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Influence of Monensin on Holstein Steers Fed High-Concentrate Diets Containing Soybean Meal or Urea^{1,2}

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ABSTRACT: We conducted two growth trials to evaluate the effects of monensin on amino acid sparing. When Holstein steers were fed a 90% concentrate diet supplemented with soybean meal (13.5% CP), the DMI, ADG, and efficiencies of feed and nitrogen utilization were greater than with urea ($P < .10$). Monensin improved ADG with both nitrogen supplements ($P < .01$), but the positive effects of monensin on efficiencies of feed ($P = .12$) and nitrogen ($P = .26$) utilization were greater for soybean meal than for urea. Increasing amounts of monensin (0, 11, or 22 mg/kg of DM) caused a linear increase in DMI with urea. Diets with soybean had greater intakes than diets with urea ($P < .01$); the greatest intake was of a soybean diet with monensin

at 11 mg/kg of DM. Holstein steers fed soybean meal at 13.5% CP had lower DMI and greater efficiencies of feed and nitrogen utilization than steers fed 16.7% CP ($P < .10$). Crude protein level had no effect on ADG ($P > .10$). Monensin always increased the efficiencies of feed and nitrogen utilization ($P < .05$), but these trends were greater for diets with 16.7 than for those with 13.5% CP. Overall, monensin decreased DMI ($P < .01$), but this effect was greater for 16.7% than for 13.5% CP. Because the positive effects of monensin on diet NE_g ($P = .16$) and efficiency of nitrogen utilization ($P = .26$) were greater for soybean meal than for urea, it seemed that monensin was sparing amino acids.

Key Words: Monensin, Protein, Feed Intake, Feed Conversion, Steers

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Introduction

Monensin has been used as a feed additive for more than 20 yr. In feedlot cattle, improvements in feed efficiency have typically been explained by increases in propionate production and decreases in methane (Goodrich et al., 1984). In vitro and in vivo studies indicated that monensin might also inhibit wasteful ruminal protein degradation (Dinius et al., 1976; Van

Nevel and Demeyer, 1977), but this potential has often been ignored. Hanson and Klopfenstein (1979) reported no increases in ADG or feed efficiency if urea was the nitrogen supplement, but diets containing low concentrations of dried brewer's distilled grain showed a monensin-dependent improvement in feed efficiency. Poos et al. (1979) indicated that monensin decreased ruminal ammonia and increased feed-protein bypass, but this effect was counteracted by a decline in microbial protein. Yang and Russell (1993) reported that monensin could decrease ruminal ammonia and increase fluid-phase microbial protein of animals fed timothy hay, but recent work indicated that animals fed alfalfa did not respond as well as those fed timothy (Lana and Russell, 1997). The following experiments were designed to compare the effect of monensin supplementation on Holstein steers fed urea or soybean meal diets.

Materials and Methods

Two trials were conducted with Holstein steer calves purchased from the same calf grower in central New York. Both experiments were conducted in a total

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Table 1. Ingredient and nutrient composition (% of DM) of diets fed to steers^a

Item	Trial 1		Trial 2	
	Urea	Soybean	13.5% CP	16.7% CP
Ingredient composition				
Corn silage (35% grain)	15.00	15.00	15.00	15.00
Cracked corn grain	80.42	72.85	72.85	65.85
Soybean meal (49% CP)	.00	9.00	9.00	16.00
Urea	1.43	.00	.00	.00
Limestone	2.25	2.25	2.25	2.25
Dicalcium phosphate	.75	.75	.75	.75
Trace mineral salt	.15	.15	.15	.15
Nutrient composition ^b				
CP	13.50	13.50	13.50	16.70
DIP, % of CP ^b	70.00	63.00	63.00	66.00
Soluble protein, % of CP	42.00	18.00	18.00	19.00
Total NSC ^b	67.00	64.00	64.00	61.00
NDF	14.00	14.00	14.00	14.00
Ash	5.81	6.29	6.29	6.64

^aDiets included monensin at 0, 11, and 22 mg/kg of DM (trial 1) or 0, 22, and 33 mg/kg of DM (trial 2); dry matter basis.

^bTabular values obtained from the output of the CNCPS model (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992). DIP = protein degradability; NSC = nonstructural carbohydrate.

confinement, slatted-floor barn at the Cornell Beef Cattle Teaching and Research Center. Three weeks before the experimental period, the steers were moved to the barn and adapted to a high concentrate level. All diets were 90% concentrate (primarily cracked corn grain), with variation in the source and amount of CP (Table 1). Monensin was added as a commercial premix to achieve the desired dietary concentration. All diets were formulated to meet NRC (1984) requirements for minerals and vitamins. The Cornell Net Carbohydrate and Protein System, version 3 (CNCPS) (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992) was used to formulate the dietary protein levels to meet experimental objectives.

Soybean vs Urea. Eighty-four Holstein steers (287 kg initial shrunk body weight) were fed in groups, and 30 steers (316 kg initial weight) were fed individually. The 114 steers were blocked by weight and allocated at random to six dietary treatments (the 30 heaviest steers were assigned to the individual pens). Each dietary treatment was fed to two pens containing seven animals each or to five individual animals. Three levels of monensin (0, 11, and 22 mg/kg of DM; Elanco, Greenfield, IN) were added to the diet, and the diets had either soybean meal or urea as a nitrogen supplement. The diets were isonitrogenous (13.5% CP, Table 1). Based on the CNCPS, the urea-based diets had a positive ruminal nitrogen balance (12 g/d or 12% above requirement), but the ruminal peptide balance was negative (-21 g/d or 36% below requirement). The soybean meal diets had positive ruminal nitrogen (6 g/d or 6% above requirement) and peptide balances (5 g/d or 9% above requirement).

The steers were implanted with Revalor (Hoechst-Roussel Agri-Vet, Somerville, NJ) on d 1. They were

fed once daily, and orts were removed whenever they accumulated (orts were less than 1% of feed offered in the overall experiment). Body weights were reduced by 4% (shrunk body weight) to account for digestive tract fill. The experiment was terminated when 70% of the steers reached USDA Choice grade as determined by ultrasound, as described by Perry and Fox (1997). Two steers were removed from the trial (one from the urea treatment and one from the soybean treatment, both with monensin at 11 mg/kg of DM) due to bloat. The experiment lasted 140 d.

Feed NE for maintenance and gain were calculated with the computer model of NRC (1996), Level 1. The data of the entire trial and each pen were used as inputs, and dietary TDN was adjusted up or down until predicted ME allowable ADG and observed ADG agreed. The NE for maintenance and gain were similar to those calculated by Zinn (1987), but the NRC (1996) accommodates a wide variety of conditions (animal, feed, management, and environment).

The performance data were analyzed as a randomized complete block design in a 2 × 3 factorial arrangement of treatments using GLM procedures of Minitab (1994). Each pen constituted an experimental unit and the data for individually fed steers were considered as a third pen (no treatment × pen interaction, $P > .05$). The model included effects of block (light vs heavy body weight), nitrogen source (soybean meal vs urea), monensin (0 mg/kg of DM vs otherwise), monensin level (11 vs 22 mg/kg of DM), nitrogen source × monensin, and nitrogen source × monensin level. Treatment effects were compared by a complete set of orthogonal contrasts (Table 2).

Feed intake variation was calculated for each individually fed steer in two ways: among steers within a day and feeding period (6 treatments × 28

Table 2. Coefficients for orthogonal contrasts

Item	Protein Monensin, mg/kg	Treatments					
		Trial 1: Trial 2:		Urea 13.5% CP		Soybean 16.7% CP	
		Trial 1:	Trial 2:				
		Trial 2:	Trial 1:	Trial 2:	Trial 1:	Trial 2:	Trial 1:
1. Protein		0	11	22	0	11	22
2. Monensin		0	22	33	0	22	33
3. Monensin level		1	1	1	-1	-1	-1
4. Protein × monensin		1	-5	-5	1	-5	-5
5. Protein × monensin level		0	1	-1	0	1	-1

replicates [140 replicates in the overall period]) and among days within a steer and feeding period (6 treatments × 5 replicates), according to Stock et al. (1995). The data were analyzed as a complete randomized design in a 2 × 3 factorial arrangement of treatments (see Table 2 for orthogonal contrasts). Because most periods showed significant interaction effects ($P < .10$), the treatment means were separated by Duncan's test at $\alpha = .05$ (Steel and Torrie, 1960).

Amounts of Soybean Meal. This trial was conducted with 120 implanted Holstein steers (145 kg initial shrunk body weight). The steers were blocked by weight and allocated randomly to 12 pens (six pens each of light and heavy body weight) with 10 animals per pen. A light and heavy weight group was assigned to each of six treatments. Three levels of monensin (0, 22, and 33 mg/kg of DM; Elanco) were fed with two different amounts of soybean meal (13.5 and 16.7% CP). The low-protein treatments were balanced to meet ruminal ammonia and peptide preferences (as in the first trial) as predicted by the CNCPS, version 3. The high-protein treatments were balanced to provide an excess of ruminal peptide (18 g/d or 34% above requirement) and nitrogen (21 g/d or 24% above requirement). Management, data collection, and calculations of NE values were similar to those in trial 1, except that the steers were implanted with Synovex-S (Syntex Animal Health, St. Louis, MO) on d 1, were re-implanted with Revalor on d 84, and received a second Revalor implant on d 168. Two steers were removed because of bloat; both steers were from the treatment with monensin at 22 mg/kg of DM and 16.7% CP. The experiment lasted 280 d.

Animal performance and feed NE values were analyzed as a randomized complete block design in a 2 × 3 factorial arrangement of treatments using GLM procedures of Minitab (1994). Each pen constituted an experimental unit. The model included effects of block (light vs heavy body weight), protein level (13.5 vs 16.7% CP), monensin (0 mg/kg of DM vs otherwise), monensin level (22 vs 33 mg/kg of DM), protein level × monensin, and protein level × monensin level. Treatment effects were compared by a complete set of orthogonal contrasts (Table 2).

Results

Soybean vs Urea. Feedlot steers were fed concentrate diets containing urea or soybean as a CP supplement and monensin at 0, 11, or 22 mg/kg of DM for 140 d (Table 3). We will discuss the overall responses, but responses at earlier time periods (1 to 84 d, and 85 to 140 d) are also shown. Steers fed soybean meal had higher DMI than those fed urea at all concentrations of monensin ($P < .01$; Table 3). The monensin level × nitrogen source interaction indicated that monensin (22 vs 11 mg/kg of DM) increased DMI for urea diets, but it decreased DMI for soybean diets ($P < .10$). Soybean meal treatments had higher ADG than urea at all concentrations of monensin ($P < .01$). Monensin improved ADG for urea and soybean meal treatments ($P < .01$). Soybean meal had a higher gain to DM intake ratio (feed efficiency) than urea ($P < .10$), and monensin improved feed efficiency for both nitrogen supplements ($P < .10$). The monensin × nitrogen source interaction indicated that monensin tended to be more effective in improving feed efficiency if soybean was fed ($P = .12$). The gain to CP intake ratio (efficiency of nitrogen utilization) was greater for soybean than for urea ($P < .05$), and monensin also improved the efficiency of dietary nitrogen utilization ($P < .05$). The monensin level × nitrogen source interaction indicated that monensin (22 vs 11 mg/kg of DM) tended to decrease efficiency of nitrogen utilization for urea diets, but it tended to increase the efficiency of nitrogen utilization for soybean diets ($P = .18$). Dietary NE values derived from DMI and ADG (NRC, 1996) were higher for soybean than for urea diets ($P < .10$). Monensin tended to increase diet NE_g ($P < .10$), and monensin was more effective in improving diet NE_g if soybean was fed ($P = .16$). The monensin level × nitrogen source interaction indicated that monensin (22 vs 11 mg/kg of DM) tended to decrease diet NE_g for urea diets, but it tended to increase NE_g for soybean diets ($P < .10$).

Steers that were fed in groups had the same pattern of feed intake regardless of nitrogen supplementation or monensin (data not shown), but steers fed

Table 3. Effects of dietary nitrogen source and monensin levels on feedlot performance of Holstein steers fed a 90% concentrate and 13.5% CP diet during 140 days (Trial 1)

Item	Treatments							SEM	Contrast <i>P</i> -level ^a				
	Nitrogen source: Monensin, mg/kg:	Urea			Soybean				1	2	3	4	5
		0	11	22	0	11	22						
No. of pens ^b	3	3	3	3	3	3	—	—	—	—	—	—	
No. of steers	19	18	19	19	18	19	—	—	—	—	—	—	
Shrunk BW, kg													
Initial	287	286	286	287	287	288	1.96	.50	.86	.82	.46	.76	
d 84	411	416	420	422	430	431	4.00	.01	.05	.46	.76	.66	
d 140	480	488	489	495	514	506	5.99	.01	.05	.53	.51	.48	
DMI, kg/d													
d 1–84	6.80	6.89	7.07	7.22	7.38	7.18	.119	.01	.26	.93	.55	.14	
d 85–140	7.73	7.86	8.19	8.23	8.68	8.15	.229	.05	.26	.68	.78	.09	
Overall	7.17	7.28	7.52	7.62	7.90	7.57	.154	.01	.23	.77	.66	.09	
Daily gain, kg													
d 1–84	1.48	1.55	1.60	1.61	1.70	1.74	.040	.01	.01	.24	.85	.92	
d 85–140	1.23	1.29	1.22	1.31	1.48	1.34	.047	.01	.14	.06	.36	.49	
Overall	1.38	1.45	1.45	1.49	1.61	1.58	.032	.01	.01	.75	.50	.63	
Gain:DM intake													
d 1–84	.216	.220	.224	.216	.223	.240	.007	.21	.07	.11	.37	.30	
d 85–140	.158	.163	.147	.156	.167	.162	.006	.17	.56	.05	.16	.29	
Overall	.188	.192	.185	.187	.197	.201	.005	.06	.09	.74	.12	.15	
Gain:CP intake													
d 1–84	1.61	1.66	1.68	1.65	1.70	1.80	.037	.06	.03	.16	.56	.31	
d 85–140	1.18	1.22	1.10	1.18	1.26	1.22	.034	.09	.45	.05	.18	.27	
Overall	1.44	1.49	1.45	1.46	1.53	1.57	.028	.02	.03	.88	.26	.18	
Diet NE, Mcal/kg													
Maintenance	2.03	2.06	2.01	2.03	2.09	2.15	.032	.06	.10	.96	.16	.10	
Gain	1.38	1.41	1.37	1.38	1.43	1.48	.027	.07	.10	.90	.16	.09	

^a1 = Effect of nitrogen source (soybean meal vs urea); 2 = effect of monensin (control vs monensin); 3 = effect of monensin level (11 vs 22 mg/kg of DM); 4 = interaction nitrogen source vs monensin (interaction 1 × 2); and 5 = interaction nitrogen source vs monensin level (interaction 1 × 3).

^bTwo pens with seven steers/pen and five individual pens with data pooled and treated as a third group pen (no treatment × pen interaction, *P* > .05).

individually (five animals per dietary treatment) had a higher apparent variation than animals fed in groups. We will discuss the overall variations, but variations at 28-d time periods are also shown (Table 4). The lowest within-day variations of DMI for individually fed steers occurred with soybean meal diets without monensin and urea diets with monensin at 22 mg/kg of DM (*P* < .05). The highest within-day variations of DMI for individually fed steers occurred with soybean meal diets with monensin at 22 mg/kg of DM and urea diets with monensin at 11 mg/kg of DM (*P* < .05). The highest among-day variations of DMI for individually fed steers occurred with urea diets with monensin at 11 mg/kg of DM (*P* < .05).

Amounts of Soybean Meal. Steers fed soybean meal to achieve 16.7% CP had greater overall DMI than steers fed 13.5% CP (*P* < .01; Table 5). Monensin decreased overall DMI (*P* < .01), but the monensin × CP interaction indicated that monensin was more potent in depressing DMI when the CP was 16.7% (*P* < .05). Monensin did not affect DMI in the early time periods, and it only caused a significant decrease in periods 7 to 10 (Figure 1). Neither CP nor monensin had an effect on overall ADG (*P* > .10). Overall gain

to DM intake (feed efficiency) was greater for 13.5 than for 16.7% CP (*P* < .10). Monensin increased (*P* < .05) overall feed efficiency at both CP percentages. The overall efficiency of nitrogen utilization was greater for 13.5 than for 16.7% CP (*P* < .01). Monensin increased the efficiency of nitrogen utilization for both CP percentages (*P* < .05). The 13.5% CP had greater overall diet NE_g than 16.7% CP (*P* < .05). Monensin increased diet NE_g at both CP percentages (*P* < .05).

Discussion

Monensin is typically fed at 33 mg/kg (Goodrich et al., 1984), but early work by Raun et al. (1974) indicated that doses as low as 22 mg/kg were as effective. Our first trial indicated that even 11 mg of monensin/kg of DM could cause an increase in feed efficiency (Figure 2), but the response was sometimes greater if the dose was 22 mg/kg of DM. The second trial indicated that monensin at 33 mg/kg of DM was more effective than at 22 mg/kg, but only if the diet had a large amount of soybean meal. Based on these

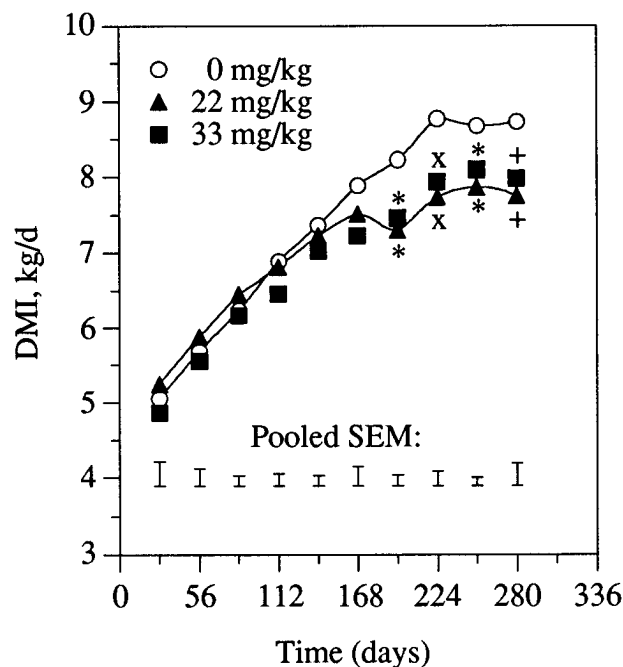


Figure 1. The effect of monensin (closed symbols) on DMI of cattle fed soybean meal supplement to achieve 16.7% CP during the course of the second feeding trial. The statistical significance ($*P < .05$; $*P = .08$; $+P = .15$) and pooled SEM (error bars) were obtained by orthogonal contrasts in a randomized complete block design.

results, optimal dose of monensin was dependent on the type and amount of CP. When urea was the supplement, monensin had no effect on the efficiencies of feed and nitrogen utilization; similar results were obtained by Hanson and Klopfenstein (1979).

The benefit of monensin in feedlot performance has been attributed primarily to improvements in energy utilization (Thornton and Owens, 1981; Wedegaertner and Johnson, 1983; Raun, 1992). Any increase in energy availability that enhances animal growth would increase protein deposition and cause an apparent improvement in the efficiency of dietary protein utilization. Because most studies have used a single type and concentration of CP in the diet, it has been difficult, if not impossible, to ascertain whether monensin is also able to mediate a direct effect on amino acid utilization (amino acid sparing).

Hanson and Klopfenstein (1979) evaluated monensin with diets containing urea or dried brewer's grains. Monensin decreased acetate:propionate ratio and increased total VFA to a similar extent in both diets, but monensin only increased feed efficiency when brewer's grains were used. The authors explained these results by stating that "this may indicate microbial protein synthesis is inhibited by addition of monensin." An alternative explanation, a decrease in wasteful ruminal degradation of feed protein (dried brewer's grains), was not considered.

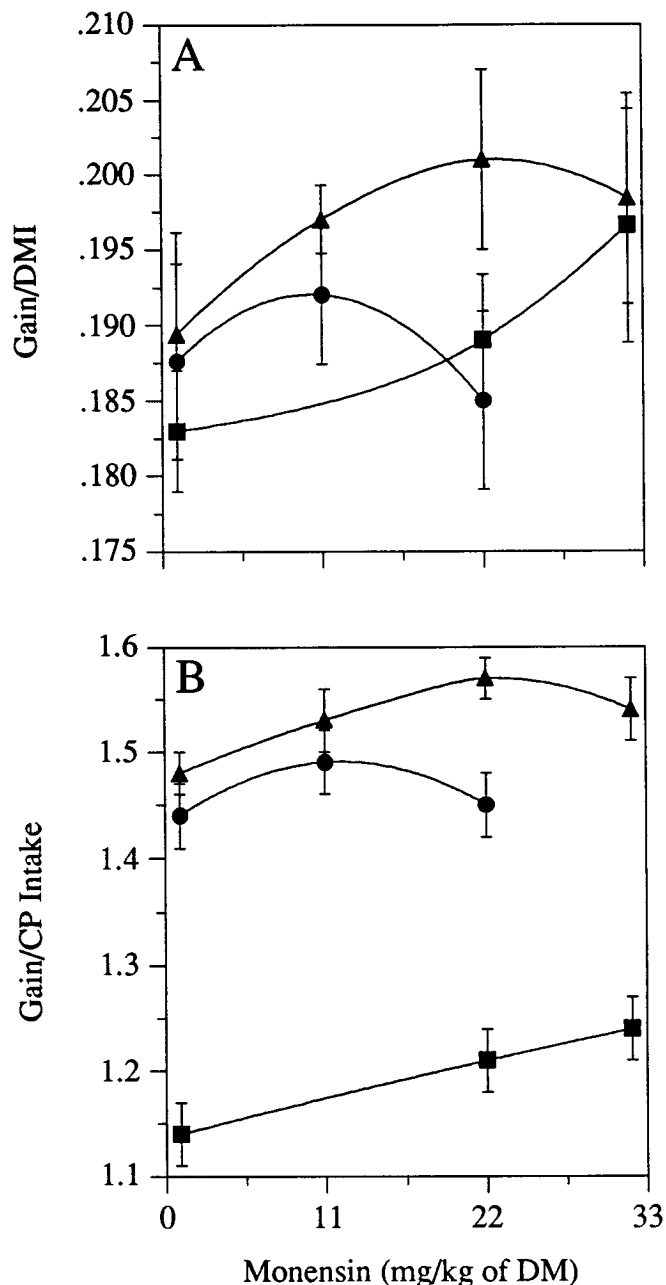


Figure 2. A summary of the effects of monensin on gain:DM intake (A) and gain:CP intake (B) of implanted Holstein steers fed high-concentrate diets. The diets were supplemented with soybean meal to achieve 13.5 (▲) or 16.7% CP (■) or urea (●) to achieve 13.5% CP. The bars show the standard deviations.

Goodrich et al. (1984) summarized the effect of monensin on animal performance. Monensin-dependent improvements in feed efficiency were 7.8% when diets contained true protein, but only 1.9% for urea-supplemented diets. Goodrich et al. (1984) concluded that "these data may also indicate a protein sparing effect of monensin," but the nature of this effect was not described. Was monensin decreasing ruminal deamination or was it improving amino acid utiliza-

Table 4. Effect of dietary nitrogen source and monensin levels on variance in feed intake within day and feeding period, and among days within feeding period for individually fed steers (Trial 1)

Item	Treatments						SEM	
	Nitrogen source:		Urea			Soybean		
	Monensin, mg/kg:	0	11	22	0	11		22
No. of steers		5	4	5	5	4	5	—
Feed intake variation among steers within a day, kg ²								
d 1–28		1.17 ^a	.74 ^{ab}	.44 ^b	1.17 ^a	.90 ^a	1.14 ^a	.154
d 29–56		1.15 ^c	1.65 ^d	.56 ^{ab}	.44 ^a	1.00 ^{bc}	2.76 ^e	.173
d 57–84		1.40 ^b	2.34 ^c	.68 ^a	.30 ^a	1.37 ^b	1.69 ^b	.151
d 85–112		1.62 ^{ab}	1.63 ^{ab}	1.71 ^b	.96 ^a	2.14 ^b	1.67 ^b	.235
d 113–140		1.28 ^{ab}	1.76 ^a	.73 ^b	1.66 ^a	1.31 ^{ab}	1.26 ^{ab}	.257
Overall		1.33 ^b	1.62 ^c	.82 ^a	.91 ^a	1.35 ^b	1.71 ^c	.089
Feed intake variation among days within a steer, kg ²								
d 1–28		.31	.46	.44	.69	.56	.74	.163
d 29–56		.66	1.25	.56	.48	.68	.91	.247
d 57–84		.32 ^{ab}	1.25 ^c	.27 ^{ab}	.17 ^a	.79 ^{bc}	.30 ^{ab}	.174
d 85–112		1.04 ^{ab}	1.46 ^b	.90 ^{ab}	.35 ^a	.80 ^{ab}	1.16 ^{ab}	.272
d 113–140		.71 ^a	2.40 ^b	.84 ^a	1.13 ^a	.89 ^a	.86 ^a	.281
Overall		.61 ^a	1.36 ^b	.60 ^a	.56 ^a	.75 ^a	.79 ^a	.115

a,b,c,d,e Means in the same row with different superscript differ ($P < .05$).

tion by increasing propionate, an alternative source of blood glucose?

Early work indicated that monensin was able to inhibit ruminal amino acid degradation in vitro (Van Nevel and Demeyer, 1977), but it was not until the 1980s that highly active, amino acid-degrading and monensin-sensitive bacteria were isolated from the rumen (Russell et al., 1988; Chen and Russell, 1989). In vivo studies with cattle fed timothy hay and soybean meal indicated that monensin could decrease ruminal ammonia, the specific activity of bacterial deamination and the numbers of obligate amino acid-fermenting bacteria (Yang and Russell, 1993), but total amino acid flow from the rumen was not determined.

In forage-fed animals, there is often an imbalance between ruminal protein and carbohydrate fermentation, and large amounts of ammonia can accumulate in the rumen. When animals are fed cereal grain, the bacteria have more energy for protein synthesis, and ruminal ammonia utilization is improved. Based on these considerations, Russell (1991) concluded that the “amino acid sparing effect of monensin” might be minimal for animals fed feedlot diets. Because older animals have lower protein needs than rapidly growing cattle, the amino acid sparing benefit of monensin would be maturity-dependent as well.

When implanted lightweight Holstein steers were fed high-concentrate diets, monensin increased feed efficiency, but only when the diet was supplemented with soybean meal (Figure 2). No increase in feed efficiency could be detected if urea was the primary nitrogen source. The idea that monensin was improving feed efficiency by decreasing ruminal amino acid degradation was supported by the effect of monensin

on diet NE_g and efficiency of nitrogen utilization. The positive effects of monensin on diet NE_g and efficiency of nitrogen utilization were greater for soybean meal than urea diets. If monensin were mediating its effect solely through energy metabolism, there should have been no monensin × nitrogen source interaction.

Steers fed soybean meal to achieve 16.7% CP had higher DMI and a lower feed efficiency than steers fed 13.5% CP (Figure 2), and 16.7% CP exceeds current NRC recommendations (1996). High doses of monensin (33 mg/kg DM) decreased DMI, but monensin also improved feed efficiency and the efficiency of nitrogen utilization. These latter effects indicated that monensin was probably decreasing ruminal deamination and ammonia accumulation. A decline in ruminal ammonia would decrease the cost of urea synthesis, and more energy would be available for growth.

Early studies indicated that monensin often decreased the feed intake of feedlot cattle, and Goodrich et al. (1984) indicated that the “greatest reduction in DM intake due to feeding monensin occurred when ME intake was low.” We only observed a decrease in DMI when CP was 16.7%, soybean meal was the CP supplement, and BW was greater than 380 kg. The cattle cited in the summary of Goodrich et al. (1984) ranged from 284 to 430 kg, and effect of monensin on lighter, faster growing cattle was not reported. The DMI is usually related to ME, but our results indicate that CP supply can also be an important variable. Whether animals consume feed to meet specific amino acid requirements, energy, or both, needs to be determined.

Monensin has been used to control feed intake during cycles of bad weather, and this benefit has been explained by reduced variations in feed intake

Table 5. Effects of dietary protein and monensin levels on feedlot performance of Holstein steers fed a 90% concentrate diet during 280 days (Trial 2)

Item	Treatments							SEM	Contrast <i>P</i> -level ^a					
	CP, % of DM:		13.5			16.7			1	2	3	4	5	
	Monensin, mg/kg:	0	22	33	0	22	33							
No. of pens		2	2	2	2	2	2	—	—	—	—	—	—	
No. of steers		20	20	20	20	18	20	—	—	—	—	—	—	
Shrunk BW, kg														
Initial		152	152	150	149	152	150	1.09	.21	.69	.10	.12	.92	
d 84		276	278	275	272	282	278	3.50	.68	.26	.35	.22	.84	
d 168		392	397	390	391	404	392	5.28	.61	.37	.13	.60	.63	
d 280		533	547	531	536	540	540	5.97	.76	.36	.23	.84	.26	
DMI, kg/d														
d 1–84		5.60	5.59	5.51	5.74	5.86	5.53	.084	.10	.55	.06	.97	.21	
d 85–168		6.95	6.69	6.86	7.38	7.17	6.91	.103	.01	.03	.68	.37	.09	
d 169–280		7.77	7.81	7.54	8.61	7.67	7.87	.128	.02	.01	.82	.02	.12	
Overall		6.87	6.81	6.73	7.38	6.97	6.88	.077	.01	.01	.31	.05	.93	
Daily gain, kg														
d 1–84		1.48	1.49	1.49	1.46	1.55	1.53	.033	.37	.19	.61	.30	.79	
d 85–168		1.37	1.42	1.38	1.42	1.45	1.35	.029	.46	.94	.06	.35	.40	
d 169–280		1.26	1.34	1.27	1.30	1.20	1.33	.022	.46	.98	.27	.11	.01	
Overall		1.36	1.41	1.36	1.39	1.38	1.39	.018	.63	.42	.43	.45	.16	
Gain:DM intake														
d 1–84		.264	.265	.270	.250	.263	.273	.006	.42	.08	.23	.20	.66	
d 85–168		.194	.198	.198	.190	.197	.189	.004	.24	.43	.40	.88	.50	
d 169–280		.157	.171	.165	.148	.153	.167	.004	.04	.02	.34	.90	.05	
Overall		.191	.201	.198	.183	.189	.197	.004	.06	.03	.52	.69	.20	
Gain:CP intake														
d 1–84		2.00	2.03	2.05	1.55	1.62	1.68	.042	.01	.13	.35	.45	.63	
d 85–168		1.46	1.57	1.49	1.15	1.21	1.17	.036	.01	.15	.14	.62	.54	
d 169–280		1.21	1.27	1.24	.90	.94	1.01	.020	.01	.02	.30	.65	.06	
Overall		1.50	1.57	1.54	1.14	1.21	1.24	.026	.01	.04	.98	.62	.30	
Diet NE, Mcal/kg														
Maintenance		2.17	2.25	2.21	2.05	2.16	2.20	.034	.05	.03	.99	.29	.30	
Gain		1.50	1.56	1.53	1.40	1.49	1.52	.028	.04	.03	.93	.25	.37	

^a1 = Effect of protein (13.5 vs 16.7% CP); 2 = effect of monensin (control vs monensin); 3 = effect of monensin level (22 vs 33 mg/kg of DM); 4 = interaction protein vs monensin (interaction 1 × 2); and 5 = interaction protein vs monensin level (interaction 1 × 3).

(Stock and Britton, 1993). Burrin et al. (1988) and Stock et al. (1995) indicated that monensin decreased the feed intake variation of cattle, and their animals were fed urea. Our individually fed steers were kept in a total confinement, slatted-floor barn, but the within-day and within-steer intake variation was sometimes significant. Monensin (22 mg/kg of DM) decreased within-day feed intake variation of individually fed steers when urea was the nitrogen supplement, but it increased the variation with soybean meal diets.

The 1996 Beef NRC has two levels. In Level 1, "ration energy values are computed by assuming contributions of each feed to arrive at total energy content of the ration, using tabular energy values." Level 2 predicts energy supply from feed physical and chemical properties, but the energy requirements are the same as those of Level 1. The difference between Level 1 and 2 is greater with respect to nitrogen metabolism. Level 1 uses simple equations to predict nitrogen availability, but Level 2 uses a Rumen Submodel of Rumen Fermentation that was derived from the CNCPS (Russell et al., 1992).

The Rumen Submodel of the CNCPS uses the prediction of ruminally available carbohydrate and protein to calculate microbial growth and ammonia accumulation in the rumen (Russell et al., 1992). This submodel has functions to account for bacterial maintenance energy expenditures, the amino nitrogen stimulation of bacteria fermenting nonstructural carbohydrate, and the negative effect of low pH on bacterial growth efficiency. Ammonia production is sensitive to microbial growth potential as well as protein escape from the rumen. The Rumen Submodel of the CNCPS predicted bacterial N flow from the rumen with an r^2 of .88, but the range of bacterial nitrogen flow in these original validations was greater than threefold (Russell et al., 1992). Because our diets only differed with respect to source and amount of CP and monensin, it seemed that our experiments would provide a rigorous test of the CNCPS and the 1996 Beef NRC.

Levels 1 (Figure 3a) and 2 (Figure 4a) of the 1996 Beef NRC tended to underpredict the ME allowable gain/DMI of our steers. Level 1 had a lower bias

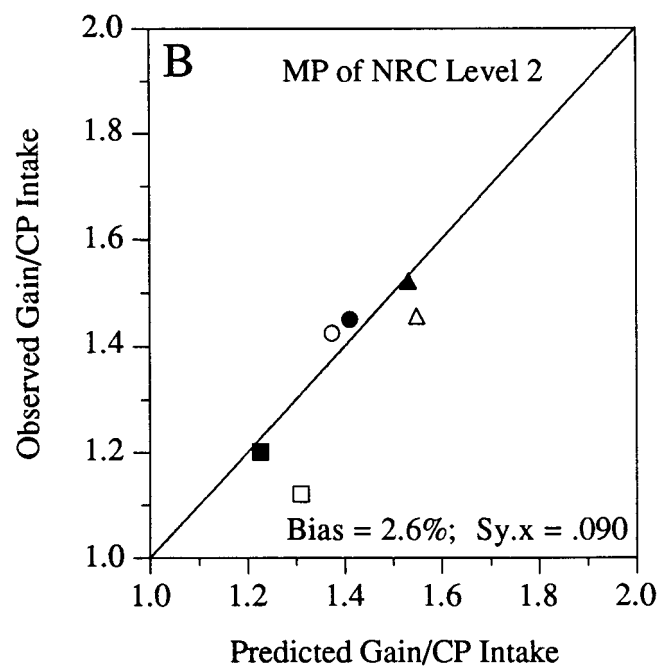
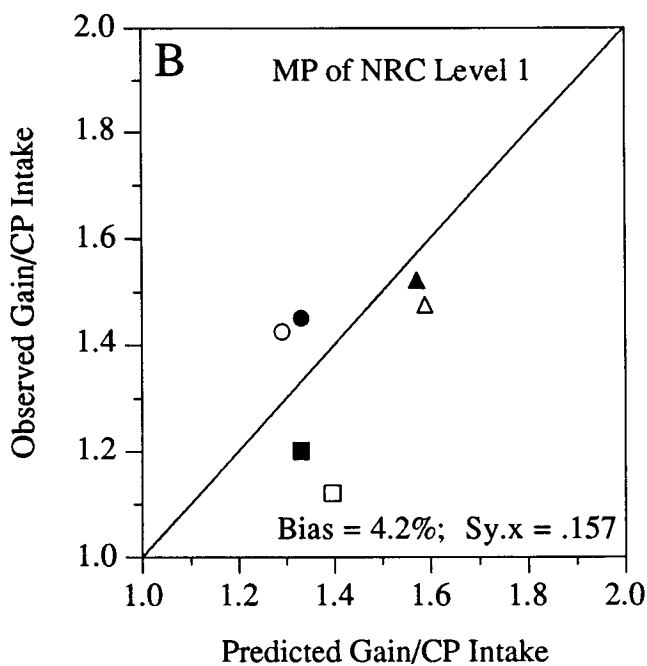
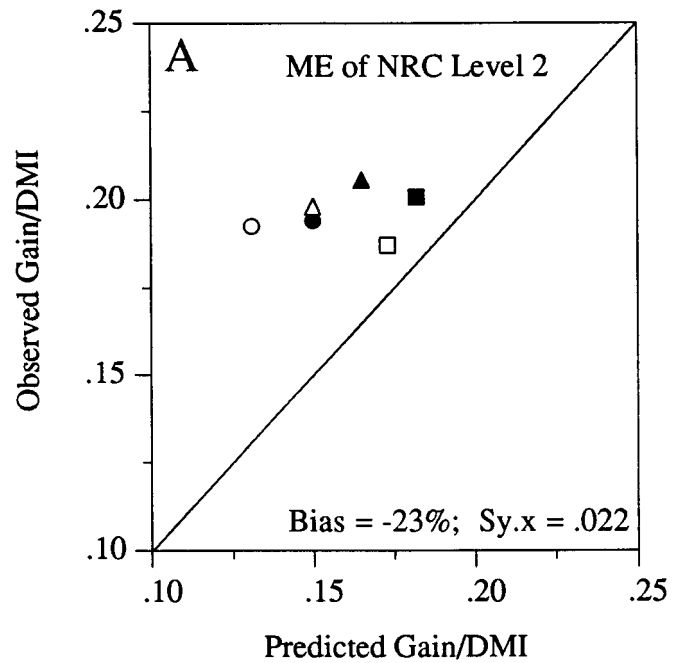
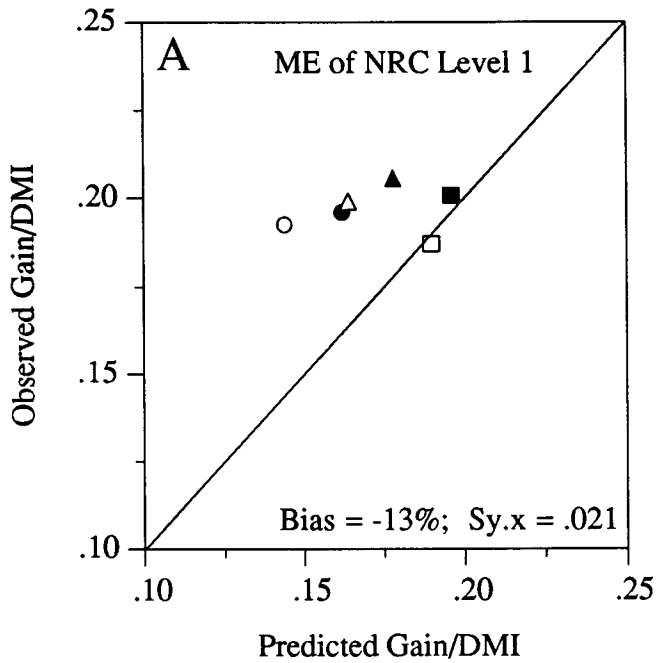


Figure 3. The relationship between the ME allowable gain/DMI predicted by Level 1 of the 1996 Beef NRC and the observed gain/DMI of the steers in our experiments is shown in panel A. The relationship between the MP allowable gain/CP intake predicted by Level 1 of the 1996 Beef NRC and the observed gain/CP intake of the steers in our experiments is shown in panel B. The diets were supplemented with soybean meal to achieve 13.5 (Δ , \blacktriangle) or 16.7% CP (\square , \blacksquare) or urea (\circ , \bullet) to achieve 13.5% CP. Open symbols show controls diets without monensin and closed symbols show diets that were supplemented with monensin.

Figure 4. The relationship between the ME allowable gain/DMI predicted by Level 2 of the 1996 Beef NRC and the observed gain/DMI of the steers in our experiments is shown in panel A. The relationship between the MP allowable gain/CP intake predicted by Level 2 of the 1996 Beef NRC and the observed gain/CP intake of the steers in our experiments is shown in panel B. The diets were supplemented with soybean meal to achieve 13.5 (Δ , \blacktriangle) or 16.7% CP (\square , \blacksquare) or urea (\circ , \bullet) to achieve 13.5% CP. Open symbols show controls diets without monensin and closed symbols show diets that were supplemented with monensin.

(1 – slope of regression that was forced through the origin) than Level 2 (–13 vs –23%). The underprediction of ME allowable gain/DMI was worse when CP was 13.5% than when CP was 16.7%. Both levels overpredicted the benefit of monensin when CP was 13.5%. The predicted monensin response was more realistic when CP was 16.7%, and this effect supported the idea that monensin-dependent increases in ME are at least partially caused by amino acid sparing in the rumen.

Level 2 of the 1996 Beef NRC was better able to predict the MP allowable gain/CP intake of our steers than Level 1 (Figure 3b vs Figure 4b), and the bias was 40% lower (2.6 vs 4.2%). The overprediction of MP allowable gain/CP intake was worse when monensin was not present and CP was 16.7%. Based on these comparisons, the Rumen Submodel of Level 2 provides a better indication of nitrogen availability than simple tabular values (Level 1).

The 1996 Beef NRC has a DMI equation that includes CP (DMI kg/kg SBW^{0.75} = .002774 × CP), but this equation only refers to all-forage diets. Because CP is inversely related to forage maturity and ADF, it is not surprising that forage CP and DMI are positively related. The 1996 Beef NRC does not relate the DMI of feedlot cattle to CP, but our experiments indicated that soybean meal supplementation could increase the DMI of feedlot cattle. This result is consistent with the effect of amino nitrogen on bacterial growth rate. When ruminal bacteria were provided with amino nitrogen, growth rate increased by as much as 75% (Van Kessel and Russell, 1996).

Implications

Steers fed urea-supplemented, high-energy diets did not respond to monensin, but steers supplemented with soybean meal showed monensin-dependent improvements in the efficiencies of feed and nitrogen utilization. Based on these results, monensin was sparing amino acids from wasteful ruminal degradation.

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