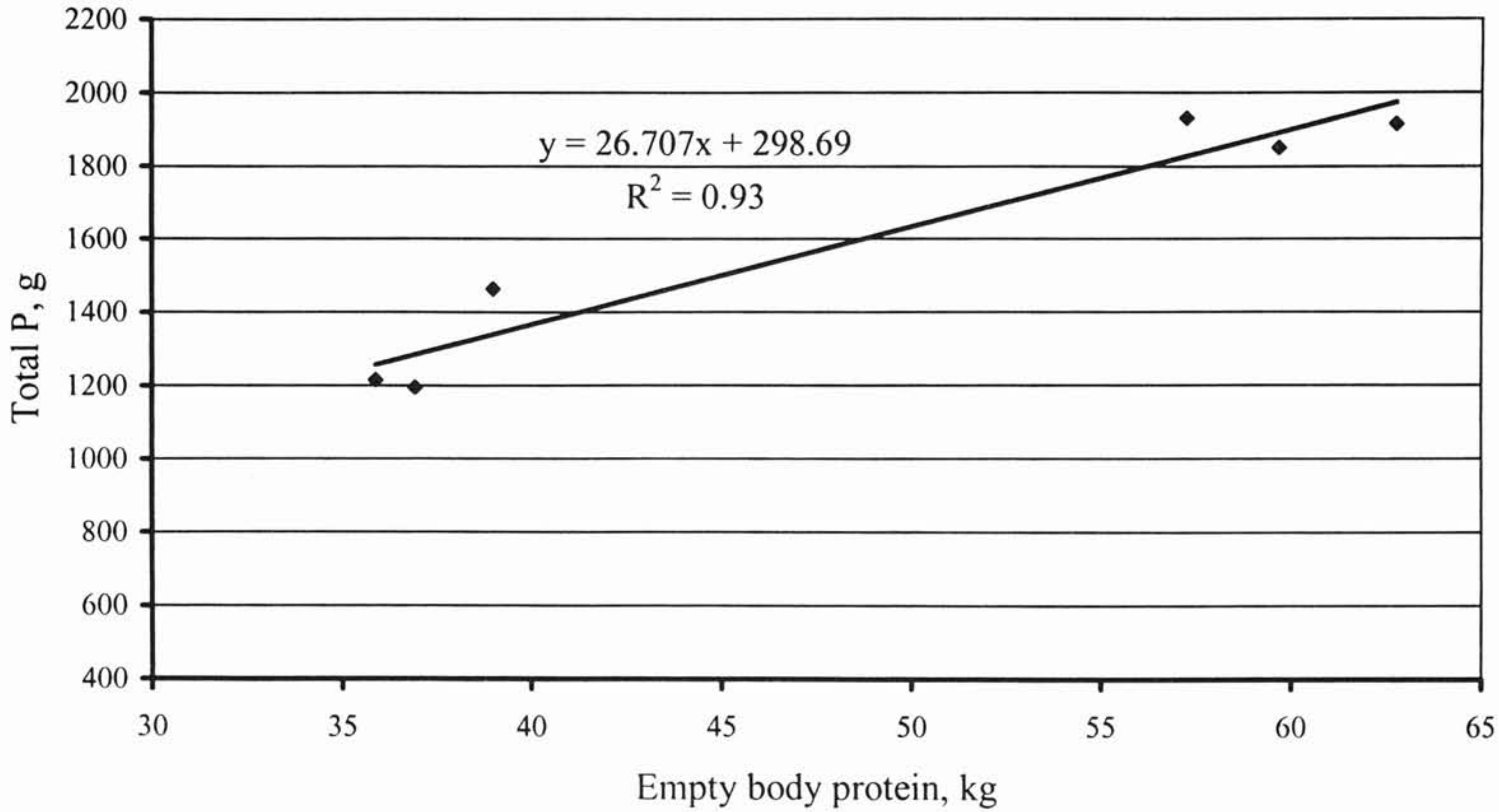

Figure 13. Relationship of total phosphorus content to empty body protein of growing beef steers grazed on winter wheat pasture.

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APPENDIX

Carcass Composition, Cattle Performance and Phosphorus Removal

Table 1. Composition of steer carcass, offal and empty body

	Composition (g/kg[a]						
Steer	% DM	Ash	OM	Protein	Fat	FFOM	P
Initial harvest[b]							
Carcass:							
R23	32.7	157	816	617	212	783	808
R25	36.7	142	841	551	170	451	819
R98	38.8	123	808	491	299	771	989
Mean:	36.1	141	822	553	227	668	872
Offal:							
R23	31.5	145	852	722	186	818	408
R25	35.8	103	864	641	231	844	376
R98	35.6	119	851	610	234	823	475
Mean:	34.3	122	856	658	217	828	420
Empty body:							
R23	32.1	154	833	657	203	799	659
R25	36.3	127	850	584	194	601	649
R98	37.2	122	830	535	280	796	703
Mean:	35.2	134	838	592	226	732	670
Final harvest[c]							
Carcass:							
W23	33.6	119	862	621	249	818	1288
W3	38.3	163	842	546	301	776	1448
Y41	35.1	120	849	615	256	811	1367
Mean:	35.7	134	851	594	269	802	1368
Offal:							
W23	35.5	116	829	631	183	800	563
W3	31.7	129	869	656	252	849	484
Y41	37.3	97	853	682	101	846	549
Mean:	34.8	114	850	656	179	832	532
Empty body:							
W23	34.5	117	843	618	224	804	1042
W3	35.0	154	873	597	293	817	1110
Y41	36.2	105	845	632	216	816	1059
Mean:	35.2	125	854	616	244	812	1070

[a]DM = dry matter, OM = organic matter, FFOM = fat-free orgainic matter

[b]Initial harvest steers harvested on 1/15/01

[c]Final harvest steers harvested on 4/16/01

Table 2. Cattle performance and phosphorus removal by pasture

	Pasture number														
	1			5			9			14			Mean of 4 reps		
Item	F/W[a]	GO[b]	Total	F/W	GO	Total	F/W	GO	Total	F/W	GO	Total	F/W	GO	Total
Number of steers	12	14		11	11		11	11		8	8		10.5	11	
Hectares	9.72	4.17		9.72	2.95		9.72	3.25		7.29	2.22		9.11	3.14	
Stocking rate, steers/ha	1.23	3.36		1.13	3.73		1.13	3.38		1.10	3.60		1.15	3.50	
ADG, kg	0.48	1.39	0.68	0.34	1.33	0.57	0.10	1.51	0.42	0.22	1.49	0.51	0.28	1.43	0.55
Gain/steer, kg	33	29	63	24	28	52	6.4	32	39	15	31	47	20	30	50
Gain/hectare, kg	41	97	139	27	105	131	6.72	108	114	16.8	113	130	23	106	129
P removal/kg of gain, g	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08	7.08
P removal/steer, g	235	203	444	167	200	367	45	225	274	109	222	332	139	213	354
P removal/hectare, g	290	696	995	189	744	933	52	764	814	120	800	920	168	750	918

[a]F/W = Fall/winter grazing (1/10/01 to 3/21/01; 70 days)

[b]GO = Grazeout (3/22/01 to 4/11/01; 21 days)

Table 3. Balance of required vs supplied minerals in steers grazing wheat pasture without supplementation or consuming the non-medicated mineral supplement (Year 2)[a,b].

		Balance		
Mineral	Requirement	Wheat pasture; no mineral supplement	236 g/d*	113 g/d**
Ca, g/d	34.2	-10.2	14.4	1.6
P, g/d	17.0	1.7	15.9	8.5
Mg, g/d	7.8	7.0	6.8	6.9
K, g/d	46.6	156.7	156.7	156.7
Na, g/d	5.4	-2.1	20.2	8.6
S, g/d	11.6	2.3	2.0	2.2
Cu, mg/d	78	-23	269	117
I, mg/d	4	-4	-4	-4
Fe, mg/d	388	939	927	933
Mn, mg/d	115	644	639	642
Se, mg/d	1	-1	5	2
Zn, mg/d	233	-70	631	267

[a]Mineral balances determined by the NRC level 1 model (1996).

[b]Actual ADG = 1.04 kg, intake of wheat forage DM = 2.74 % of mean BW (283 kg).

*Observed intake of the non-medicated mineral supplement (Year 2).

**Assuming target intake of the non-medicated mineral supplement of 113 $g^{-1}\cdot steer^{-1}\cdot d^{-1}$.

VITA

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Master of Science

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five percent reduction in DMI. Shelling (1984) also suggested that a more realistic decrease in DMI in cattle fed concentrate rations was about five to six percent. Monensin decreased DMI by about three percent in cattle fed high-roughage diets in confinement. Lemenager et al. (1978b) reported that 200 mg monensin decreased ($P < 0.02$) DMI 15.6% in 625 kg steers consuming low-quality winter range. Bartley et al. (1979) reported that monensin and lasalocid decreased DMI and improved feed efficiency by maintaining ADG. In their study, 156 mg monensin resulted in a greater improvement in feed efficiency than either 69 or 195 mg lasalocid in steers consuming 75% alfalfa hay, 25% concentrate diets.

Gas production. Bergen and Bates (1984) showed that monensin was effective in decreasing methane production in the rumen. Chalupa et al. (1980) reported that monensin decreased methane production by 15 to 40%. In their study, monensin did not increase hydrogen gas production, and reduced CO_2 production by 10%. Bartley et al. (1979) also reported that 0, 11, 22, 33, 44, 55, and 66 ppm monensin and lasalocid decreased gas production in the rumen of Angus/Holstein steers consuming alfalfa hay and concentrate diets.

Dry matter digestibility. It has also been reported that monensin was responsible for changes in DM digestibility. Lemenager et al. (1978b) examined the effects of monensin on IVDMD, and demonstrated that IVDMD was depressed in animals that were not allowed an adaptation period to monensin. However, if animals were allowed an adaptation period to monensin, there was no difference in IVDMD. These researchers suggested that decreased DMI by monensin-fed cattle was a result of decreased rate of digestion rather than decreased extent of digestion. Dinius et al. (1976) conducted an experiment that compared 0, 11, 22, and 33 ppm of monensin on in-vitro fiber digestibility. These researchers found that there was no difference ($P > 0.10$) in weight loss of the cotton fiber between treatments. These researchers also reported that monensin did not affect ($P > 0.10$) apparent digestibility of DM, CP or carbohydrate fractions.

Protein utilization. Schelling (1984) and Bergen and Bates (1984) reported that monensin had a protein sparing effect in the rumen. These researchers also suggested that monensin decreased dietary protein requirement. Monensin decreased the amount of bacterial N reaching the small intestine, which allowed more ruminally undegraded intake protein (RUP) to be digested in the small intestine. In vivo trials conducted by Bergen and Bates (1984) concluded that monensin increased RUP by 22 to 55% in five experiments. This research suggested that monensin also decreased efficiency of microbial crude protein synthesis. This was likely due to a deficiency of dietary N available for rumen microbes, which reduced microbial activity. This agrees with Bartley et al. (1979), who reported that 11 to 66 ppm monensin and lasalocid decreased microbial protein production.

Lactic acid. Ionophores have also been shown to decrease or prevent lactic acidosis in cattle. Monensin inhibits hydrogen-producing and formate-producing bacteria, while stimulating succinate-producing and propionate-producing bacteria. This agrees with Dennis et al. (1981), who reported that monensin and lasalocid decreased lactate-producing bacteria. Bergen and Bates (1984) reported that ionophores had an antibiotic effect in the rumen, which inhibited growth of gram-positive bacteria. These bacteria were largely responsible for lactic acid production in the rumen. Monensin aided in maintaining ruminal pH by inhibiting lactate-producing bacteria, but did not affect bacteria that convert lactate to propionate. Nagaraja et al. (1982) evaluated the effects of 0, 0.33, 0.65, and 1.30 mg/kg of BW of monensin, lasalocid, and thiopeptin daily on lactic acid production. These researchers found that lasalocid increased ($P < 0.01$) ruminal pH over control for each treatment, and 0.65 and 1.30 mg/kg of BW of monensin increased ($P < 0.05$) rumen pH over control. L (+) lactate was decreased by 0.33, 0.65, and 1.30 mg lasalocid/kg BW, and was decreased by 0.65 and 1.30 mg monensin/kg of BW. D (-) lactate was numerically decreased by 1.3 mg/kg BW of monensin and lasalocid.

Effects of Lasalocid on Intake and Performance

Lasalocid in cattle fed high-concentrate diets. The effects of lasalocid on cattle fed high-concentrate rations have been studied for many years. Lasalocid improves feed efficiency of feedlot cattle by improving daily gain while maintaining feed intake. Delfino et al. (1988) examined the effects of varying levels of lasalocid on feedlot performance in cattle. Lasalocid was fed at levels of 0, 24, 36, and 54 mg/kg of DM, and daily DMI were 8.6, 8.8, 8.4, and 8.5 kg, respectively. This level of intake resulted in ionophore intakes of 0, 211, 302, and 459 mg. Monensin was also added to the diet as a separate treatment at 11 mg/kg, (94 mg), for the first 28 days of the experiment, and 33 mg/kg (277 mg), for the remainder of the trial. The results of this experiment demonstrated that adding lasalocid or monensin had no affect ($P > 0.10$) on feed intake. During the first 28 days of the trial, heifers fed lasalocid at 459 mg daily had greater daily gains ($P < 0.05$) than those fed either diet without lasalocid (control) or 302 mg lasalocid.

Overall, there was no difference ($P = 0.12$) in average daily gain between treatments. This is in contrast with results reported by Rode (1987), who showed that lasalocid in a grain supplement improved rate of gain by 17% compared with steers fed barley supplement without lasalocid.

Delfino et al. (1988) also demonstrated that monensin and lasalocid improved feed efficiency. Cattle receiving 459 mg lasalocid daily required less DM/kg of weight gain ($P < 0.05$) during the first 28 days of the trial. Heifers fed lasalocid at 302 or 459 mg daily required less ($P < 0.10$) total DM/kg of weight gain than control or monensin fed heifers. Berger et al. (1981) compared 0, 273, and 401 mg lasalocid, and 268 mg monensin, and demonstrated that ADG ($P < 0.05$) and feed efficiency ($P < 0.05$) were improved as a result of lasalocid supplementation.

A second experiment conducted by Delfino et al. (1988) examined the effects of lasalocid supplementation on DM digestibility and energy utilization. Cattle were fed different levels of intake (21, 44, 67, and 89 g DM/kg of body weight$^{0.75}$). These levels restricted DMI for steers that weighed between 605 and 626 kg. Daily DMI was 2.78, 5.49, 8.23, and 10.86 kg/d for 21, 44, 67 and 89 g DM/kg of body weight$^{0.75}$, respectively. Lasalocid was added at either 0 or 36 mg/kg DM, and provided 100, 198, 296, and 391 mg of lasalocid for the various feeding levels respectively. The addition of lasalocid to these diets did not affect dry matter or energy digestibility ($P > 0.10$), however it did increase nitrogen digestibility by 4% ($P < 0.05$) over the control diets. Lasalocid also did not affect total CH_4 production ($P > 0.10$). However, when expressed as CH_4 lost as a percentage of digestible energy, lasalocid supplementation tended ($P <$

0.10) to decrease CH_4 production. Lasalocid also tended ($P > 0.10$) to decrease the acetate to propionate ratio.

The overall results of the study by Delfino et al. (1988) showed that in a 90% concentrate diet, lasalocid tended to improve feed efficiency ($P < 0.10$) while not decreasing DMI. Furthermore, the addition of monensin and lasalocid had no effect on carcass characteristics when compared with control. This is in agreement with Berger et al. (1981), who observed no differences in carcass characteristics as a result of lasalocid or monensin supplementation.

Lasalocid in cattle fed forage-based diets. Considerable research has been conducted to examine the effects of lasalocid when administered to cattle on high roughage diets. Goodrich et al. (1984) showed that lasalocid increased ADG while maintaining DMI when supplemented in high roughage diets. These results are supported by research conducted by Thonney et al. (1981) who compared 183 mg of monensin to 83, 175, and 220 mg of lasalocid, or 149 mg of lasalocid in mycelium cake. These results demonstrated that lasalocid supplementation of high-roughage diets increased ADG over either supplement without lasalocid or monensin-supplemented cattle. In their trial, the greatest ADG response occurred at 175 mg of lasalocid daily. This research demonstrated that 175 mg lasalocid daily increased ADG ($P < 0.005$) over monensin. However, monensin supplementation resulted in a lower intake of DM/kg of gain. Consequently, there was no difference in feed efficiency between lasalocid and monensin. Gill et al. (1981) reported that 100 mg of lasalocid daily increased ADG of steers grazing warm season native grass pastures by 0.17 lb over supplement without lasalocid.

Lasalocid is effective in altering the acetate to propionate ratio in plasma. However, Thonney et al. (1981) reported that lasalocid had less distinct effects than monensin. Monensin increased ($P < 0.05$) propionate concentrations, and tended ($P < 0.10$) to decrease plasma acetate to propionate ratio to a greater degree than lasalocid (Thonney et al., 1981). Spears and Harvey (1984) also reported that lasalocid increased ($P < 0.05$) ruminal propionate proportion and decreased ($P < 0.01$) acetate to propionate ratio when supplemented to mixed cool season grass and legume pastures.

Research has also been conducted to examine the efficacy of using mineral supplements as a vehicle for ionophores. Rode et al. (1994) examined the effect of 200 mg lasalocid on intake of a mineral supplement by heifers grazing mixed cool-season pastures. Intakes for this experiment were similar for both control and lasalocid containing minerals. Desired lasalocid concentration was 2,000 mg lasalocid/kg of mineral supplement, however, the actual level of lasalocid was 1,370 mg lasalocid/kg of supplement. Intake of mineral in this experiment was quite variable, ranging from 43 to 158 g/heifer, which provided between 58.9 and 216.5 mg lasalocid/heifer in year one, and 91 to 240 g/heifer, which provided 123.3 and 328.8 mg lasalocid/heifer in year two. The heifers fed the lasalocid-containing supplement gained 0.05 kg more ($P = 0.04$) than the heifers consuming the non-medicated mineral supplement in year one, but only 0.02 kg more ($P = 0.51$) in year two. These researchers suggested that the lack of improvement in year two might have been due to a greater amount of higher quality forage, which allowed little room for improvement in ADG. Jacques et al. (1987) conducted an experiment that examined the effects of 0, 100, 200, and 300 mg of lasalocid daily on forage intake, digestibility, ruminal fermentation, liquid flow, and performance of beef cows grazing winter range. In this study, lasalocid did not affect change in body condition score ($P > 0.10$), or body weight change at 30, 60, or 90 days. Also, lasalocid did not affect total DMI.

Jacques et al. (1987) conducted a second experiment in which lasalocid was fed at 0, 0.22, 0.44, or 0.66 mg/kg of BW to cows and steers to determine effects on total diet and organic matter digestibility. Daily ionophore intake was calculated as: 0, 104, 209, and 326 mg for cows, and 0, 48, 101, and 147 mg for steers. In this trial, a quadratic ($P < 0.01$) effect was seen for total and forage OM digestibility. Total OM digestibility decreased by 2.3% from supplement without lasalocid to 209 mg/cow, and increased to 2.4% greater than control at 326 mg/cow. Organic matter digestibility was lowest ($P < 0.01$) at 104 mg of lasalocid but increased for greater amounts of lasalocid. A similar, non-significant quadratic response was observed in steers. The study by Jacques et al. (1987) demonstrated that lasalocid did not change ruminal pH, ammonia nitrogen, total concentration of volatile fatty acids, proportion of individual VFAs, or ruminal liquid dilution rate. This experiment suggested that lasalocid, when fed to mature cows on dormant forage had little effect on performance.

Lasalocid in cattle grazing wheat pasture. Little research has been conducted to examine the effects of lasalocid on cattle grazing wheat pasture. Andersen and Horn (1985) conducted an experiment that examined the effects of lasalocid on intake and performance of cattle grazing wheat pasture. The heifers used in their experiment were allocated into three groups that were fed supplements containing 0 (control), 100, and 200 mg lasalocid daily. Heifers receiving 200 mg lasalocid daily had ADG that tended ($P > 0.05$) to be greater than the control and 100 mg treatment group for days one through

57 of the trial. For the entire experiment, daily gains of cattle receiving 200 mg of lasalocid daily were greater ($P < 0.05$) than either the control or the 100 mg treatments. This agrees with Horn et al. (1984) who reported that ADG was greater ($P < 0.05$) for cattle fed 200 mg lasalocid daily than 100 mg or ground corn without lasalocid. Daily gain was improved similarly for year two, and there was no difference ($P > 0.05$) between treatment levels. Forage intake was unaffected by administration of lasalocid ($P > 0.15$). Lasalocid supplementation did not affect ruminal pH, or total VFA concentrations during either year of the trial. The results of this experiment demonstrated that over the entire two-year period lasalocid supplementation at the rate of 200 mg daily increased ADG by 0.25 lb ($P < 0.05$) over control and 100 mg.

Effects of Monensin on Intake and Performance

Monensin in cattle fed high-concentrate diets. Monensin has been available for use in the cattle feeding industry for many years, and the effects of monensin supplementation have been well documented by multiple researchers. Goodrich et al. (1984) summarized performance data on nearly 16,000 cattle that were used in trials to determine the effects of monensin on performance of feedlot cattle. In these trials, monensin was fed at 0, 5.5, 11, 22, 27.5, 33, and 44 g/ton, which provided 0, 51, 102, 197, 242, 286, and 375 mg daily. These researchers concluded that monensin numerically increased ADG by 1.6% over diets with no monensin. Goodrich et al. (1984) also reported that ADG was improved to a greater degree in trials where ADG was low. These researchers suggested that this effect was due to a greater response to monensin by cattle that cannot efficiently convert feed to live weight gain. Other trials have also reported improvements in daily gain as a result of monensin supplementation (Steen et al., 1977; and Lana et al., 1997). In contrast, other researchers have reported that monensin had no effect on ADG. Perry et al. (1976), Raun et al. (1976), Potter et al. (1985), and Zinn et al. (1994) reported that ADG was not significantly changed by monensin supplementation.

Effects of monensin on DMI have also been well documented. Many researchers have found that monensin supplementation resulted in a reduction in DMI. For example, Potter et al. (1985) conducted a trial that compared 0 and 287 mg monensin daily in feedlot rations. These results showed a decrease in DMI of 7.72% ($P < 0.01$) while ADG was maintained as a result of 287 mg of monensin daily. Goodrich et al. (1984) reported a reduction in DMI of 6.4% due to monensin supplementation. Stock et al. (1995) also reported a 0.11 and 0.12 kg reduction in DMI ($P < 0.05$) from monensin addition at the rate of 192 and 287 mg, respectively, in high-concentrate diets. Raun et al. (1976) conducted a series of experiments that compared various levels of monensin in concentrate rations. They fed monensin at 0, 2.7, 5.5, 11, 22, 33, 44, and 88 ppm, which provided 0, 26, 51, 103, 189, 275, 371, and 649 mg of monensin daily, and concluded that intake of feedlot diets was reduced ($P < 0.01$) by 189 mg and greater amounts of monensin.

Monensin is well known to improve feed efficiency in cattle. Multiple research trials have reported improvements in feed efficiency as a result of monensin supplementation. Goodrich et al. (1984) reported an improvement in feed per 100 kg of gain of 7.5%, which is less than the 8.6% reported by Potter et al. (1985). Feed efficiency was improved in this trial by reducing the feed to gain ratio from 7.31 for control to 6.68 for monensin. Perry et al. (1976) found that 33 mg/kg of monensin in feedlot diets increased feed efficiency by 10%. This agrees with Raun et al. (1976), who showed that monensin supplementation between 100 and 500 mg daily improved feed efficiency ($P < 0.05$). In this trial, feed/gain was reduced from 8.99 kg for control to 7.54 kg for 500 mg monensin. Feed efficiency was further improved by feeding 750 mg of monensin during the last 106 days of the experiment. Lana et al. (1997) conducted a trial that examined the effects of monensin supplementation in soybean meal or urea-based diets. These researchers found that monensin increased feed efficiency for both forms of nitrogen, however, it is more effective in soybean meal than urea-based diets ($P < 0.10$).

Monensin has predictable effects on VFA proportions in the rumen. Multiple research trials have proven that monensin decreased acetate and butyrate and increased propionate concentration. Perry et al. (1976) reported a decrease of 16% in acetate, a decrease of 46% in butyrate, and an increase of 75% in propionate due to monensin supplementation ($P < 0.001$).

The effects of monensin supplementation on carcass characteristics have been examined as part of some research trials. Goodrich et al. (1984) reported that monensin decreased carcass dressing percentage, marbling, fat thickness, quality grade, and yield grade. Other researchers have concluded that monensin had no affect on carcass characteristics (Perry et al., 1976; Gay et al., 1977; and Steen et al., 1977).

Monensin has also been shown to change nitrogen and energy metabolism. Lana et al. (1997) compared three levels of monensin supplementation, 0, 11, and 22 mg/kg of DM for soybean meal and urea-based diets. The monensin levels for each diet were 80 and 165 mg for urea and 87 and 167 mg for the soybean meal diet. These researchers concluded that monensin supplementation in soybean meal-based diets increased NE_g, while it decreased NE_g in urea-based diets. Lana et al. (1997) also suggested that monensin tended ($P = 0.18$) to decrease efficiency of nitrogen utilization for urea-based diets but it increased efficiency of nitrogen utilization for soybean meal-based diets. Goodrich et al. (1984) also reported that monensin improved NE_g values of concentrate diets. Zinn et al. (1994) reported that 206 and 212 mg monensin daily in finishing diets that contained 10 and 20% forage, respectively, reduced the amount of microbial nitrogen passage from the rumen. This agrees with Burrin et al. (1988), who also reported that monensin increased dietary nitrogen passage from the rumen. This increased nitrogen passage was likely a major cause of the protein sparing effect observed by monensin supplementation (Perry et al., 1983).

Monensin in cattle fed forage-based diets. Multiple studies have been conducted that examined the effect of monensin on intake and performance of cattle consuming forage-based diets. Monensin, when supplemented in forage-based diets increased ADG. Several studies (Potter et al., 1976; Rouquette et al., 1980; Barnett et al., 1982; Potter et al., 1986) have reported that monensin increased ADG of cattle consuming forage-based diets. Potter et al. (1976) examined the effects of different levels of monensin on performance of cattle grazing mixed pastures of warm and cool season grasses and legumes. These researchers compared 0, 50, 100, 200, 300, and 400 mg monensin daily, and concluded that 100 and 200 mg monensin increased ($P < 0.01$) ADG by 0.05 and 0.10 kg, respectively over supplement without monensin. Three hundred and 400 mg monensin increased ADG by 0.05 and 0.03 kg, respectively over supplement without monensin. Oliver (1975) conducted a study that examined 0, 25, 50, 100, and 200 mg monensin daily in steers grazing bermudagrass pastures, and found that all levels of monensin increased ($P < 0.05$) ADG over control, and the greatest improvement was 0.59 lb at 100 mg monensin. Potter et al. (1986) reported that 200 mg monensin daily increased ($P < 0.01$) ADG from 0.03 to 0.17 kg in cattle fed high-forage diets. Other researchers have published similar results. Research conducted at Kansas State University by Brazle and Laudert (1998) examined the effects of monensin supplementation in mineral mixtures on cattle grazing native pastures. In this study, monensin was added to the mineral supplement at the rate of 1,620 g/ton. Steers were allotted into two treatments. One group served as control and received mineral without monensin, while the other group received mineral formulated to administer 200 mg monensin daily. During the initial 83 days, control steers in this study consumed 5.3 ounces of mineral, while treatment steers consumed 3.4 ounces of mineral, which provided 170 mg of monensin daily. Results showed that monensin supplementation decreased ($P < 0.03$) daily mineral intake by 1.9 ounces and increased ($P < 0.05$) ADG by 0.19 lb over control. During the final 114 days, control steers consumed 4.6 ounces of mineral supplement, while treatment steers consumed 3.3 ounces of mineral supplement that provided 170 mg of monensin. Results during this period showed that monensin decreased mineral consumption ($P < 0.08$), and increased ADG ($P < 0.08$) by 0.16 lb. Monensin decreased mineral consumption ($P < 0.05$) over the entire two-year study by 1.6 ounces, and increased ADG ($P < 0.05$) by 0.19 lb over control. Males et al. (1979) reported that 200 mg monensin daily increased ($P < 0.05$) ADG of steers grazing wintered tall fescue pastures. These researchers also examined the effects of 220 mg monensin in a liquid supplement, and found that ADG increased during days 1 through 56, and was not different over the entire 112-d trial.

Multiple researchers have reported a decrease in DMI as a result of monensin supplementation. Thonney et al. (1981) and Wyatt et al. (1989) reported reduced DMI as a result of monensin supplementation. Potter et al. (1986) reported a 3.1% decrease in DMI as a result of monensin supplementation. Potter et al. (1976) reported that 200 mg monensin daily had no effect on DMI, while 300 and 400 mg daily reduced DMI by five percent in cattle consuming mixed cool season grass and legume pasture or greenchop. Lemenager et al. (1978a) reported that 200 mg of monensin daily depressed forage intake by mature cows during winter grazing. In this trial, monensin decreased relative intake by 13.6% ($P < 0.05$) in trial one and 19.6% ($P < 0.05$) in trial two. An interesting result of the study conducted by Lemenager et al. (1978a) was that calves reared by cows fed monensin experienced a greater weight gain prior to weaning than calves from non-supplemented cows.

Monensin improves feed efficiency when supplemented in forage-based diets. Rouquette et al. (1980) reported that 200 mg of monensin in 0.91 kg of supplement increased feed efficiency by 21 to 36% in steers and heifers grazing bermudagrass pastures. Barnett et al. (1982) found that monensin increased feed efficiency by 14.3% in cows receiving diets of restricted intake. Potter et al. (1976) reported that 100 to 300 mg monensin daily increased feed efficiency by 20%. These results are in agreement with those reported by Potter et al. (1986) who showed that 200 mg of monensin improved feed efficiency by 15.3% ($P < 0.01$) when fed to cattle consuming both high and low quality forage diets. These researchers also showed that monensin decreased feed to gain ratio from 12.4:1 to 10.5:1.

In high-forage diets, monensin increased propionate and decreased acetate proportions, thus altering the acetate to propionate ratio. Potter et al., (1976); Lemenager et al., (1978a); Thonney et al., (1981); Wyatt et al., (1989); and Galloway et al., (1993) have all reported that monensin decreased acetate and butyrate concentration, and increased propionate concentration in the rumen. Although monensin changed individual VFA concentrations, it had little effect on total VFA concentration (Potter et al., 1976).

Monensin in cattle grazing wheat pasture. The effects of monensin on cattle grazing wheat pasture are similar to its effects on other forage-based diets. Monensin has been shown in multiple experiments to increase ADG. Horn et al., (1978); Horn et al., (1981); Davenport et al., (1989); Horn et al., (1990); Horn et al., (1992); Beck et al., (1993); Andrae et al., (1994); and Paisley et al., (1998) have all reported increased ADG as a result of monensin supplementation. Beck et al. (1993) found that 150 mg of monensin in two pounds of energy supplement tended ($P < 0.15$) to increase ADG by 0.45 lb over cattle consuming no energy supplement. This was supported by Andrae et al. (1994), who found that 150 mg or greater (161 mg) of monensin daily was more efficacious than levels less than 150 mg (123 mg). These researchers reported that monensin supplemented cattle had 0.56 lb greater ADG than non-supplemented cattle.

Monensin has been shown in multiple trials to decrease DMI in forage-based diets. Monensin has also been shown to decrease DMI by cattle grazing wheat pasture. According to Ellis et al. (1983), monensin decreased intake of high-quality forages. Horn et al. (1981) reported that 200 mg of monensin daily decreased ($P < 0.05$) DMI of wheat pasture. Davenport et al. (1989) conducted an experiment that examined the effects of a monensin ruminal delivery device on ADG, forage intake, and ruminal fermentation of steers grazing wheat pasture. This device was designed to administer 100 mg of monensin for 120 to 140 days. In their experiment, monensin did not affect ($P > 0.10$) wheat forage DMI or digestibility. Branine and Galyean (1990) also found that monensin did not affect ($P > 0.10$) DMI of wheat forage. There are also reports that suggested that the effect of monensin on wheat pasture DMI was variable. Horn et al. (1977) reported that 200 mg monensin daily tended ($P > 0.05$) to increase DMI by 12%.

Several experiments (Horn et al., 1977; Horn et al., 1981; Davenport et al., 1989) have shown that monensin altered acetate to propionate ratios by decreasing acetate concentration and increasing propionate concentration in cattle grazing wheat forage. Although monensin alters individual VFA proportions, it does not significantly change total VFA concentrations. Branine and Galyean (1990) reported that 170 mg monensin had little effect on total VFA concentrations in cattle grazing wheat pasture.

Monensin has been shown to increase ruminal pH in cattle grazing winter wheat. (Horn et al., 1977; Horn et al., 1981; Branine and Galyean, 1990). Feeding monensin to cattle grazing wheat pasture has also resulted in decreased CH_4 and CO_2 production, as well as decreased ruminal ammonia nitrogen production (Horn et al., 1977). Horn et al. (1977) reported a 15% reduction in CH_4 production by cattle supplemented with monensin. Horn et al. (1981) reported that monensin reduced total gas production (CO_2 and CH_4) by 7%.

Monensin and Lasalocid for Treatment and Prevention of Bloat

According to Howarth and Horn (1983), bloat caused by grazing legumes or wheat pasture is a major source of death loss to stocker producers in the southern Great Plains. Legume bloat is a frothy bloat that is usually caused by rapid degradation of soluble protein, which forms a stable foam in the rumen (Clarke and Reid, 1974; and Ball et al., 1996). Majak et al. (1983) reported that bloat in cattle was also caused by an increase ($P < 0.01$) of buoyant particles in the rumen. Rumen fill is also an important factor in the formation and severity of bloat. According to Majak et al. (1983), fasting cattle had lower incidences of bloat than cattle with greater amounts of ruminal fill. Wheat pasture bloat has been associated with changes in grazing behavior of cattle (Howarth and Horn, 1983). These researchers reported that prior to an approaching weather front, cattle refrained from grazing, and following the passage of the front, engorged themselves and 25% of the cattle bloated. These researchers also examined wheat forage samples from bloat provocative and non-bloat provocative pastures, and found that crude protein and soluble nitrogen fractions were greater ($P < 0.05$) in bloat provocative pastures. Rumen motility was also suggested as a cause of bloat in cattle. However, Horn et al. (1977) reported that wheat pasture bloat was not a result of reduced ruminal motility.

Monensin and lasalocid have been shown in several experiments to be effective in reducing bloat in cattle. Multiple studies have been conducted to evaluate the effects of monensin and lasalocid on forage bloat. Table 1 summarizes studies that evaluated the effects of monensin and lasalocid on bloat caused by different types of forage diets. Bartley et al. (1983) conducted an experiment that examined different levels of monensin for bloat caused by grazing alfalfa. These researchers determined that 0.66 mg of monensin/kg of BW reduced bloat score between 33 and 71%. Bartley et al. (1983) also fed monensin at 0.99 and 1.32 mg/kg of BW, which reduced ($P < 0.02$) bloat score by 66.8 and 71.9%, respectively. Monensin can also reduce incidence of bloat caused by grazing wheat pasture. Paisley and Horn (1998) reported that 301 mg of monensin fed to 528 kg steers grazing wheat pasture reduced bloat score by 94.3%. This is in agreement with Lowe et al. (1991) who reported that 300 mg of monensin daily via a ruminal delivery device reduced bloat score. Bagley and Feazel (1989) conducted an experiment that examined the effects of a monensin ruminal delivery device (MRDD) on forage bloat. This MRDD contained 1,500 mg monensin and was designed to release 100 mg/d for 150 d. These researchers reported that monensin reduced ($P < 0.05$) incidence of bloat from 33% for control to 4% for monensin. In this study, only one steer receiving monensin bloated, and was classified as moderately bloated.

Bartley et al. (1983) examined the effects of lasalocid on bloat caused by alfalfa. These researchers reported that 0.66 mg lasalocid/kg of BW reduced bloat score between 25 and 30%. In their experiment, bloat score was decreased by 27% by lasalocid at 0.99 mg/kg of BW. Lasalocid is less effective than monensin in reducing bloat caused by wheat pasture. Paisley and Horn (1998) reported a reduction in bloat score of 12.3% from 301 mg lasalocid daily, compared to 94% for monensin. Bartley et al. (1983) examined the effects of feeding 1.32 mg/kg of BW lasalocid long-term in sorghum/alfalfa diets. These researchers found that bloat score reached zero after four days of lasalocid treatment, and did not change for the duration of the 60-d study. Lasalocid also prevented bloat until seven days after it was removed (Bartley et al., 1983). These researchers also compared lasalocid at 1.32 mg/kg of BW to 0.66 mg/kg of BW to determine the optimum dosage of lasalocid, and found that 1.32 mg lasalocid/kg of BW reduced bloat score more than 0.66 mg/kg of BW. Bartley et al. (1983) suggested that 1.32 mg lasalocid/kg of BW was nearly the maximum level of lasalocid required to control bloat.

As illustrated by Table 1, monensin is more effective in reducing bloat than lasalocid. When fed at about the same level, the average percent reduction from monensin and lasalocid was 57.7 and 21.3%, respectively. It is difficult to determine the optimum level of monensin and lasalocid from the data presented, however it is clear that monensin causes a greater reduction in bloat than lasalocid in alfalfa and wheat pasture-induced bloat.

Optimum Level of Monensin and Lasalocid for increasing ADG

Research has been conducted to compare different levels of monensin and lasalocid, and to determine the most effective dosage of each ionophore. Table 2 is a summary of studies conducted to evaluate the effect of monensin on high-concentrate rations, and the effect of different levels of monensin on ADG and feed efficiency. Goodrich et al. (1984) summarized 29 feedlot trials that examined the effects of monensin on feedlot performance. These trials compared 0, 5.5, 11, 22, 27.5, 33, and 44 g monensin/ton, which provided 0, 51, 102, 197, 242, 286, and 375 mg of monensin daily. Results showed that ADG was slightly greater than control (0.01 to 0.04) with increasing levels of monensin up to 242 mg daily. All levels of monensin in this experiment decreased ($P < 0.01$) DMI. Decreasing DMI was greater with increasing amounts of monensin with the greatest reduction in DMI occurring at 375 mg.

According to Goodrich et al. (1984), feed efficiency was improved ($P < 0.01$) by all levels of monensin, and the greatest improvement in feed efficiency was 10.3% by 242 mg monensin daily, and declined with greater amounts of monensin.

Steen et al. (1977) examined the effects of increasing levels of monensin on cattle consuming corn/corn silage diets. This study compared 0, 100, and 200 mg monensin, and increasing levels of monensin that began at 150 mg and increased at 28-d intervals until it reached 300 mg. These researchers found that ADG was increased by 0.19 and 0.26 lb by 100 and 200 mg monensin, respectively. Increasing monensin at 28-d intervals decreased DMI by 1.0 kg, compared with 0.08 and 1.2 kg reductions for 100 and 200 mg of monensin, respectively. All levels of monensin caused an increase in feed efficiency, however, 200 mg of monensin resulted in the greatest improvement in feed efficiency. Montgomery et al. (2000) reported that 254 and 315 mg monensin increased ADG by 0.03 and 0.01 kg, respectively over 191 mg monensin. These researchers did not report a negative control group. Increasing levels of monensin and lasalocid will increase ADG and feed efficiency to a point when ADG and feed efficiency plateau, or in some cases (Goodrich et al., 1984) decline. Burrin et al. (1988) conducted an experiment that examined the effects of monensin at 86 and 228 mg daily on performance of cattle during adaptation to finishing diets. These researchers concluded that feeding 228 mg monensin daily decreased ($P = 0.20$) ADG by 0.06 kg below diets with no monensin, although this lower DMI did not affect feed efficiency. The diets fed by these researchers contained corn plus corn silage base with urea or urea supplements added as the protein source. Lana et al. (1997) compared urea vs soybean meal with monensin, and did not find a similar decrease in ADG. Burrin et al. (1988) reported that 228 mg of monensin daily decreased variation in DMI. These results are in agreement with those of Stock et al. (1995), who demonstrated that 181 mg monensin daily, decreased DMI variation of high-concentrate diets. Raun et al. (1976) compared 0, 26, 51, 103, 189, 275, 371, and 649 mg of monensin daily in high-concentrate rations, and concluded that DMI decreased with increasing levels of monensin. Daily gain of cattle fed 0 to 649 mg monensin ranged from 0.94 to 1.01 kg. At the highest level, ADG was less than control ($P < 0.01$). Feed efficiency in this experiment was improved ($P < 0.05$) for concentrations of 51 mg and further improved ($P < 0.01$) by 103 mg treatments and greater. According to Raun et al. (1976), the greatest increase in ADG (5.2%) was seen at 103 mg, and the greatest decrease in DMI (13%) was seen at 275 mg. These researchers suggested that monensin levels between 100 and 750 mg daily improved feed efficiency, however, 275 mg was the optimum concentration for cattle consuming high-concentrate rations.

Monensin has also been studied extensively on cattle consuming high-forage diets. Table 3 is a summary of experiments that examined the effects of monensin on steers and heifers fed forage-based diets, or grazing pastures. Potter et al. (1976) conducted a series of trials that examined the effects of monensin supplementation on cattle grazing mixed pastures of orchard grass, alfalfa, brome grass, and ladino clover. These experiments compared 0, 50, 100, 200, 300, and 400 mg monensin administered in 0.45 kg of supplement daily. Monensin levels of 100 and 200 mg improved ADG by 0.05 and 0.10 kg over supplement without monensin, respectively. Three hundred and 400 mg monensin increased ADG by 0.05 and 0.03 kg over supplement without monensin. According to these researchers, the optimum level of monensin was 200 mg daily, which resulted in an increase in ADG of 17%, and an increase in feed efficiency of

20%. Potter et al. (1976) also conducted a trial that compared these levels of monensin on cattle fed harvested forages (greenchop) in confinement. These researchers found that all levels of monensin improved feed efficiency, and 200 mg monensin caused the greatest improvement in ADG and feed efficiency. Other researchers have reported increased ADG from lower levels of monensin. Oliver (1975) compared 0, 25, 50, 100, and 200 mg monensin, and reported that 100 mg monensin increased ADG by 0.32 kg over no supplement and 0.22 kg over supplement without monensin. Conflicting results have been reported by Thonney et al. (1981) who compared monensin and lasalocid, and reported that 183 mg of monensin resulted in a 0.09 kg decrease in ADG compared with supplement without an ionophore. These researchers suggested that the decreased ADG in monensin-fed cattle was due to a 15% reduction in DMI.

The effects of lasalocid on ADG and feed efficiency are summarized in Table 4. It can be concluded from these trials that there is little additional increase in ADG from lasalocid levels greater than 200 mg. According to the lasalocid technical manual (1985), ADG of cattle on pasture fed 200 mg lasalocid was 1.40 lb, while ADG of cattle fed 300 mg was 1.42 lb. Thonney et al. (1981) also compared increasing levels of lasalocid supplementation to 613 lb angus steers consuming ad libitum amounts of alfalfa cubes. This experiment compared diets formulated to administer 0, 100, 200, or 300 mg lasalocid, or 200 mg of lasalocid in mycelium cake, which provided 0, 83, 175, 220, and 149 mg lasalocid, respectively. In this trial, 175 mg of lasalocid resulted in the greatest ADG, and the best feed efficiency. Thonney et al. (1981) reported that 175 and 220 mg lasalocid daily increased ($P < 0.05$) ADG by 0.23 and 0.01 kg, respectively over steers consuming supplement without an ionophore. Spears and Harvey (1984) compared 0, 200, and 300 mg lasalocid in cattle grazing cool-season pastures, and found that the greatest increase in ADG was seen at 200 mg. Boling et al. (1982) reported that ADG was similar for 308 and 226 mg of lasalocid. Andersen and Horn (1985) compared 0, 100, and 200 mg lasalocid daily for cattle grazing winter wheat pasture. These researchers found that cattle receiving 200 mg lasalocid had 0.25 lb greater ADG ($P < 0.05$) than control or 100 mg. Delfino et al. (1988) examined the effects of different concentrations of lasalocid on high-concentrate diets. This experiment compared 0, 211, 302, and 459 mg lasalocid daily. Monensin was also added as a separate treatment at 94 mg for the first 28 d, and 277 mg for the remainder of the experiment. These researchers reported that monensin and lasalocid did not affect DMI ($P > 0.10$). During the first 28 d of the experiment, heifers supplemented with 459 mg of lasalocid had greater ADG ($P < 0.05$) than either control or 302 mg treatments. For the entire duration of the experiment, there were no differences in ADG between treatments ($P = 0.12$). Feed efficiency was improved ($P < 0.10$) for heifers fed 302 and 459 mg lasalocid over control and monensin, respectively.

Summary and Conclusions

Considerable research has been conducted in an attempt to improve efficiency of beef production. Ionophores, such as monensin and lasalocid have been helpful in reaching the goal of improved livestock performance and ultimately profitability. At the cellular level, the observed effect of ionophores is caused by altering ionic transport across microbial cell membranes. Some researchers (Shelling, 1984) suggested that performance changes resulted from system modes of action, such as: modification of

VFA production, modification of feed intake, changes in gas production, and modification of DM digestibilities.

The effects of lasalocid on ADG and DMI have been studied for many years, and multiple studies have shown that lasalocid increases ADG when fed in high-concentrate diets (Berger et al., 1981; and Delfino et al., 1988). According to Delfino et al. (1988), lasalocid did not decrease DMI, but gain:feed was increased. Similar effects are observed when lasalocid is fed to cattle consuming high-roughage diets. Thonney et al. (1981) reported that 175 mg lasalocid increased ADG in cattle consuming high-roughage diets. Lasalocid increased propionate concentration and decreased acetate concentration in both high-roughage (Thonney et al., 1981) and high-concentrate (Delfino et al., 1988) diets. Lasalocid on wheat pasture increases ADG as it does in other forage-based diets. Andersen and Horn (1985) reported that 200 mg lasalocid increased ADG by 0.25 lb when supplemented to cattle grazing winter wheat pasture.

Monensin improves feed efficiency by reducing DMI and maintaining ADG. Goodrich et al. (1984) summarized performance data of nearly 16,000 feedlot cattle and found that monensin reduced DMI by 6.4%, and non-significantly increased ADG by 1.6%. Monensin also altered VFA proportions. Multiple trials have shown that monensin increased propionate concentration and decreased acetate and butyrate concentration. When fed to cattle consuming forage-based diets, monensin increased ADG. Multiple studies have shown increased ADG due to monensin supplementation (Potter et al., 1976; Rouquette et al., 1980; Barnett et al., 1982). Effects of monensin on cattle grazing winter wheat pasture are similar to other high-roughage diets. Monensin increased ADG, and decreased DMI when supplemented to cattle grazing wheat pasture.

A central issue in this research is the most effective dosage of monensin and lasalocid. Many trials have been conducted that examined multiple levels of each ionophore (Tables 2, 3, and 4). It can be concluded that the greatest increase in ADG and feed efficiency occurred between 100 and 200 mg of monensin in high-concentrate and forage-based diets in many of these experiments. The manufacturers recommended feeding level of monensin for grazing cattle is 200 mg daily, however, monensin and lasalocid can be included in finishing diets up to 360 mg.

According to manufacturers recommendation, lasalocid should be fed at 200 mg daily to grazing cattle. Multiple studies (Thonney et al., 1981; Spears and Harvey, 1984; Delfino et al., 1988) reported that 200 mg of lasalocid daily in high-concentrate and high-roughage diets was the most effective dosage. It can be concluded from multiple trials that feeding lasalocid at levels greater than 200 mg will not further increase ADG, although feed efficiency can be increased by lasalocid levels greater than 200 mg.

Research has been conducted that examined the effects of monensin and lasalocid on bloat caused by grain and forage (Bartley et al., 1983; Paisley and Horn, 1998). Multiple studies have shown that 0.66 to 1.32 mg/kg of monensin decreased bloat caused by alfalfa between 32 and 71.9%, and as much as a 94.3% decrease in bloat caused by wheat pasture. Lasalocid is less effective in reducing forage bloat. Studies conducted by Bartley et al. (1983), and Paisley and Horn (1998) showed that 0.66 to 1.32 mg/kg lasalocid reduced forage bloat by only 12.3 to 27.3%.

Table 1. Effects of monensin and lasalocid on severity of bloat

Trial	Diet	Cattle Weight (kg)	Monensin (mg/kg body wt.)	Mean Bloat Score: Control	Mean Bloat Score: Monensin	Percent reduction
Bartley et al. (1983) exp. 1	Alfalfa		0.66	3.1	0.90	71.0
	Alfalfa		1.32	3.2	0.90	71.9
Bartley et al. (1983) exp. 2	Alfalfa		0.99	3.25	1.08	66.8
Bartley et al. (1983) exp. 3	Alfalfa		0.66	3.13	2.10	32.9
Branine and Galyean (1990)	Wheat	393 ± 8	0.43	2.29	2.05	10.5
Katz et al. (1986)	Alfalfa	400 - 550	0.66	3.2	1.90	41.0
	Alfalfa	400 - 550	0.99	3.1	0.80	73.0
Paisley and Horn (1998)	Wheat	528 ± 30	0.57	0.88	0.05	94.3
Mean:			0.79	2.77	1.22	57.7
Bagley and Feazel (1989)[a]	CS Grass/Clover	249	0.40	33%	4%	29

Trial	Diet	Cattle Weight (kg)	Lasalocid (mg/kg body wt.)	Mean Bloat Score: Control	Mean Bloat Score: Lasalocid	Percent reduction
Bartley et al. (1983) exp. 1	Alfalfa		0.66	3.00	2.10	30.0
	Alfalfa		1.32	3.10	2.60	16.1
Bartley et al. (1983) exp. 3	Alfalfa		0.66	3.22	2.41	25.1
	Alfalfa		0.99	3.09	2.25	27.3
Katz et al. (1986)	Alfalfa	400 - 550	0.66	2.90	2.20	26.0
	Alfalfa	400 - 550	0.99	2.80	2.40	12.0
Paisley and Horn (1998)	Wheat	528 ± 30	0.57	0.88	0.77	12.3
Mean:			0.84	2.71	2.10	21.3

[a]Bagley and Feazel (1989) reported bloat as percentage of cattle bloated

Table 2. Effects of monensin on growth performance of cattle fed various concentrate diets

Body Wt. (kg)	Diet	Monensin (mg)	DMI (kg)	ADG (kg)	Gain:Feed	Reference
271	Corn/Corn Silage	0	14.10	1.18	0.084	Perry et al., 1976
269		213	12.90	1.23	0.095	
345	Corn/Corn Cob	0	6.84	0.80	0.117	Raun et al., 1976
348	+ Alfalfa or SBM	100	6.92	0.94	0.136	
350		500	6.33	0.85	0.134	
380		750	5.68	0.76	0.134	
340 to 385	Corn/Corn Cob	0	9.73	0.94	0.097	
		26	9.63	0.98	0.102	
		51	9.26	0.99	0.107	
		103	9.39	1.01	0.108	
		189	8.58	0.98	0.114	
		275	8.33	0.97	0.116	
		371	8.43	0.95	0.113	
		649	7.38	0.81	0.110	
239	Corn/Corn Silage	0	8.21	1.03	0.125	Steen et al., 1977
238	+ SBM	100	8.07	1.12	0.139	
236		200	7.85	1.15	0.146	
235	Diet with increasing	150 - 28d	7.76	1.12	0.144	
	levels of monensin	200 - 28d				
	at 28 d intervals	250 - 28d				
		300 - 99d				
284	Various Concentrate	0	8.49	1.09	0.128	Goodrich et al., 1984
283	Diets	51	8.36	1.13	0.135	
		102	8.36	1.13	0.135	
		197	8.03	1.10	0.137	
		242	7.90	1.12	0.142	
		286	7.80	1.08	0.138	
		375	7.65	1.06	0.139	

Table 2 cont'd. Effects of monensin on growth performance of cattle fed various concentrate diets

Body Wt. (kg)	Diet	Monensin (mg)	DMI (kg)	ADG (kg)	Gain:Feed	Reference
327	Multiple Concentrate	0	9.47	1.32	0.139	Potter et al., 1985
	Diets	316	8.70	1.32	0.152	
312	Corn/Corn Silage	0	7.53	1.05	0.139	Burrin et al., 1988
	+ Urea	86	7.79	1.07	0.137	
		228	6.92	0.99	0.143	
351	Corn/Corn Silage	0	9.37	1.26	0.134	
	+ Urea Supplement	114	9.38	1.23	0.131	
		333	9.16	1.19	0.130	
372	Milo	0	7.81	1.39	0.178	Brandt et al., 1991
372		106	7.69	1.49	0.194	
372		205	7.45	1.23	0.165	
314	Concentrate + 10%	0	7.48	1.70	0.227	Zinn et al., 1994
319	Forage	227	7.35	1.63	0.222	
319	Concentrate + 20%	0	7.46	1.46	0.196	
315	Forage	234	7.58	1.51	0.199	
287	Concentrate + Urea	0	7.17	1.38	0.192	Lana et al., 1997
286		88	7.28	1.45	0.199	
286		182	7.52	1.45	0.193	
287	Concentrate + SBM	0	7.62	1.49	0.196	
287		96	7.9	1.61	0.204	
288		184	7.57	1.58	0.209	
261	Corn/Alfalfa	191	5.76	1.24	0.215	Montgomery et al., 2000
262		254	5.76	1.27	0.220	
259		315	5.72	1.25	0.219	

Table 3. Effects of monensin on growth performance of cattle fed forage-based diets

Body Wt. (kg)	Diet	Monensin (mg)	DMI (kg)	ADG (kg)	Gain:Feed	Reference
235	Costal Bermudagrass	0	NA	0.46	NA	Oliver, 1975
	Costal Bermudagrass + Corn	0		0.56		
	+ Monensin	25		0.70		
		50		0.73		
		100		0.78		
		200		0.71		
318	Greenchop (Cool Season Forages)	0	6.91	0.49	0.071	Potter et al., 1976
319		50	6.95	0.54	0.078	
321		100	7.00	0.54	0.077	
319		200	7.00	0.59	0.084	
319		300	6.55	0.54	0.082	
322		400	6.59	0.52	0.079	
178	Wheat Pasture	0	NA	0.54	NA	Horn et al., 1978
181		85		0.73		
210	Wintered Tall Fescue	0	NA	0.57	NA	Males et al., 1979
		200		0.64		
217	Wintered Tall Fescue	0	NA	0.65	NA	
	d 1 - 56	100		0.76		
	Wintered Tall Fescue	0	NA	0.77	NA	
	d 57 - 112	100		0.77		
250	Bermudagrass	0	NA	0.42	NA	Rouquette et al., 1980
		200		0.52		

NA: Data not available

Table 3 cont'd. Effects of monensin on growth performance of cattle fed forage-based diets

Body Wt. (kg)	Diet	monensin (mg)	DMI (kg)	ADG (kg)	Gain:Feed	Reference
223	Wheat Pasture	0	16.0	0.64	0.040	Horn et al., 1981
		200	18.1	0.73	0.040	
277	Wheat Pasture	0	32.41	0.56	0.017	
		200	30.25	0.63	0.021	
278	Alfalfa Cubes	0	21.30	0.61	0.029	Thonney et al., 1981
		183	18.10	0.52	0.029	
250	Mixed Cool Season Grass	0	NA	0.66	NA	Wagner et al., 1984
	and Legume Pasture	200		0.72		
239	Mixed Pastures	0	NA	0.56	NA	Potter et al., 1986
		200		0.65		
236	Mixed Pastures	0		0.50		
		200		0.59		
254	Harvested Forage	0		0.61		
		200		0.70		
238	Wheat Pasture	0	11.0	0.38	0.034	Davenport et al., 1989
		100	11.9	0.44	0.037	
205	Ammoniated	0	9.49	0.41	0.043	Wyatt et al., 1989
	Bermudagrass	200	9.04	0.48	0.053	
211	Mixed Warm and	0	NA	0.60	NA	Parrott et al., 1990
	Cool Season Past.	90		0.64		
222	Cool Season	0		0.97		
	Cereal Grain Past.	121		1.02		
228	Wheat Pasture	0		0.61		
		105		0.69		

NA: Data not available

Table 3 cont'd. Effects of monensin on growth performance of cattle fed forage-based diets

Body Wt. (kg)	Diet	monensin (mg)	DMI (kg)	ADG (kg)	Gain:Feed	Reference
224	Wheat Pasture	0	NA	0.86	NA	Horn et al., 1990
222		0		0.74		
222		197		1.05		
219		318		1.03		
243	Wheat Pasture	0	NA	1.10	NA	Horn et al., 1992
235		0		1.10		
247		181		1.31		
244		306		1.33		
269	Wheat Pasture	0	NA	1.05	NA	Beck et al., 1993
		150		1.25		
241	Wheat Pasture	0	NA	1.05	NA	Andrae et al., 1994
250		123		1.25		
		161		1.34		
232	Wheat Pasture	0	NA	1.15	NA	Paisley et al., 1998
234		183		1.32		
246	Native Warm Season Pasture	0	NA	1.17	NA	Brazle and Laudert, 1998
250		170		1.27		

NA: Data not available

Table 4. Effects of lasalocid on growth performance of cattle fed forage-based and high-concnentrate diets

Body Wt. (kg)	Diet	lasalocid (mg)	DMI (kg)	ADG (kg)	Gain:Feed	Reference
181	Native Warm Season Pasture	0	NA	0.98	NA	Gill et al., 1981
		100		1.06		
278	Alfalfa Cubes	0	9.66	0.61	0.063	Thonney et al., 1981
		83	10.24	0.70	0.068	
		175	10.18	0.84	0.083	
		220	9.49	0.62	0.065	
		149	9.58	0.75	0.078	
144	Wheat Pasture	0	NA	0.80	NA	Horn et al., 1984
		100		0.78		
		200		0.90		
299	Fescue, Orchardgrass, Ladino clover	0	NA	0.50	NA	Spears and Harvey, 1984
		200		0.60		
		300		0.57		
221	Wheat Pasture	0	9.74	1.03	0.106	Andersen and Horn 1985
		100	9.14	1.03	0.113	
		200	9.36	1.14	0.122	
347	Mixed Cool Season	0	NA	0.35	NA	Rode et al., 1994
351	Pasture	200		0.40		
354	Mixed Cool Season	0		0.60		
353	Pasture	200		0.62		

NA: Data not available

Table 4 cont'd. Effects of lasalocid on growth performance of cattle fed forage-based and high-concentrate diets

Body Wt. (kg)	Diet	lasalocid (mg)	DMI (kg)	ADG (kg)	Gain:Feed	Reference
346	Corn/Corn Silage	0	7.05	0.99	0.140	Berger et al., 1981
		124	6.95	1.02	0.150	
		182	7.05	1.04	0.150	
209	Corn/Cottonseed Hulls/SBM	0	10.41	1.11	0.110	Boling et al., 1982
		226	10.23	1.25	0.120	
		308	9.30	1.26	0.140	
NA	Pasture	0	NA	0.57	NA	Lasalocid Tech. Manual (1985)
		50		0.58		
		60		0.59		
		100		0.60		
		200		0.64		
		300		0.64		
279	Fescue, Orchardgrass, Bluegrass	0	NA	0.84	NA	Lasalocid Tech. Manual (1985)
		200		0.97		
		600		0.80		
		1000		0.81		
308	Barley/Alfalfa/Canola Meal	0	8.60	1.24	0.144	Delfino et al., 1988
310		211	8.80	1.36	0.155	
309		302	8.40	1.35	0.161	
306		394	8.50	1.37	0.161	

NA: Data not available

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CHAPTER III

EFFECT OF MINERAL SUPPLEMENTATION WITH OR WITHOUT IONOPHORES ON GROWTH PERFORMANCE OF WHEAT PASTURE STOCKER CATTLE

ABSTRACT: Two experiments were conducted during the years of 2000/2001 and 2001/2002 to determine intake of a non-medicated free-choice mineral supplement, and monensin and lasalocid-containing mineral supplements, and their effects on weight gain of growing cattle grazing winter wheat pasture. Treatments for both studies were: 1) control, no supplement; 2) non-medicated free choice mineral supplement; 3) R-1620 monensin free choice mineral supplement with monensin included at 1,620 grams/ton; and 4) B-1440 lasalocid free choice mineral supplement with lasalocid included at 1,440 grams/ton. In year one, intake of the non-medicated mineral supplement was 213 g/steer and was greater ($P < 0.001$) than intake of the monensin mineral supplement. Intake of the monensin mineral supplement was 45 g/steer, which provided 83 mg/d of monensin, and was less ($P < 0.01$) than intake of the lasalocid mineral supplement (163 g/steer), which provided 258 mg/d of lasalocid. Daily gain of steers across all treatments in year one averaged 0.41 kg/d during the first 70 days, 1.37 kg during the 21-d grazeout period, and 0.50 kg/d over the entire 91-d grazing period. Daily gain of steers during any of the three periods was not different ($P \geq 0.37$) between control and non-medicated mineral. Steers consuming the monensin mineral supplement had greater ($P < 0.05$) ADG than steers consuming the non-medicated mineral. Monensin-fed steers tended ($P = 0.11$) to have greater ADG than lasalocid-fed steers. In year two, daily intake of the non-

medicated mineral supplement averaged 236 g/steer and was greater ($P < 0.01$) than intake of the monensin mineral supplement. Intake of the monensin mineral supplement averaged 68 g/steer, which provided 125 mg/d of monensin, and was less ($P < 0.05$) than intake of the lasalocid mineral supplement (172 g/steer; 277 mg/d of lasalocid). Steers consuming the non-medicated mineral supplement had greater ADG ($P < 0.001$) than control. Monensin-fed steers had greater ADG than steers consuming the non-medicated mineral supplement ($P < 0.05$), and lasalocid mineral supplement ($P < 0.05$). This experiment demonstrated that free-choice mineral supplementation was an effective method of supplying monensin and lasalocid to cattle grazing wheat pasture.
Key words: Mineral, Monensin, Lasalocid, Steers, Wheat pasture

Introduction

Winter wheat (*Triticum aestirum*) is an important crop in the southern Great Plains that can be used not only for grain production, but also as a source of high-quality forage for cattle. Wheat is also a unique dual-purpose crop that allows producers to maximize economic return from a single field. If wheat is grazed at the proper stocking rate and if cattle are withdrawn from wheat prior to the appearance of the first hollow stem stage of maturity, grain yield is not decreased. Winter wheat also offers producers a wider array of management opportunities. By utilizing winter wheat pasture, producers are able to add weight gains and retain ownership of stocker cattle until times of seasonally high prices in March and April (Harrington, 2001).

Death losses of cattle from bloat grazing wheat pasture during times of rapid forage growth may be substantial. Some research suggests that monensin and lasalocid are effective in reducing bloat in cattle. Bartley et al. (1983) reported that monensin reduced legume bloat, whereas lasalocid was less effective in reducing bloat caused by legume and wheat pasture.

The ionophores monensin and lasalocid are currently used in all areas of the cattle industry, and it has been well established that these ionophores improve feed efficiency in cattle. Monensin and lasalocid increased ADG by 0.08 to 0.11 kg over the carrier supplement (Horn et al., 1981; Spears and Harvey, 1984; Andersen and Horn, 1987) when fed to cattle consuming forage-based diets. The objective of this research was to determine the intake of a non-medicated free choice mineral supplement, the same free choice mineral supplement with monensin, and a lasalocid-containing free choice mineral supplement, and their effects on growth performance of stocker cattle grazing winter wheat pasture.

Materials and Methods

Study Site. This research was conducted at the Marshall Wheat Pasture Research Unit located southeast of Marshall, OK. The predominant soil type for this location is Kirkland silt loam, and mean annual rainfall is 805 mm. Tonkawa variety wheat was planted in September, following normal planting procedures for this location.

Cattle

Yr 1 (2000/2001). All experimental animal use has been reviewed and accepted by the Oklahoma State University Institutional Animal Care and Use Committee. One-hundred-thirty-six Santa Cruz steers (½ Santa Gertrudis ¼ Red Angus and ¼ Gelbvieh) with an average initial weight of 254 kg from a single ranch were used for this trial.

Upon arrival on December 8, 2000, cattle were weighed, vaccinated for respiratory diseases (IBR, BVD, PI-3, BRSV), given a permanent identification tag, and allowed to remain in drylot and grass traps until standing crop (kg DM/ha) of wheat forage increased to an amount that would withstand grazing. Steers were offered hay and protein supplement until they were placed on wheat. Steers were weighed at initiation of the trail on January 10, prior to grazeout on March 21, and after grazeout on April 11. All weights were measured following an overnight shrink (approximately 16 – 18 hours) without feed or water.

Yr 2 (2001/2002). One-hundred-seventy-two fall-weaned Red Angus crossbred steer calves with an average initial weight of 227 kg were used during the 2001/2002 wheat pasture year. Receiving and vaccination procedures were identical to yr 1. Steers were weighed at initiation of the trial on November 15, once intermediately on February 8, and upon completion of the trial on March 13, 2002. Steers were weighed each time following an overnight shrink (approximately 16 to 18 hours) without feed or water.

Treatments

Yr 1 and 2. Steers were randomly allotted by weight to four treatments with a randomized complete block design with four blocks of each treatment. This experiment was blocked by pasture during both years. Pastures 1 through 4, 5 through 8, 9 through 12, and 13 through 16 were individual blocks, and treatments were randomly assigned within each block. Treatments included: 1) control, no supplement; 2) non-medicated free choice mineral supplement; 3) R-1620 monensin-containing free-choice mineral supplement with monensin included at 1,620 g per ton; and 4) B-1440 lasalocid-containing free choice mineral supplement with lasalocid included at 1,440 g per ton.

Guaranteed analysis and ingredient composition of the mineral supplements in yr 1 is shown in Table 5. Composition of the non-medicated mineral supplement and the monensin mineral supplement were the same with the exception of added monensin. Mineral supplements were offered on a free choice basis in weather-vane type mineral feeders, and intake measurements and samples of the mineral supplements were taken weekly for ionophore analysis by the manufacturers. Any remaining monensin mineral at the end of the week was removed, and replaced with fresh supplement. Intakes were determined by subtracting the weight of the remaining mineral at the end of the week from the weight of the mineral at the beginning of the week. Whenever the mineral supplements were wet, they were collected, dried, and then weighed to determine the dry weight. In yr 1, mean $\pm$ SD of monensin and lasalocid concentrations (n = 10) of the R-1620 and B-1440 were 1,696 $\pm$ 127 and 1,347 $\pm$ 178 grams/ton, respectively.

During yr 1, two steers died from bloat. One control steer died on March 11, and one steer consuming the non-medicated mineral died on April 1. Therefore, beginning on February 16, until March 30 (42 days), only control steers were offered a mixture of 75% salt and 25% Bloat Guard Medicated Premix (52% poloxalene; Pfizer Animal Health, Exton, PA). Consumption per pasture averaged 10.5, 6.7, 3.8, and 10.6 $g \cdot steer^{-1} \cdot d^{-1}$ of poloxalene.

Treatments in yr 2 were identical to yr 1. Guaranteed analysis and ingredient composition of mineral supplements in yr 2 is shown in Table 6. Composition of the non-medicated and R-1620 mineral supplements were the same with the exception of added monensin. Samples were collected weekly for ionophore analysis as in yr 1. During yr 2, monensin mineral supplement not consumed was replaced weekly with fresh supplement beginning on January 23 until completion of the trail. Mean ± SD of monensin (n = 15) and lasalocid (n = 16) concentrations of R-1620 and B-1440 were 1,732 ± 159 and 1,497 ± 121 grams/ton respectively.

Grazing Management and Sampling

Yr 1 and 2. The steers continuously grazed sixteen, 7.29 to 9.72 ha wheat pastures containing eight to 12 steers/pasture in yr 1. The pastures were primarily rectangular shaped with a single Mira-Fount automatic livestock water fountain located at one end of each pasture near the adjacent road. A single, weather vane type mineral feeder, and a temporary windbreak was located within approximately 12 to 15 m of the water.

In yr 1, poor forage growth early in the growing season caused a shortened grazing period. Stocking rate during the fall-winter period was 1.12 steers/ha, and was increased to 3.33 steers/ha during the grazeout period by reducing pasture size by two thirds. The grazeout period began on March 21, 2001 immediately following the appearance of first hollow stems. Increased standing crop in yr 2 allowed a greater number of steers to be used. Ten to 13 steers were allotted to each pasture, which resulted in an initial stocking rate of 1.37 steers/ha. The grazing period began on November 15 and concluded on March 13 (118 days). One steer was added to each pasture on November 20, 2001, which resulted in a stocking rate of 1.45 steers/ha. We experienced a severe ice storm in January, which caused the electric fences to collapse, allowing the steers to co-mingle. Consequently, steers were removed from wheat pastures and placed in a native grass trap, where they were fed hay from January 30 to

February 7, 2002 (9 days), until they could be re-sorted and placed back on wheat pastures.

Control pastures were divided into four sections approximately equal in size, and one forage sample was collected at a random location within each section. These samples were collected monthly by hand clipping control pastures to ground level using a 0.186 m^2 clipping frame to determine standing crop (kg DM/ha). These samples were dried and ground through a two mm screen in preparation for analysis of Na, K, Mg, Ca, P, and determination of the K:Na ratio (Table 7). Samples within each pasture were composited for each sampling date. One-half gram samples were microwave digested in 10 mL of HNO_3 for three minutes at 40 PSI, three minutes at 85 PSI, and 10 minutes at 150 PSI. Digested samples in solution were then transferred to 25 ml volumetric flasks, and brought to volume with distilled water. Samples were analyzed using a Spectroflame Inductively Coupled Plasma instrument (Spectro, Fitchburg, MA).

Statistical Analysis

Yr 1 and 2. Data were analyzed as a randomized complete block design using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary NC). Pasture served as the experimental unit, and treatment was included in the model as a fixed effect, with block, and block x treatment as random effects. Denominator degrees of freedom were determined using the Satterthwaite approximation. Intake data were separated using planned contrasts that compared mineral vs monensin, and monensin vs lasalocid. Treatment sums of squares for performance data were separated using planned contrasts that compared control vs mineral, mineral vs monensin, and monensin vs lasalocid. During yr 1, two steers died, and two statistical outliers were deleted.

Mineral composition of wheat forage data was analyzed by year using the PROC MIXED procedure of SAS. There were no significant differences ($P > 0.10$) in mineral composition between pastures during yr 1 and 2, except for Mg concentration in pasture five which was different from pastures 9 ($P = 0.05$) and 14 ($P = 0.006$) in yr 1. Therefore mean mineral composition was pooled across pastures and was reported for each sampling date ($\pm$ std. dev.).

Results

Yr 1. The year of 2000/2001 was one of the poorest years on record for wheat pasture. Weather conditions during August until mid-September were hot and dry with daytime ambient temperatures ranging from 30.6°C to 43.3°C, with 0.025 cm of rainfall. The winter months were characterized by cold, wet conditions. Average temperature from October through April ranged from (–2.2°C) to 17.7°C with 38.0 cm of rainfall. Average temperature and rainfall since 1892 from October through March for central Oklahoma ranged from 2.2°C to 16.7°C, and 2.87 to 9.75 cm, respectively. Year 1 standing crop is shown in Figure 1. On January 9, 2001, prior to the beginning of the trial, standing crop averaged 896 kg/ha, and remained relatively stable throughout the grazing season. Weather conditions during yr 2 were more favorable for wheat growth. Average temperature at planting was 28.7°C, and 5.87 cm of rainfall was received during the month of August. Year 2 standing crop is shown in Figure 2. At the beginning of the trial, standing crop was 1,680 kg/ha, which increased to 2,848 kg/ha in December, and remained stable until it declined slightly to 2,107 kg/ha in March. Average standing crop for yr 2 was 2,417 $\pm$ 439 kg/ha.

Mineral analysis of the wheat forage was conducted to characterize the mineral content of the pastures during yr 1 and 2. In yr one, Mg concentration in pasture five was different ($P < 0.05$) from pastures nine and 14. However, there were no other significant differences ($P > 0.15$) in mineral composition between pastures for yr 1 and 2. Mean mineral concentration was pooled across pastures and is reported by sampling date in Table 7. In yr 1, Na and Ca concentrations were increased slightly by the end of the trial, while K, P, and Mg concentration remained relatively constant throughout the trial. Sodium concentration remained relatively constant throughout yr 2. Phosphorus concentration declined slightly until February 11, and Mg, K, and Ca concentrations declined slightly during the trial.

Mean daily consumption of the mineral supplements (± SD) is shown in Table 8. The targeted daily intake of each mineral supplement was 113 g/steer. Daily intake of the non-medicated mineral averaged 213 g/steer, and was greater ($P < 0.001$) than intake of monensin mineral. Average daily intake of the monensin mineral supplement was 45 g/steer, which provided 83 mg of monensin, and was considerably less than the targeted intake of 200 mg/steer. Intake of the monensin mineral supplement was also less ($P < 0.01$) than intake of the lasalocid mineral supplement. Intake of the lasalocid mineral supplement was 163 $g \cdot steer^{-1} \cdot d^{-1}$, which provided an average of 258 mg of lasalocid/steer.

Weekly intakes of the three mineral supplements in yr 1 are shown in Figure 3. During weeks one through four, intake of the non-medicated mineral supplement and the lasalocid mineral supplement increased, and then decreased slightly during week five. Intake of the monensin mineral remained stable through week five. Intake of all three mineral supplements increased to 362, 317, and 106 g/steer for non-medicated, lasalocid, and monensin mineral supplements, respectively, likely due to poor weather conditions. During this week, wheat pastures were covered with snow and ice, and steers spent additional time near the windbreaks and mineral feeders. Mean intake of monensin and lasalocid mineral supplements are shown separately in Figures 4 and 5, respectively. Daily monensin intake averaged 92 mg during weeks one through five, reached 189 mg during week six, and decreased to 45 mg from weeks seven through 10. Daily lasalocid intake averaged 266 mg during weeks one through five, peaked at 503 mg during week six, and averaged 186 mg for the remainder of the trial.

Table 9 shows mean steer performance for the fall/winter period (70-d), grazeout (21-d) and the overall trial (91-d) during yr 1. Two steers died from bloat while on trial. One control steer died on March 11, and one steer consuming the non-medicated mineral died on April 1. Daily gain of steers across all treatments was 0.41 kg during the initial fall/winter period, 1.37 kg during the 21-d grazeout period, and 0.63 kg during the entire 91-d trial. There were no differences among comparisons of control vs mineral ($P \geq 0.37$) during the fall/winter, grazeout, or overall trial. For the overall trial, steers consuming the monensin mineral supplement had 0.14 kg greater ($P < 0.05$) ADG than steers consuming the non-medicated mineral supplement. Daily gain of steers consuming the monensin mineral supplement tended ($P = 0.11$) to be greater than the lasalocid mineral supplement (0.74 vs 0.64 kg/d for monensin and lasalocid, respectively). Although not included as a planned contrast, ADG of steers consuming the lasalocid mineral supplement was 0.09 kg/d greater ($P = 0.15$) than control steers. The low ADG, and reduced total weight gain in the current trial was likely due to low availability of wheat forage, and a shortened grazing season.

Yr 2. There was no occurrence of bloat during yr 2. Mean daily consumption $\pm$ SD of the three mineral supplements is shown in Table 10. Intake of the non-medicated mineral supplement averaged 236 $g \cdot steer^{-1} \cdot d^{-1}$ and was greater ($P < 0.001$) than intake of the monensin mineral supplement. Daily intake of the monensin mineral supplement was 68 $g \cdot steer^{-1} \cdot d^{-1}$, which provided 125 mg/d of monensin. This amount is less than the targeted intake of 200 mg/d. The reduced intake of the monensin mineral supplement was consistent with results of year one. Daily intake of the lasalocid mineral supplement was 172 $g \cdot steer^{-1} \cdot d^{-1}$, and was greater ($P < 0.05$) than intake of the monensin mineral supplement. Intake of lasalocid mineral supplement provided 277 mg/d of lasalocid, and was consistent with intakes from yr 1. Weekly intake of the three mineral supplements in yr 2 is shown in Figure 6. Weekly intake of the non-medicated and lasalocid mineral supplements increased during weeks one through 11, and peaked at 408 and 352 $g \cdot steer^{-1} \cdot d^{-1}$, respectively. Intake of the monensin mineral supplement remained constant during these weeks, averaging 70 $g \cdot steer^{-1} \cdot d^{-1}$. Week 11 was the period that steers were removed from wheat pastures due to the ice storm, and consequently, mineral was not offered during this time. Intake of the non-medicated and lasalocid mineral supplements was substantially lower (177 and 129 $g \cdot steer^{-1} \cdot d^{-1}$, respectively) after cattle were placed back on wheat pastures on week 12. However, intake of the monensin mineral supplement was only slightly lower at 62 $g \cdot steer^{-1} \cdot d^{-1}$. Following week 12, intake of the non-medicated, and lasalocid mineral supplements increased to 360 and 197 $g \cdot steer^{-1} \cdot d^{-1}$, respectively, by the completion of the trial. Weekly intakes of monensin and lasalocid are shown in Figures 7 and 8, respectively. Weekly monensin intake remained relatively constant, ranging from 92 to 175 $mg \cdot steer^{-1} \cdot d^{-1}$, with an average intake of 125 mg·steer-

$^{1}\cdot d^{-1}$. During weeks one through 11, lasalocid intake increased from 95 to 558 mg·steer$^{-1}\cdot d^{-1}$. Lasalocid intake was lower (205 mg) on week 12 after cattle were placed back on wheat pastures, but it increased to 312 mg by the completion of the trial.

Weights and weight gains of steers in yr 2 are shown in Table 11. Weight gains of steers of all treatments averaged 1.14 kg/d over the 118-day trial. Steers consuming the non-medicated mineral supplement had 0.12 kg greater ($P < 0.001$) ADG than control. Monensin-fed steers had 0.06 kg greater ($P < 0.05$) ADG than steers fed the non-medicated mineral supplement. Monensin supplemented steers also had 0.06 kg greater ($P < 0.05$) ADG than steers receiving the lasalocid mineral supplement. Although not included as a planned contrast, ADG of steers consuming the lasalocid mineral supplement was 0.12 kg/d greater ($P < 0.001$) than control steers.

Discussion

Monensin decreased intake of the mineral supplement during both years in this experiment, which agrees with Brazle and Laudert (1998). These researchers reported that 1,620 g monensin/ton decreased intake of a free choice mineral supplement by 45 g/d. Daily intake of the lasalocid mineral supplement in yr 1 and 2 of the current study was greater than the targeted intake of 113 g·steer$^{-1}\cdot d^{-1}$. Rode et al. (1994) reported that intake of a free choice non-medicated mineral supplement and a lasalocid-containing mineral supplement was similar, although variability of intake for both minerals was high. A wide range in intake of the non-medicated and lasalocid mineral supplements was also observed in this experiment. As illustrated by Table 8, in yr 1 there was greater variation in intake of the non-medicated ($\pm$ 100 g) and lasalocid mineral supplements ($\pm$

91 g) than the monensin mineral supplement ($\pm$ 27 g). Similar results were also observed in yr 2. Variation in intake of the non-medicated mineral supplement, the lasalocid mineral supplement, and the monensin mineral supplement in yr 2 were $\pm$ 104, 86, and 18 g, respectively, as shown in Table 10.

In yr 2, steers fed the non-medicated mineral supplement had greater ($P < 0.01$) ADG than control. It is possible that this increase in ADG was due to elimination of mineral deficiencies in the wheat forage by the non-medicated mineral supplement. Mineral balance was calculated by the NRC level 1 model (1996), and is shown in appendix table 3. Wheat forage energy values (NE_m and NE_g) were set at 1.63 and 1.03 Mcal/kg, respectively, by adjusting TDN to 70%. Crude protein was set at 24%, and mineral content of the wheat forage was as shown in Table 7. Average daily gain was set at 1.04 kg, (the actual ADG of the control steers), and DMI was determined as 2.74% of mean BW. Wheat forage without mineral supplementation was deficient in Ca, Na, Cu, I, Se and Zn. Intake of the non-medicated mineral supplement during yr 2 was 236 $g \cdot steer^{-1} \cdot d^{-1}$, and resulted in mineral intakes that exceeded all requirements except iodine. Iodine was not listed in the guaranteed analysis, and therefore could not be included in the mineral balance. When mineral balance was calculated at the target intake of 113 $g \cdot steer^{-1} \cdot d^{-1}$, all mineral requirements were exceeded.

In both years of this study the monensin mineral supplement increased ($P < 0.05$) ADG over the non-medicated mineral supplement. It is well established in the literature that monensin increases ADG when fed to cattle grazing wheat pasture. Horn et al. (1981) reported that ADG of heifers fed supplement with monensin was 0.08 kg greater ($P < 0.01$) than those fed supplement without monensin. Davenport et al. (1989) reported that monensin administered via a ruminal delivery device tended to increase (P < 0.11) ADG by 0.06 kg. Horn et al. (1988) reported that a monensin ruminal delivery device, formulated to administer 100 mg monensin daily, increased ADG by 0.09 to 0.11 kg. Brazle and Laudert (1998), reported that monensin increased (P < 0.05) ADG by steers grazing native pastures by 0.09 kg. It is also reported in the literature that lasalocid increases ADG by about 0.11 kg (Horn et al., 1984; and Andersen and Horn, 1987) over supplement without lasalocid in cattle grazing wheat pastures. In year two of the current study, the lasalocid mineral supplement increased (P < 0.001) ADG by 0.12 kg over non-supplemented steers.

An issue of major importance in this study was the appropriate level of monensin and lasalocid for increasing ADG in growing cattle consuming forage-based diets. The most effective level of monensin for increasing ADG in stocker cattle consuming forage-based diets is 200 mg. Experiments have been conducted examining the effects of monensin and lasalocid in high-concentrate and forage-based diets on ADG and feed efficiency, and have been summarized in Chapter II, Tables 2, 3, and 4. Monensin intake in experiments with high-concentrate diets ranged from 0 to 649 mg, with the majority of experiments ranging from 0 to 200 and 0 to 300 mg. Monensin intake in the trials with forage-based diets ranged from 0 to 400 mg, and a majority of these trials examined 0 to 200 mg monensin. Oliver (1975) reported that 100 mg monensin resulted in a 0.32 kg increase in ADG over no supplementation, and a 0.22 kg increase in ADG over supplementation without monensin by stocker cattle grazing bermudagrass during the summer. Potter et al. (1976) compared 0, 50, 100, 200, 300, and 400 mg monensin in cattle grazing cool-season pastures and consuming greenchop cool-season forages in confinement. These researchers found that 100 and 200 mg monensin increased ADG by 0.05 and 0.10 kg and feed efficiency by 0.006 and 0.013 kg, respectively, over supplement with no monensin. Potter et al. (1976) further reported that 300 and 400 mg monensin increased ADG by 0.05 and 0.03 kg, respectively, over supplement without monensin. Horn et al. (1990) and Horn et al. (1992) determined the effects of monensin in a free-choice energy supplement in cattle grazing wheat pasture. Horn et al. (1990) reported that supplement consumption resulted in monensin intakes of 197 and 318 mg daily by the two treatment groups, respectively. These researchers reported that monensin increased ($P < 0.05$) ADG by 0.24 kg over no energy supplement during the 120-day trial. Horn et al. (1992) reported that supplement consumption resulted in monensin intakes of 181 and 306 mg monensin daily by each group fed the energy supplement, respectively. These researchers found that the monensin-containing energy supplement increased ($P < 0.003$) ADG by 0.22 kg over no energy supplement. It can be concluded from multiple studies that 100 to 300 mg of monensin increases ADG in growing cattle consuming forage-based diets, which agrees with the manufacturers recommended level of 200 mg.

The most effective level of lasalocid for increasing ADG in growing cattle consuming forage-based diets is 200 mg. However, there is little additional improvement in ADG from levels greater than 200 mg. Thonney et al. (1981) reported that 175 mg lasalocid increased ADG by 0.23 kg and improved feed efficiency by 0.02 kg (gain:feed) over supplement with no lasalocid (control) in cattle consuming alfalfa cubes. These researchers further reported that cattle consuming 220 mg of lasalocid had an ADG of 0.62 kg, compared with 0.61 kg for control. However, these authors offered no explanation for the lack of increase in ADG from 220 mg of lasalocid. Spears and Harvey (1984) reported that 200 and 300 mg lasalocid increased ADG by 0.10 and 0.07 kg over supplement without lasalocid, respectively. Delfino et al. (1988) determined the effects of 0 to 394 mg lasalocid, and reported that 211 mg lasalocid increased ADG by 0.12 kg over the same concentrate diet with no lasalocid, while 394 mg lasalocid increased ADG by 0.13 kg over the same diet without lasalocid. However, 394 mg lasalocid improved gain:feed by 0.017 and 0.006 over the diets without lasalocid and 211 mg lasalocid, respectively. Boling et al. (1982) reported that 200 mg lasalocid increased ADG by 0.14 kg over concentrate diets without lasalocid, while 308 mg lasalocid increased ADG by 0.15 kg over the diet without lasalocid.

In addition to the effects of monensin and lasalocid on ADG, these levels of ionophore intake have been shown to reduce the incidence of bloat. During yr 1 of the current experiment, the incidence of bloat increased to the degree that without intervention, death losses would increase. Therefore, a mixture of 75% salt and 25% Bloat Guard Medicated Premix (52% poloxalene) was fed for 42-d beginning on February 16. Because control steers were fed poloxalene, we were unable to make comparisons between treatments to determine if monensin and lasalocid reduced bloat in this study. However, it was of interest to determine if the levels of monensin and lasalocid intake in the current study were sufficient to reduce bloat. Therefore, ionophore intakes in this experiment were compared to those in the existing literature.

Studies have been conducted that examined the effects of monensin and lasalocid on bloat (Bartley et al., 1983; Katz et al., 1986; Branine and Galyean, 1990; Paisley and Horn, 1998). Many of these studies used cattle that were much heavier than typical stocker cattle, and monensin and lasalocid levels were reported as mg/kg BW. In these trials, monensin and lasalocid levels ranged from 0.57 to 1.32 mg/kg BW and averaged 0.79, and 0.84 mg/kg BW for monensin and lasalocid, respectively. Average reduction in bloat score by monensin and lasalocid was 57.7 and 21.3%, respectively (Chapter II, Table 1). Bartley et al. (1983) examined 0.66, 0.99, and 1.32 mg/kg BW for monensin and lasalocid on bloat caused by alfalfa. These researchers reported that 0.66 and 1.32 mg monensin/kg of BW reduced bloat score by 71.0 and 71.9%, respectively. Paisley and Horn (1998) reported that 0.57 mg/kg of BW (300 mg) of monensin reduced bloat score by 94.3% in 528 kg steers. Bagley and Feazel (1989) reported that 0.40 mg monensin/kg of BW (100 mg) resulted in a 29% reduction in the number of cattle bloated while consuming bloat-provocative legumes.

Lasalocid is less effective in reducing bloat in cattle consuming high-forage diets. Bartley et al. (1983) reported that 0.99 mg lasalocid/kg of BW caused 27% reduction in bloat score. Katz et al. (1986) reported greater reductions from monensin than lasalocid. These researchers compared 0.66 and 0.99 mg/kg BW of monensin and lasalocid and found that monensin reduced bloat by 41 and 73% and lasalocid reduced bloat by 26 and 12%, respectively.

In yr 1 of the current study, mean monensin and lasalocid intake was 0.35, and 1.02 mg/kg of mean BW, respectively, during the fall/winter grazing period. This level of monensin intake was less than levels reported by Bartley et al., (1983); Katz et al., (1986); Branine and Galyean (1990); and Paisley and Horn, (1998). Lasalocid intake during year one was within the range of 0.66 to 1.32 mg/kg of BW reported by Bartley et al. (1983).

In yr 2 of the current study, mean monensin and lasalocid intake was 0.42 and 0.94 mg/kg BW, respectively. Monensin intake was similar to that reported by Branine and Galyean (1990) of 0.43 mg/kg of BW which resulted in a 10.5% reduction in mean bloat score in cattle grazing wheat pasture. Lasalocid intake was also within the range of 0.57 to 1.32 mg/kg BW reported in the literature (Bartley et al., 1983; and Paisley and Horn, 1998). No steers died from bloat during yr 2 of the experiment. Although intake of monensin was less than levels reported in the literature (Bartley et al., 1983), lasalocid intakes during both years of the experiment should have been adequate to prevent bloat.

Implications

Free-choice supplementation of grazing cattle is a common practice in the cattle industry. It allows producers to supply nutrients, ionophores, or bloat-preventative compounds to cattle with minimal labor and management. This experiment demonstrated that mineral supplementation is an effective method of administration of monensin and lasalocid to cattle grazing wheat pasture. However, in order to formulate mineral supplements to supply proper levels of the ionophore, concentrations must be very high (1,440 and 1,620 g/ton in this experiment for lasalocid and monensin, respectively), which causes concerns about palatability of the supplement. Reduced intake of the monensin mineral supplement restricted the amount of monensin consumed, which could reduce the response, not allowing the cattle to achieve the potential gain possible from 200 mg of monensin. Therefore, additional research should be conducted to increase palatability and consequently intake of the monensin-containing mineral supplement.

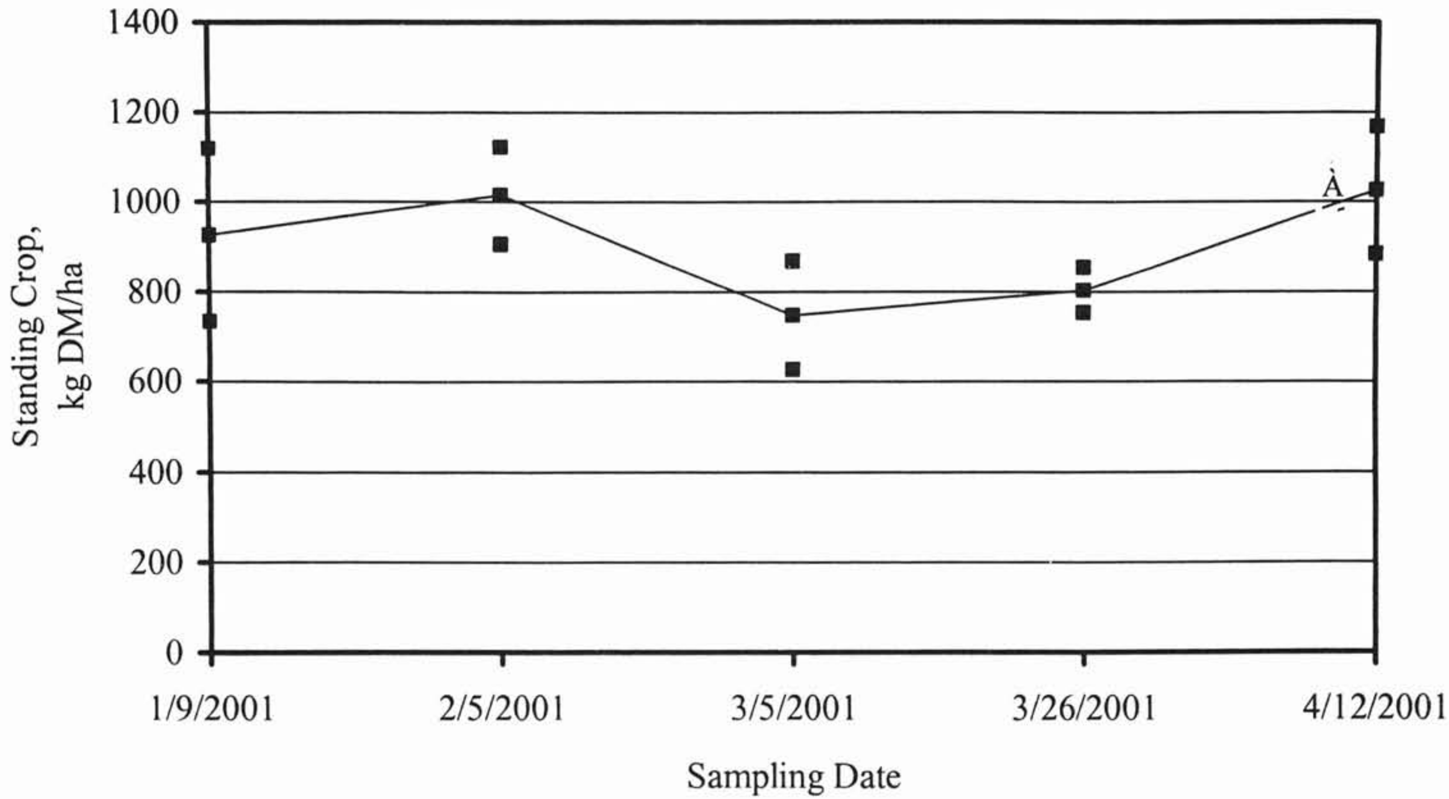

Figure 1. Wheat forage standing crop, yr 1.

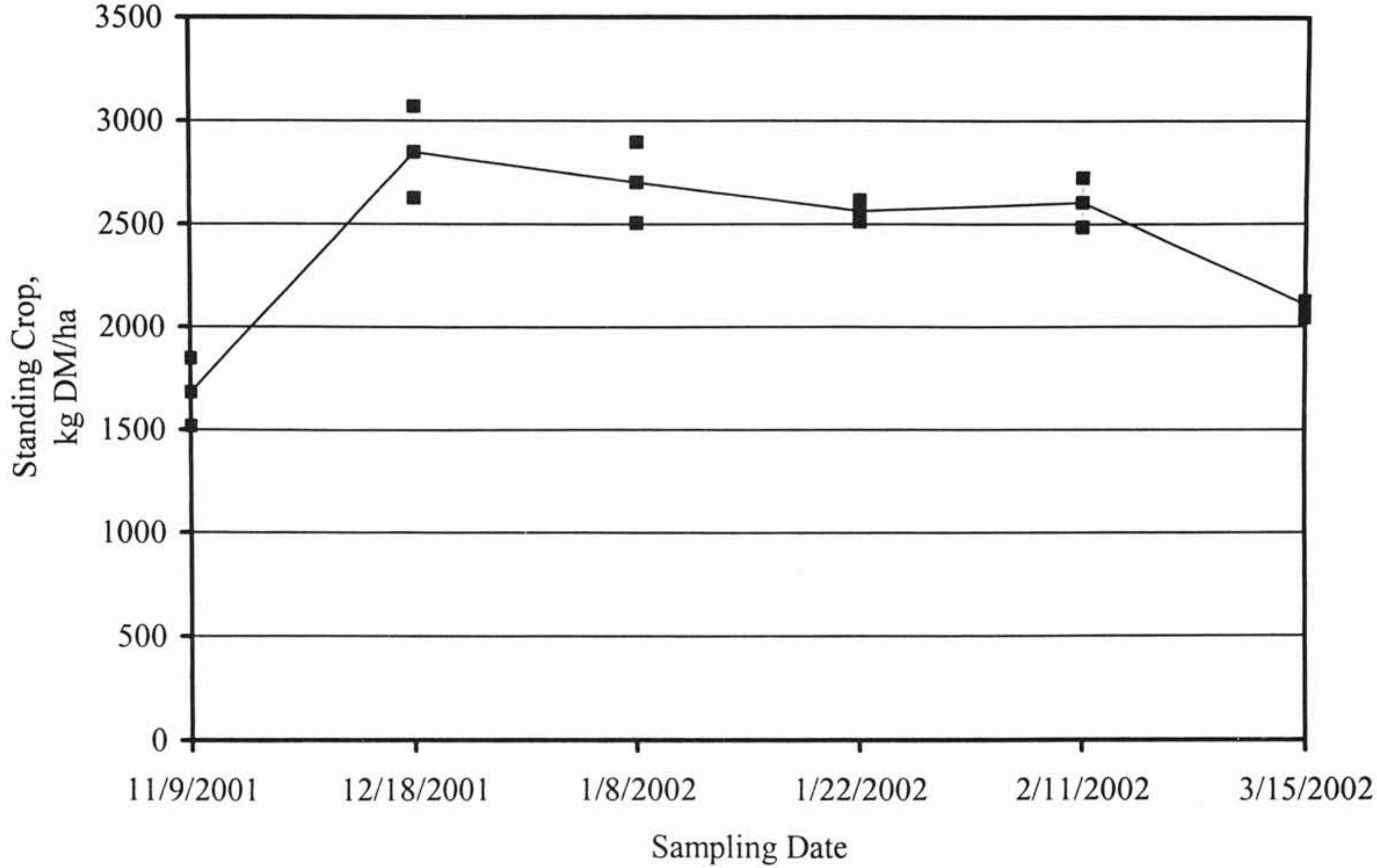

Figure 2. Wheat forage standing crop, yr 2.

Table 5. Guaranteed analysis and ingredient composition of mineral supplements, yr 1

Item	Treatment[a] Non-medicated mineral	R-1620 (monensin)	B-1440 (lasalocid)
Guaranteed Analysis			
Calcium, not less than	9.00%	9.00%	14.00%
Calcium, not more than	11.00%	11.00%	16.00%
Phosphorus, not less than	6.00%	6.00%	6.50%
Salt, not less than	21.75%	22.00%	18.00%
Salt, not more than	26.00%	26.00%	21.50%
Magnesium, not less than	0.30%	0.30%	1.00%
Potassium, not less than	0.60%	0.60%	2.20%
Copper, not less than	1,200 ppm	1,200 ppm	650 ppm
Selenium, not less than	21 ppm	21 ppm	21 ppm
Zinc, not less than	1,250 ppm	1,250 ppm	2,180 ppm
Iodine, not less than	87 ppm	87 ppm	81 ppm
Vitamin A, not less than	200,000 IU/lb	200,000 IU/lb	110,000 IU/lb
Vitamin E, not less than	200 IU/lb	200 IU/lb	56.61 IU/lb
Ingredient (lb/ton)			
Dicalcium phosphate 21%	595.30	590.05	607.32
Salt	485.00	485.00	400.00
Dried molasses	400.00	400.00	50.00
Calcium CO3 (limestone)	280.00	275.00	483.00
Distillers grains (corn)	105.00	100.00	-
Cottonseed meal	-	-	200.00
Molasses, cane	65.00	60.00	-
Beef pasture trace mineral premix	25.00	25.00	25.00
Potassium chloride 50%	-	-	60.00
Dynamate (K, MG, SO4)	-	-	60.00
Mineral oil	20.00	20.00	30.00
Magnesium oxide	-	-	25.00
Bovatec premix 68G	-	-	21.18
Rumensin premix 80G	-	20.25	-
Selenium 0.4% premix (20X)	10.50	10.50	10.50
Copper sulfate 25%	6.90	6.90	-
Iron oxide	2.90	2.90	10.00
Vitamin E 227,000 IU	1.80	1.80	-
Vitamin A 650,000 IU	1.40	1.40	-
Vitamin A 30,000 IU/lb	-	-	10.00
Beef vitamin 6905-B1	-	-	7.00
EDDI 9.2%	1.20	1.20	1.00
Total, lb	2000	2000	2000

[a]R-1620 = monensin mineral supplement with monensin included at 1,620 g/ton.
B-1440 = lasalocid mineral supplement with lasalocid included at 1,440 g/ton.

Table 6. Guaranteed analysis and ingredient composition of mineral supplements, yr 2

Item	Treatment[a]		
	Non-medicated mineral	R-1620 (monensin)	B-1440 (lasalocid)
Guaranteed analysis			
Calcium, minimum	9.40%	9.40%	13.50%
Calcium, maximum	11.20%	11.20%	16.20%
Phosphorus, minimum	6.00%	6.00%	6.50%
Salt, minimum	22.00%	22.00%	18.20%
Salt, maximum	26.40%	26.40%	21.80%
Magnesium, minimum	-	-	1.00%
Potassium, minimum	0.60%	0.60%	2.00%
Copper, minimum	1,250 ppm	1,250 ppm	1,250 ppm
Selenium, minimum	23.80 ppm	23.80 ppm	23.80 ppm
Zinc, minimum	3,000 ppm	3,000 ppm	3,000 ppm
Vitamin A, minimum	300,000 IU/lb	300,000 IU/lb	300,000 IU/lb
Vitamin D_3, minimum	30,000 IU/lb	30,000 IU/lb	30,000 IU/lb
Vitamin E, minimum	100 IU/lb	100 IU/lb	100 IU/lb
Ingredient (lb/ton)			
Dicalcium phosphate	590	590	718
Salt	486	486	400
Dried molasses	460	460	50
Calcium carbonate	276	276	359
Corn distillers dried grains with solubles	130.2	110	-
Soybean meal	-	-	242
Vitamin A, D, E premix	3.0	3.0	3.0
Trace mineral premix	34.8	34.8	50.8
Bovatec-68	-	-	21.2
Rumensin-80	-	20.2	-
Magnesium oxide	-	-	24
Dynamate	-	-	58
Dyna-K (KCl)	-	-	60
Mineral oil	-	-	14
Vegetable oil	20	20	-
Total, lb	2000	2000	2000

[a]R-1620 = monensin mineral supplement with monensin included at 1,620 g/ton
B-1440 = lasalocid mineral supplement with lasalocid included at 1,440 g/ton

Table 7. Mineral composition of wheat forage

Date	% DM basis					
	Na	K	K:Na ratio	Ca	P	Mg
			(Year 1)			
1/9/01	0.015	1.783	120	0.235	0.264	0.146
2/5/01	0.019	1.564	94	0.235	0.232	0.157
3/5/01	0.039	2.068	54	0.217	0.284	0.161
3/26/01	0.077	2.609	38	0.294	0.250	0.161
4/12/01	0.055	2.670	59	0.270	0.277	0.158
Mean ± SD	0.041 ± 0.026	2.139 ± 0.491	73 ± 33	0.250 ± 0.031	0.261 ± 0.021	0.157 ± 0.006
			(Year 2)			
11/30/01	0.021	3.291	168	0.329	0.279	0.193
12/18/01	0.025	2.722	117	0.244	0.243	0.164
1/22/02	0.038	2.229	58	0.269	0.207	0.169
2/11/02	0.025	1.504	60	0.239	0.202	0.152
3/15/02	0.023	2.599	119	0.242	0.296	0.146
Mean ± SD	0.026 ± 0.007	2.469 ± 0.661	104 ± 46	0.265 ± 0.038	0.245 ± 0.042	0.165 ± 0.018

Table 8. Mean ± standard deviation for daily consumption of mineral supplements, yr 1

	Non-medicated mineral	(R1620) monensin	(B1440) lasalocid	SE	Comparisons[a] Mineral vs R-1620	R-1620 vs B-1440
Number of observations:[b]	40	40	40			
Mineral intake g/steer	213 ± 100	45 ± 27	163 ± 91	19.4	0.0002	0.002
Ionophore intake, mg/steer[c]	0	83 ± 51	258 ± 142	21.5		0.001

[a]Observed significance levels for comparison contrasts.

[b]Ten weeks and four pastures per treatment.

[c]Based on monensin and lasalocid concentrations of 1,620 and 1,440 grams/ton, respectively.

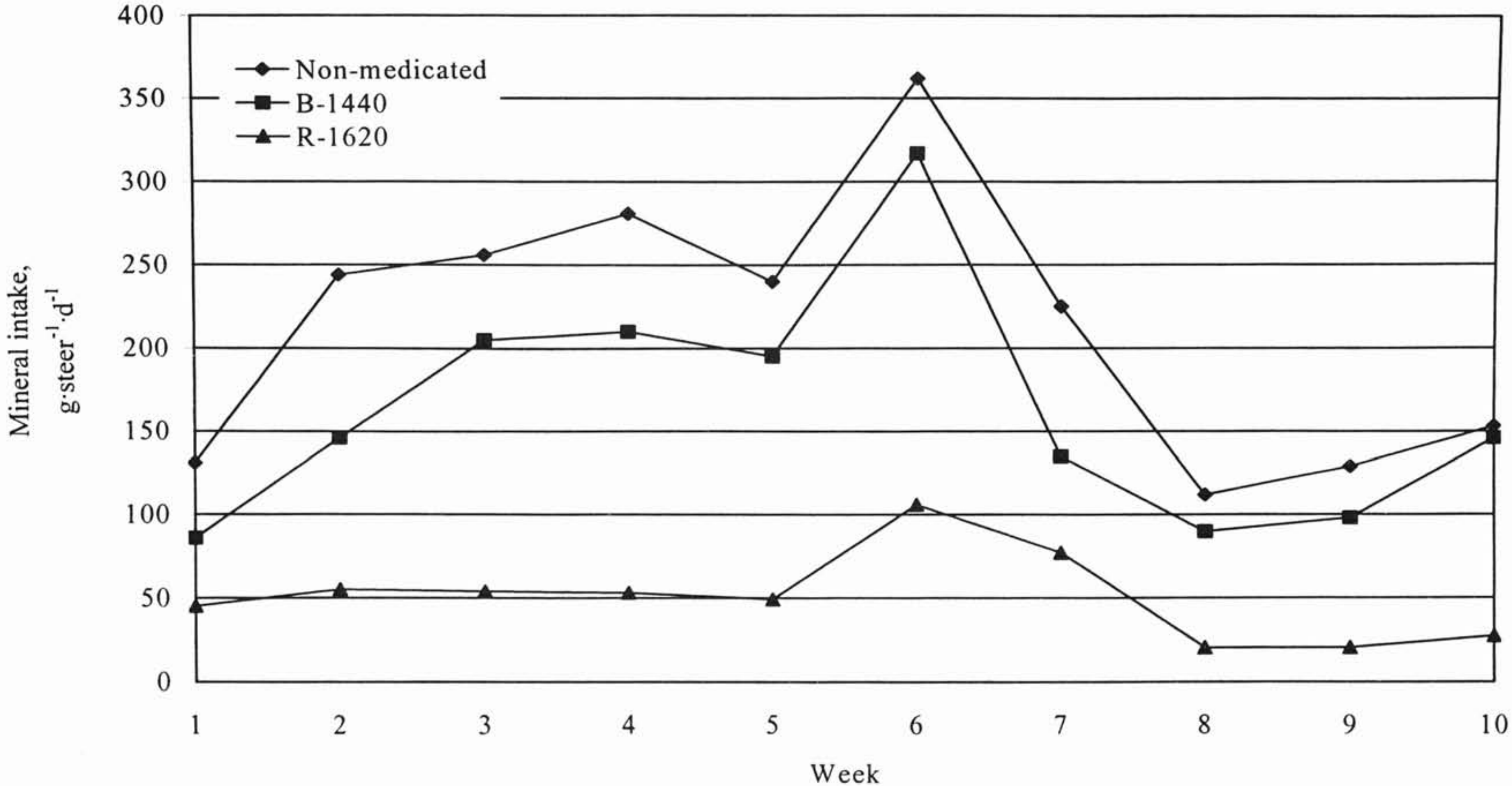

Figure 3. Weekly intakes of the non-medicated, B-1440 and R-1620 mineral supplements, yr 1. Intakes were determined by weighing the remaining mineral at the end of each week. Any wet mineral was dried, prior to weighing.

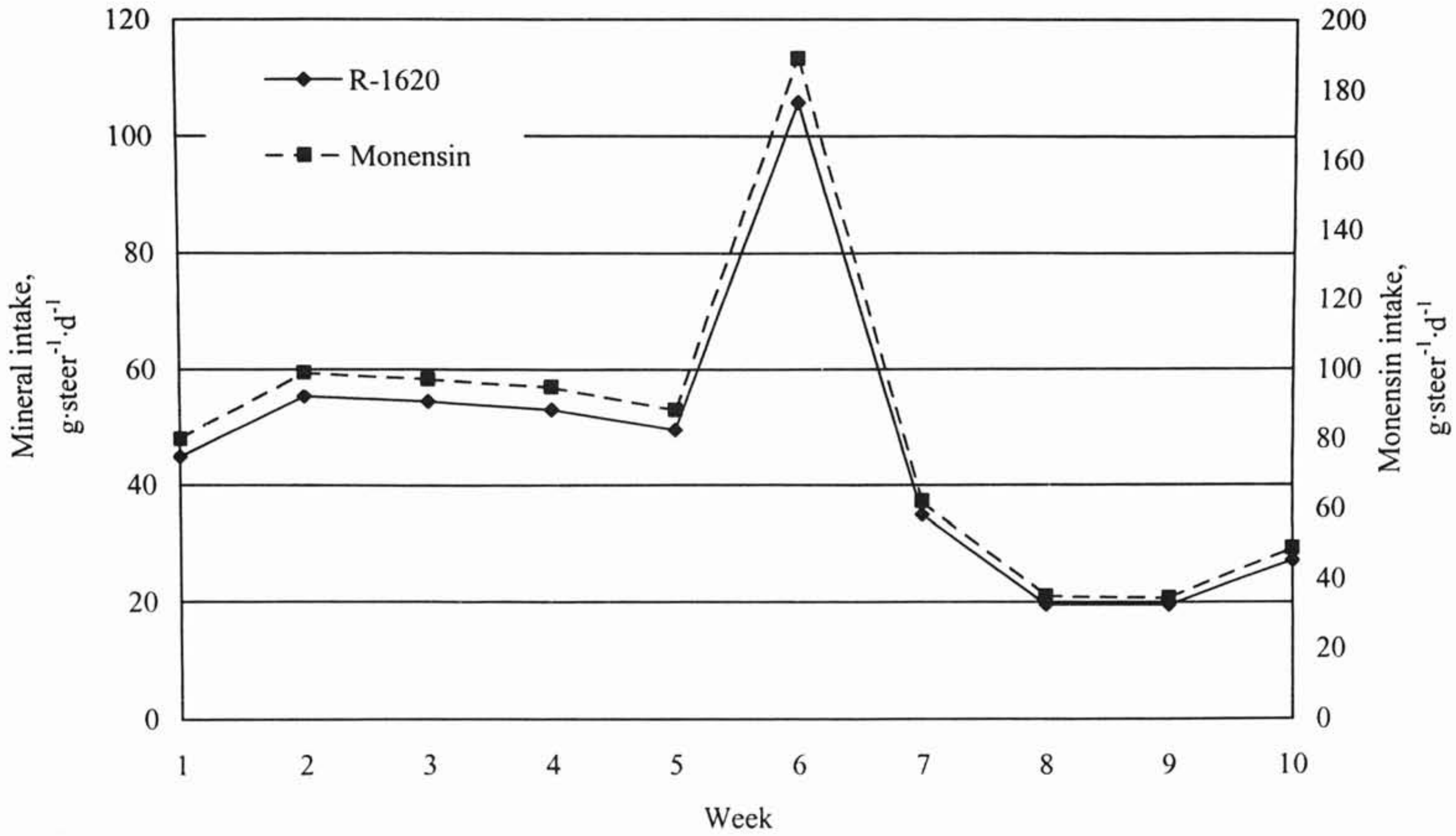

Figure 4. Weekly intake of the monensin mineral supplement (R-1620) and monensin, yr 1. Monensin intakes are based on monensin concentrations of 1,620 g/ton.

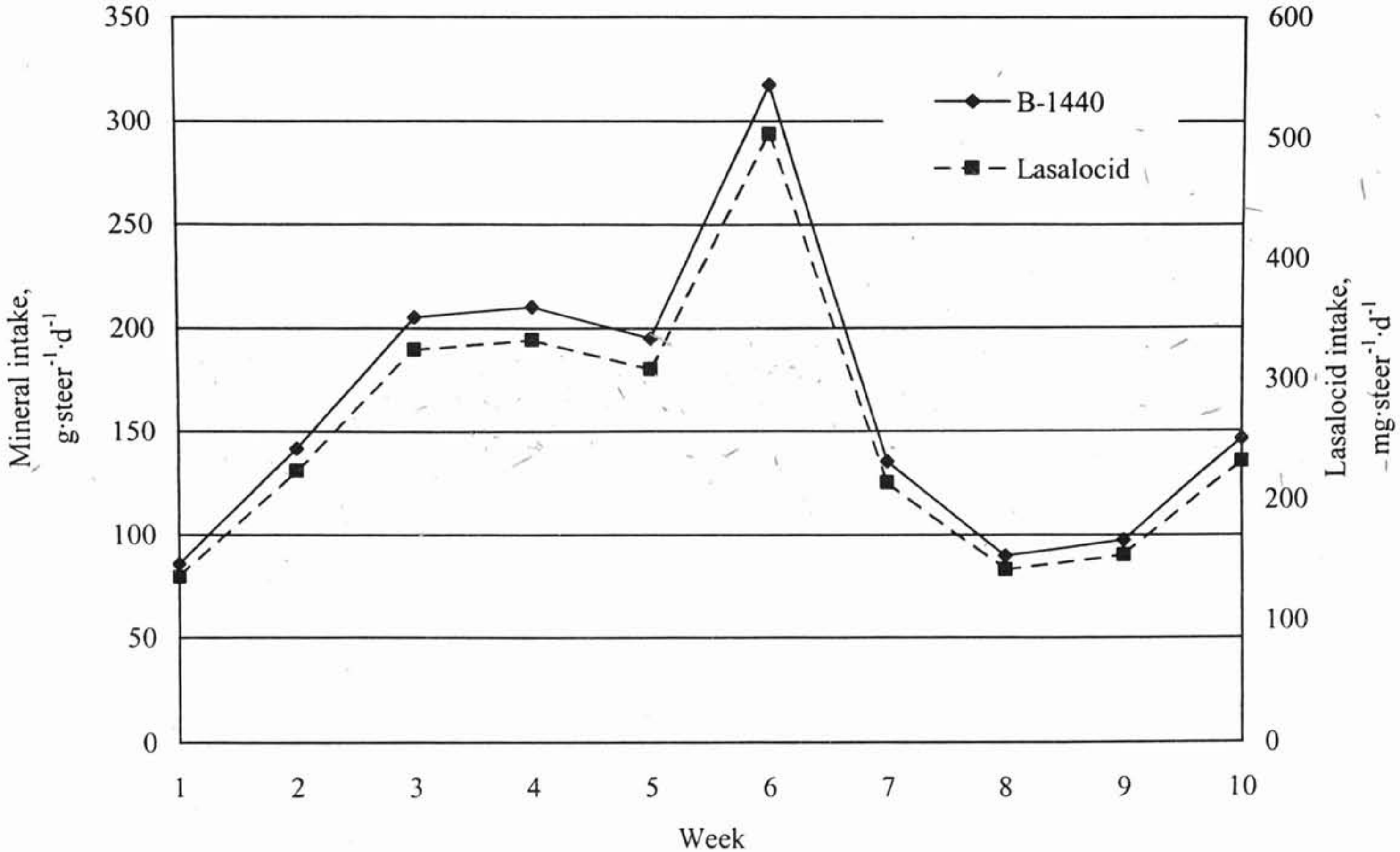

Figure 5. Weekly intake of the lasalocid mineral supplement (B-1440) and lasalocid, yr 1. Lasalocid intakes a based on lasalocid concentrations of 1,440 g/ton.

Table 9. Least square means for growth performance of steers fed non-medicated, monensin-containing or lasalocid-containing mineral supplements, yr 1

	Treatment					Comparisons[a]		
	Control	Non-medicated mineral	(R-1620) Monensin	(B-1440) Lasalocid	SE	Control vs Non-medicated	R-1620 vs Non-medicated	R-1620 vs B-1440
Number of pastures	4	4	4	4				
Number of steers[b]	39	30	29	34				
Fall/winter (70 days)								
Wt, kg	254	254	254	253	3.0	0.96	0.86	0.73
Total gain, kg	22	26	36	30	4.0	0.41	0.11	0.29
ADG, kg	0.31	0.38	0.52	0.43	0.058	0.41	0.11	0.29
Grazeout (21 days)								
Wt, kg	275	280	291	283	5.0	0.51	0.15	0.29
Total gain, kg	28	28	31	28	1.5	0.92	0.23	0.17
ADG, kg	1.34	1.35	1.47	1.33	0.073	0.92	0.23	0.17
Overall (91 days)								
Wt, kg	303	308	322	311	5.4	0.51	0.10	0.18
Total gain, kg	50	55	67	58	3.9	0.37	0.04	0.11
ADG, kg	0.55	0.60	0.74	0.64	0.043	0.37	0.04	0.11

[a]Observed significance levels for comparison contrasts.

[b]One steer died from pasture five (control) and one steer died from pasture 6 (non-medicated mineral) and two statistical outliers were deleted.

Table 10. Mean ± standard deviation for daily consumption of mineral supplements, yr 2

	Non-medicated mineral	(R1620) monensin	(B1440) lasalocid	SE	Comparisons[a] Mineral vs R-1620	R-1620 vs B-1440
Number of observations:[b]	60	60	60			
Mineral intake g/steer	236 ± 104	68 ± 18	172 ± 86	22.9	0.002	0.017
Ionophore intake,[c] mg/steer	0	125 ± 33	277 ± 140	24.8		0.003

[a]Observed significance levels for comparison contrasts.

[b]Fifteen weeks and four pastures per treatment.

[c]Based on monensin and lasalocid concentrations of 1,620 and 1,440 grams/ton, respectively.

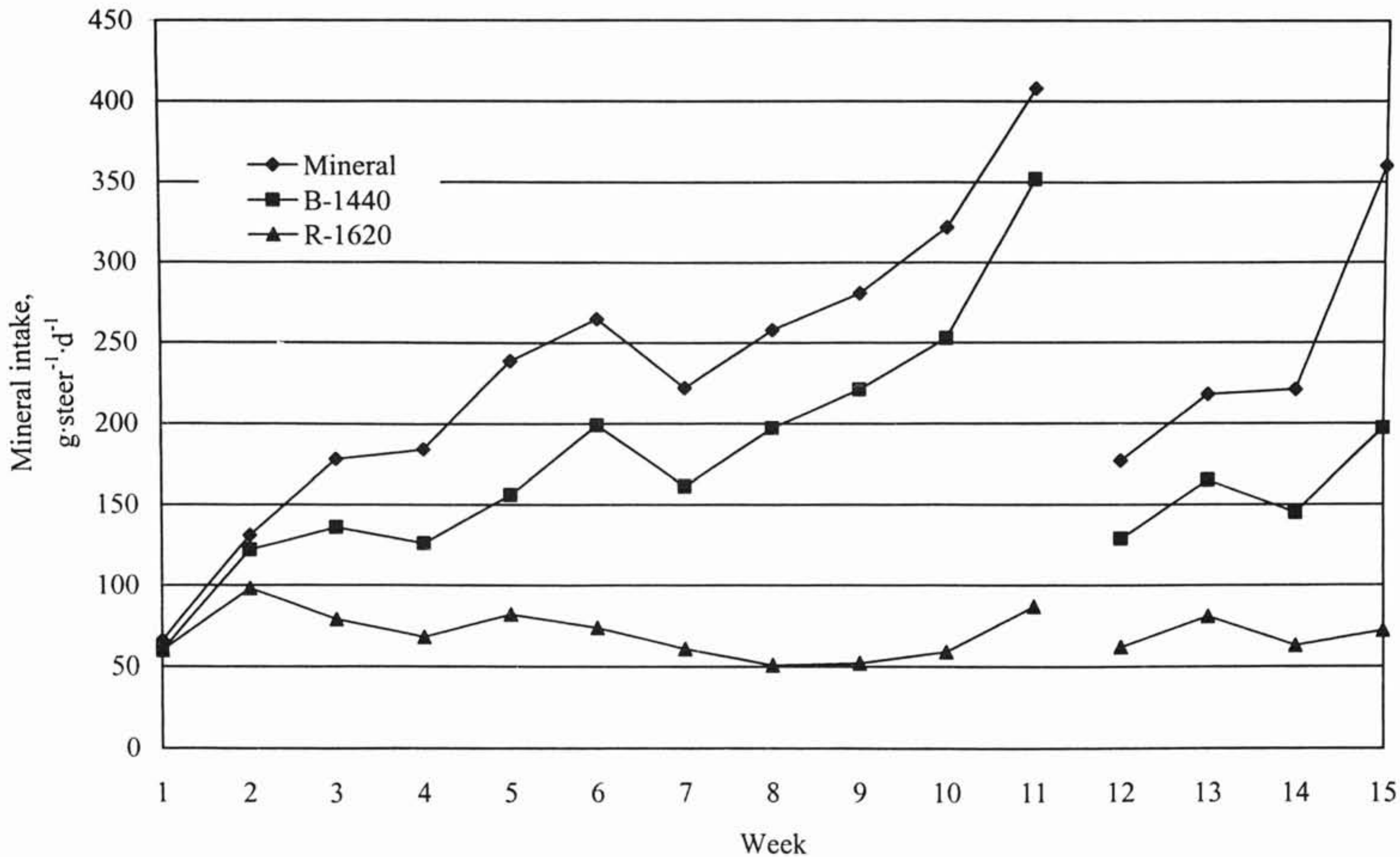

Figure 6. Weekly intakes of the non-medicated, B-1440 and R-1620 mineral supplements, yr 2. Intakes were determined by weighing the remaining mineral at the end of each week. Any wet mineral was dried, prior to weighing. Mineral was not fed during week 11 because steers were removed from wheat pastures during this week.

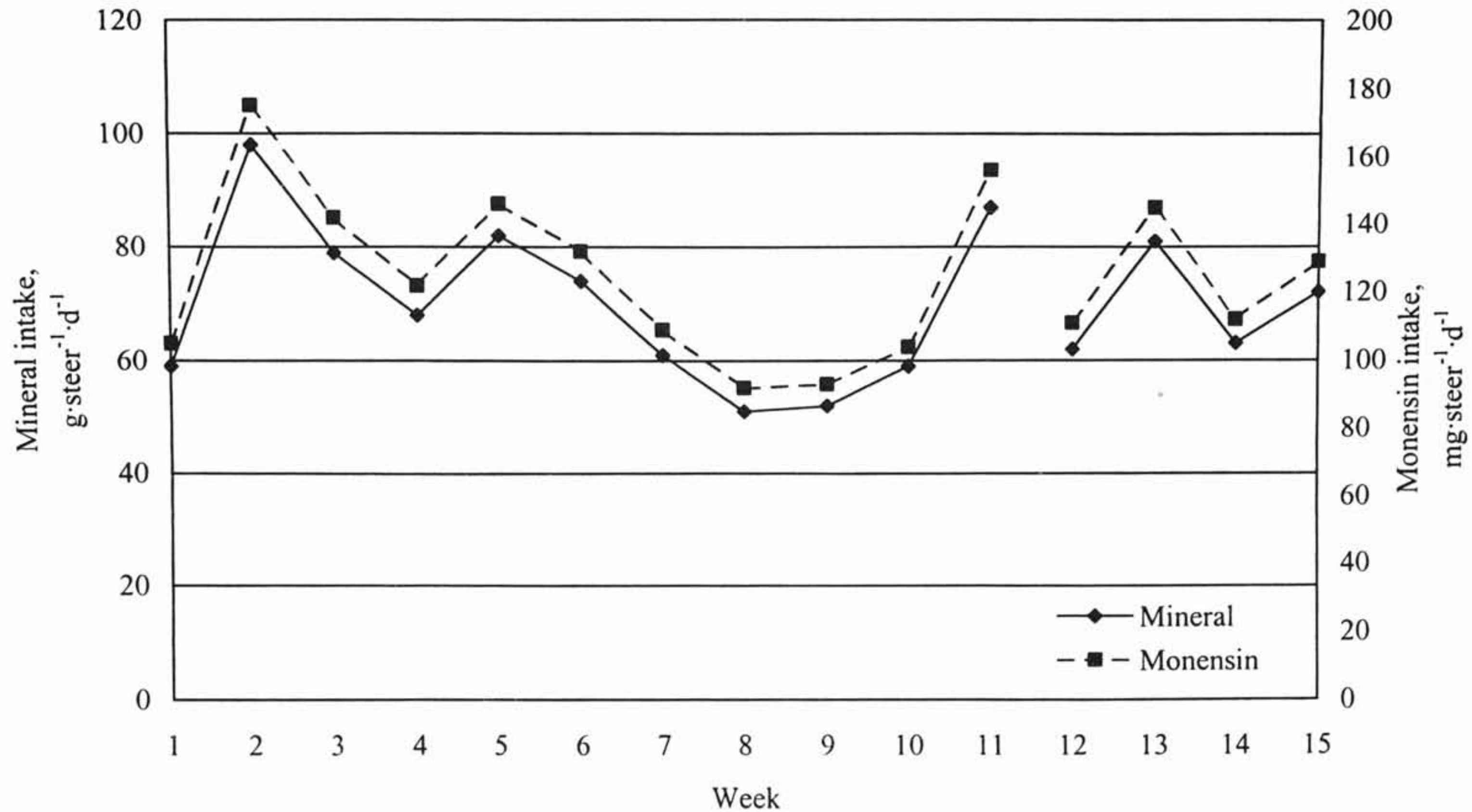

Figure 7. Weekly intake of the monensin mineral supplement (R-1620) and monensin, yr 2. Monensin intakes are based on monensin concentrations of 1,620 g/ton. Mineral was not fed during week 11 because steers were removed from wheat pastures during this week.

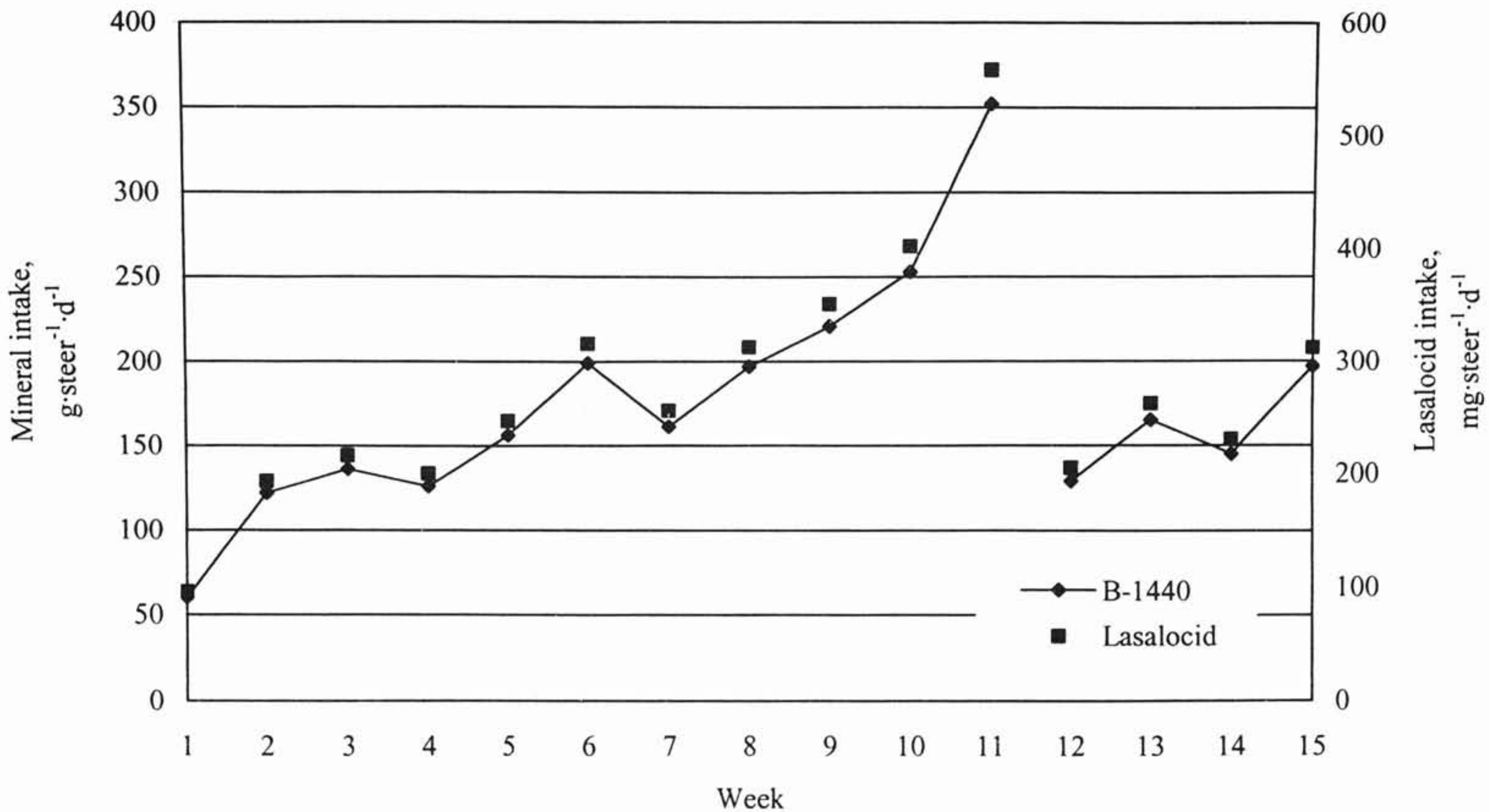

Figure 8. Weekly intake of the lasalocid mineral supplement (B-1440) and lasalocid, yr 2. Lasalocid intakes are based on lasalocid concentrations of 1,440 g/ton. Mineral was not fed during week 11 because steers were removed from wheat pastures during this week.

Table 11. Least square means for growth performance of steers fed non-medicated, monensin-containing or lasalocid-containing mineral supplements, yr 2

	Treatment					Comparisons[a]		
	Control	Non-medicated mineral	(R-1620) monensin	(B-1440) lasalocid	SE	Control vs Non-medicated	R-1620 vs Non-medicated	R-1620 vs B-1440
Number of pastures	4	4	4	4				
Number of steers	49	40	40	43				
Overall (118 days)								
Initial wt, kg								
11/15/01	226	227	228	227	3.4	0.91	0.76	0.87
Final wt, kg								
3/13/02	349	363	373	364	4.2	0.02	0.13	0.18
Total gain, kg	123	136	144	137	2.4	0.0001	0.03	0.03
ADG, kg	1.04	1.16	1.22	1.16	0.020	0.0001	0.03	0.03

[a]Observed significance levels for comparison contrasts.

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CHAPTER IV

REVIEW OF LITERATURE-MINERALS

Introduction

Applying animal manure to fields to add nutrients and improve overall fertility for growing crops is a normal practice in the Great Plains. However, with the evolution and expansion of concentrated animal feeding operations and increased regulations, more attention is being directed to the proper management of animal waste. In recent years, there has been increased concern about the application of livestock manures onto agricultural land. McCollum (2002) reported that the primary issue surrounding waste management is distribution, and is influenced by the nutrient balance (N:P) of the manure. This balance can be improved by increasing soil nitrogen while maintaining soil phosphorus levels for growing crops, or by reducing the amount of phosphorus applied by reducing the amount of phosphorus excreted by livestock. McCollum (2002) also reported that the issue of disposal could be resolved by transporting the manure away from the source; however, the cost of transporting and applying manure to agricultural land may limit the distance that the manure can be transported.

Environmental concerns about land application of manures from concentrated animal feeding operations include buildup of nutrients in the soil, eutrophication of waters, and odor (Jongbloed and Lenis, 1998). Jongbloed and Lenis (1998) reported that leaching and runoff from manure application caused eutrophication of ground and fresh water supplies, which caused algal blooms and death to aquatic life. They also suggested that excessive application of manures caused accumulation of heavy metals in the topsoil.

Accumulation of certain metals, such as copper, may cause toxicity to some animals (i.e. sheep), and may also negatively impact soil life such as earthworms. Jongbloed and Lenis (1998) also reported that ammonia and greenhouse gasses are a major cause of concern with animal waste disposal.

To accurately assess the amount of phosphorus that is extracted from the soil, phosphorus accretion by different pathways must be quantified. In winter wheat production, removing biomass as hay, harvesting grain, or grazing stocker cattle can remove phosphorus from the soil. McCollum (2002) reported that phosphorus removal by grazing cattle was dependant upon total weight gained, and for a 150-d grazing season, ranged between 1.6 and 1.7 lb P/acre retained by the calf.

Wheat pasture is an important small grain crop that can be used not only for grain production, but also as high-quality forage for grazing cattle. If cattle are removed from wheat pasture prior to the appearance of the first hollow stem stage of maturity, producers can harvest a grain crop from the same field. The objective of the current study was to quantify phosphorus accretion in stocker cattle grazing winter wheat pasture. The following is a review of literature that examines growth and body composition, and mineral content and accretion in animal tissues.

Growth and Body Composition of Animals

Rate of tissue accretion. Many trials have been conducted to examine the accretion rates of different body components, such as dry matter, protein, fat, and ash. Shields et al. (1983) conducted an experiment that determined the body composition of pigs from birth to 145 kg. These pigs were harvested at birth, 1.5, 6.4, and 18 kg, and at

18 kg increments to 145 kg. This experiment demonstrated the physiological changes of animals growing to maturity. Percent water, protein, and fat increased quadratically ($P < 0.01$), while ash increased linearly ($P < 0.01$). These results agree with Wagner et al. (1999), who demonstrated that empty body protein, lipid, and water increased quadratically, while ash increased linearly. These researchers also reported that as empty body weight increased, the percentage of lipid in fat increased, and the percent water in fat decreased. This is supported by Ellenberger et al. (1950), who reported that increased percent fat caused an increase in percent dry matter.

Ellenberger et al. (1950) conducted a comparative slaughter study to determine the composition of the bodies of Ayrshire, Holstein, and Jersey dairy cattle. These researchers compared body composition of fetuses, and calves at birth, three months, six months, nine months, and twelve months of age, and 2 ½ to 6 ½ year old cows. They conducted seven analyses on the whole body of each animal. These included analysis of: 1) blood; 2) skin and hair; 3) internal organs including mesenteric fat; 4) horn and hoof; 5) contents of the gastrointestinal tract and bladder; 6) skeleton; and 7) soft tissue. For each of the seven analyses, these researchers reported percent DM, organic nonfat, fat, ash, calcium, phosphorus, and calcium to phosphorus ratio. Calcium and phosphorus were also reported on a fat-free dry matter basis. Table 12 is a summary of the composition of the bodies of 12-month old dairy cattle. Dry matter in the various body components ranged from 18.68 to 53.78%. Fat-free organic matter ranged from 11.88 to 30.21% in internal organs and skin and hair, respectively. Fat ranged from 0.07% in blood to 26.85% in internal organs. Ash was greatest in the skeleton, at 19.22%, and averaged 0.82% in the other body components. There was also great variation in the concentration of calcium and phosphorus in different body tissues (0.02 to 7.14% and 0.02 to 3.42% for calcium and phosphorus, respectively).

Wagner et al. (1999) reported that protein accretion rate peaked between 25 and 45 kg, which agrees with the 35 kg maximum level reported by Shields et al. (1983). Shields et al. (1983) reported that percent water and protein increased during the early stages of growth, and decreased during later stages of growth. Percent protein increased until pigs reached 35 kg and then declined while percent fat increased. Beyond 36 kg, fat content increased in a curvilinear fashion. Shields et al. (1983) also reported that skeletal size and backfat thickness increased with increasing weight. These results further demonstrated that longissimus muscle area increased to 145 kg, and that over 109 kg, percent lean tissue declined.

Mahan and Shields (1998) examined the macro and micromineral composition of swine body tissue. This experiment used 81 pigs that were allotted to treatments to be harvested at birth, weaning, and at 15 kg intervals until 145 kg of body weight. These researchers reported that from birth to 20 kg, muscle accretion occurred at a more rapid rate than ash accretion. From 20 to 125 kg, the rate of accretion of muscle tissue and ash became similar. These researchers reported that from 125 to 145 kg, rate of muscle tissue deposition decreased more rapidly than rate of ash deposition.

Body composition. Body composition is dependant upon animal age and stage of production. Shields et al. (1983) reported that fat composed less than two percent of empty body weight at birth, 11% at 6.4 kg, and was similar from 6.4 to 36 kg. Ellenberger et al. (1950) reported that calves contained 25.81% DM, 2.80% fat, and 4.12% ash at birth, and at six months of age, body composition increased to 30.93, 7.20, and 4.52% for DM, fat, and ash, respectively. Once animals reached maturity, DM, fat, and ash were 41.56, 17.85, and 5.30%, respectively. Ferrell and Jenkins (1998) reported that 498 kg steers, sired by various sire groups, averaged 48% DM, 27.9% fat, and 5.3% ash.

Mineral Composition of Animal Tissues

Phosphorus concentration in tissues. The primary focus of this review is to examine the absorption and retention of phosphorus in animal tissue. Ammerman et al. (1974) reported that there were wide variations in mineral content between different tissues in the body. Table 13 summarizes phosphorus concentration in various body components reported by Ellenberger et al. (1950). These researchers demonstrated that whole bodies of newborn calves contained an average of 0.76% phosphorus. They also reported that percent phosphorus in whole empty body changed little from birth (0.76%) to 12 months of age (0.77%). Percent phosphorus in whole body increased as animals increased in age from 12 months to 2 ½ years, and plateaued in cows over 2 ½ years of age. Phosphorus in whole bodies of cows between the ages of 2 ½ to 3 ½ years averaged 0.93%. This level decreased only slightly to between 0.86% and 0.90% phosphorus for 4 ½ to 5 ½ and 6 to 12 years of age, respectively. Ammerman et al. (1974) reported higher tissue phosphorus levels than those reported by Ellenberger et al. (1950). Ammerman et al. (1974) showed that phosphorus ranged from 1.22 to 1.26% in liver, 0.89 to 1.05% in heart, 0.68 to 0.78% in muscle, and 17.63 to 18.06% in bone. Skeletal phosphorus in the experiment conducted by Ellenberger et al. (1950) ranged from 2.1 to 3.4% for the calf groups, and 4.9% for the cows.

Mahan and Shields (1998) demonstrated that calcium and phosphorus concentration in pigs did not steadily increase throughout the life of the animal. These researchers showed that calcium and phosphorus concentration increased from birth to weaning, remained relatively constant from 20 to 75 kg, and then increased from 75 to 145 kg. In this trial, the ratio of calcium to phosphorus did not remain static from birth to 145 kg. Calcium is located primarily in the bones of the animal, whereas phosphorus is located in both hard and soft tissues (Mahan and Shields, 1998). NRC (1996) reported that 80% of the phosphorus in the body is located in bone and teeth, while the remainder is located in soft tissue. NRC (1996) also reported that calcium and phosphorus are usually discussed together because of their importance in bone formation. Dietary calcium ratios from 1:1 to 7:1 had similar results, provided that phosphorus was in sufficient quantities to meet animal requirements. NRC (1996) further reported that phosphorus was important in growth and cellular metabolism. Phosphorus is an important component in DNA, RNA, ATP, ADP, and AMP (adenosine monophosphate). It is also essential in phospholipid formation, and is required by ruminal microorganisms.

Percent of total phosphorus in various tissues. Ellenberger et al. (1950) demonstrated that phosphorus concentration varied widely between body components such as skeleton, meat, visceral organs, feet and hooves, skin and hair, and blood. These researchers reported that the skeleton contained 88.0% of total phosphorus for newborn calves, 77.8% of total phosphorus for five to six month old calves, to an average of 83.9% of total phosphorus for three to 12 month old calves. Percent of total phosphorus in bovine lean tissue ranged from 11.0% in three to 12 month old calves to 8.85% of total phosphorus in cows. Percent of total phosphorus in visceral organs was 4.17% for three to 12 month old calves, and 2.85% for cows. In this experiment, feet and hooves contained the smallest percent of phosphorus compared to the total. For all calves, feet and hooves contained 0.03% of total phosphorus while for cows, feet and hooves comprised only 0.02%. The percent of total phosphorus contained in skin and hair was 0.71 and 0.39% for calves and cows, respectively.

Mineral Absorption by Animal Tissues

Mineral intake and absorption. Research has been conducted to examine the absorption of minerals into animal tissue. Scott and Buchan, (1985) have shown that little or no phosphorus absorption occurs in the rumen or omasum of ruminants. Ternouth et al. (1996) reported that phosphorus absorption was linearly related to phosphorus intake. NRC (1996) reported that the phosphorus requirement of a 200 kg growing calf, with an ADG of 1 kg/d, is 10 g P daily. McLean and Ternouth (1994) examined the effects of phosphorus fertilization on the growth and nutrient balance of cattle grazing pastures that are typically low in available phosphorus. These researchers reported that phosphorus absorption (mg/kg live weight) increased as phosphorus fertilization rate increased. Similar results were reported by Braithwaite (1975) who showed that phosphorus absorption was directly related to phosphorus intake. This phenomenon was also apparent for other minerals. Calcium absorption increased with increasing levels of dietary intake (Braithwaite, 1975). Once absorptive capacity is reached, the amount of minerals transported across the small intestine will no longer increase. Braithwaite (1975) reported that calcium absorption did not increase above levels of 200 mg/kg of BW daily for mature animals and 400 mg/kg of BW daily for young animals. Maximum daily phosphorus absorption in their study was 45 mg/kg BW for mature animals, and 101 mg/kg BW in young animals.

Rate of phosphorus absorption and accretion. Research has been conducted that compared phosphorus absorption rates for different types of diets. Scott and Buchan (1985) conducted an experiment that compared intestinal phosphorus absorption rates (g/d) for concentrate, hay, and 50% hay and concentrate diets in sheep. Total duodenal phosphorus flow was 10.81, 14.58, and 14.54 g/d for concentrate, 50:50 concentrate:hay, and hay diets, respectively. The results of this experiment showed that intestinal phosphorus absorption was greatest for diets that were formulated with 50% forage and 50% concentrate. Intestinal phosphorus absorption rates were 7.41, 9.74, and 8.57 g/d for concentrate, 50:50 concentrate:hay, and hay, respectively. Jongbloed (1987) reported that phosphorus accretion in swine body tissue ranged between 5 and 8 g P/kg of live BW. This is in agreement with results cited by Ternouth et al. (1996), who reported that phosphorus accretion rate was 5.8 g/kg of live weight for 200 to 400 kg growing cattle. McCollum (2002) also reported that grazing cattle gaining 1.5 lb daily retained five g P/d.

Phosphorus in saliva acts as a buffer for VFAs in the rumen, and it is important in maintaining homeostatic levels of phosphorus in the body (Scott and McLean, 1981). According to these researchers, saliva was the main pathway of phosphorus entry into the gastrointestinal tract, and provided five to six grams of phosphorus daily, as opposed to two grams daily from dietary phosphorus.

Nutrient Excretion. Phosphorus, like other nutrients, is excreted via the urine and feces. Scott and Buchan (1985) examined the effect of diet on absorption and excretion of phosphorus in sheep. These researchers concluded that plasma phosphorus levels were not affected by diet. Scott and Buchan (1985) further reported that increased plasma phosphorus levels caused decreased renal reabsorption rate, and increased urinary and fecal excretion rate. There was also a difference in phosphorus excretion rate between types of diets. Urinary excretion was higher ($P < 0.01$) and fecal excretion was lower ($P < 0.01$) for concentrate vs. hay diets. Scott and Buchan, (1985) concluded that increasing the amount of forage in the diet caused a shift from urinary excretion to fecal excretion of phosphorus. The difference in reabsorption rates was due to differences in efficiency of reabsorption in the renal tubules (Scott and Buchan, 1985).

Braithwaite (1975) examined calcium and phosphorus intake and absorption, and demonstrated that urinary calcium levels declined with increased calcium retention, and urinary phosphorus levels increased with increasing levels of phosphorus absorption. Ternouth et al. (1996) suggested that urinary phosphorus excretion was dependant upon renal tubule reabsorption ability, and that urinary phosphorus levels increased significantly once the renal tubule reabsorption capacity was reached. Ternouth et al. (1996) cited research that showed that this capacity was reached when plasma inorganic phosphorus levels exceeded 50 mg/L and intake of phosphorus exceeded 30 mg/kg of live weight.

Summary and Conclusion

Traditionally, manure from cattle feeding operations has been applied to agricultural land, and used as a nutrient source for growing crops or pastures. With the evolution and expansion of confined animal feeding operations in the United States comes increased concern about the issue of waste disposal. Environmental concerns such as nutrient leaching into groundwater and eutrophication of lakes and streams as a result of surface runoff have resulted in government intervention. In addition, Jongbloed and Lenis (1998) suggested that ammonia and greenhouse gasses are a major cause for concern with management of animal waste. The primary issue surrounding animal waste management is distribution (McCollum, 2002). Due to transportation costs, much of the livestock waste is applied to land surrounding feeding operations. A concern is that nutrient levels (N and P) can accumulate in the soil, with the major concern being an increase of soil phosphorus concentration. McCollum (2002) further reported that this issue can be corrected by more appropriate distribution of the manure; however, transportation and application costs may limit the distance to which the manure can be transported. In this situation, the amount of soil phosphorus removed from the land to which the manure is applied must be known in order to determine the amount of manure that can be applied the following year without causing phosphorus buildup.

This review examines the literature regarding mineral accretion, specifically phosphorus accretion, in growing animal tissues. Growth and chemical maturity has been well reported in the literature and is well understood in livestock such as cattle, sheep, and swine (Shields et al., 1983; Wagner et al., 1999). Further studies have examined mineral accretion in body tissues (Ellenberger et al., 1950; Ammerman et al. 1974). These studies have demonstrated that there is a maximum level of mineral absorption by animal tissues, and any mineral in excess of this is excreted. Accretion rates in animal tissues for minerals such as calcium and phosphorus have been determined in both swine and cattle. Jongbloed (1987) reported that phosphorus accretion was between 5 and 8 g/kg of live weight. This is supported by Ternouth et al. (1996) who reported that phosphorus accretion for 200 to 400 kg growing cattle was 5.8 g/kg of live weight.