Effects of energy, mineral supplementation, or both, in combination with monensin on performance of steers grazing winter wheat pasture[1]

B. G. Fieser,* G. W. Horn,*[2] and J. T. Edwards†

*Department of Animal Science, and †Department of Plant and Soil Sciences, Oklahoma Agricultural Experiment Station, Stillwater 74078

ABSTRACT: A 2-yr study was conducted during the 2004 to 2005 (YR1) and 2005 to 2006 (YR2) winter wheat grazing seasons to determine the effects of supplementation strategies and delivery methods on supplement intake and growth performance of grazing steers (YR1, n = 253, initial BW 255 ± 25 kg; YR2, n = 116, initial BW 287 ± 14 kg). The 5 treatments were as follows: 1) negative control (NC), no supplemental nutrients; 2) free-choice, nonmedicated mineral (MIN); 3) free-choice, medicated mineral with 1,785 mg of monensin/kg of mineral mixture (RMIN); 4) RMIN and soybean hulls (SH-RMIN); and 5) a soybean hull-based energy supplement containing 165 mg of monensin/kg (GRNGOLD). Energy supplements were hand-fed on alternate days (average daily intake = 0.91 kg/steer). Inclusion of monensin in the free-choice mineral mixture decreased intake of the mineral mixture by 63% in YR1 and 55% in YR2 when no other supplement was offered. Consumption of RMIN provided from 129 to 161 mg of monensin/steer on average, whereas GRNGOLD provided 150 mg of monensin/d. Compared with NC, MIN did not affect ADG in YR1 ($P = 0.38$) but increased ($P = 0.01$) ADG by 0.22 kg/steer in YR2. Conversely, ADG of RMIN steers was greater ($P = 0.03$) than that of MIN steers during YR1 (0.72 vs. 0.55 kg/steer) but not different ($P = 0.35$) in YR2. Providing supplemental energy increased ADG by 0.13 kg/steer (0.85 vs. 0.72 ± 0.053) in YR1 compared with RMIN, but no increase in ADG was observed in YR2. No difference ($P > 0.24$) was observed in ADG between SH-RMIN and GRNGOLD in either year. Conversion of the energy supplements (kg of as-fed supplement divided by kg of additional ADG) was excellent in YR1, resulting in 1 kg of BW gain for each 3.1 kg of supplement consumed. However, due to smaller increases in ADG with the energy and monensin supplements in YR2, supplement conversion for YR2 averaged 17.6. The absence of a difference ($P > 0.24$) in ADG between steers that received SH-RMIN and GRNGOLD suggests that the method of delivery (separate packages vs. a single package) for energy, monensin, and mineral supplementation is not important.

Key words: energy supplementation, mineral supplementation, monensin, wheat pasture

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INTRODUCTION

Growing cattle on winter wheat pasture is an important facet of the beef cattle industry in Oklahoma and the southern Great Plains, with as many as 6 to 7 million cattle annually grown on wheat pasture. Supplementation of stocker cattle grazing wheat pasture serves to 1) improve efficiency of production by correcting nutrient deficiencies; 2) provide feed additives such as ionophores, antibiotics, or bloat preventatives; 3) substitute for forage to increase stocking rate or extend available forage supplies; and 4) enhance cattle management (Lusby and Horn, 1991; Horn and Paisley, 1999; Horn et al., 2005). Because of the large amounts of ruminally degradable N in wheat forage and to decrease the incidence and severity of bloat, much of our previous research (Horn et al., 2005) focused on developing self-limited and hand-fed monensin-containing energy supplements for growing cattle on wheat pasture. The hand-fed supplement has been designated the Oklahoma Green Gold supplementation program, and the specifications of the supplement were reported by Horn (2006). With greater fuel and labor costs, our recent

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[2]Corresponding author: gerald.horn@okstate.edu

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approach (Gibson, 2002) has been to deliver monensin via a free-choice mineral mixture.

The objective of this study was to compare strategies for delivering supplemental minerals, energy, and monensin concerning supplement intake and steer performance. Additionally, a new strategy for supplementation on wheat pasture, in which monensin was provided in a free-choice mineral mixture and supplemental energy was provided in the form of a commodity feedstuff (soybean hulls) was investigated.

MATERIALS AND METHODS

Study Site and Treatments

One hundred forty hectares of clean-tilled winter wheat at the Oklahoma State University Wheat Pasture Research Unit near Marshall, OK, was divided into 18 pastures during the winter wheat grazing seasons of 2004 to 2005 (**YR1**) and 2005 to 2006 (**YR2**). All pastures were planted to hard red winter wheat (*Triticum aestivum*, variety Jagalene; AgriPro, Berthoud, CO) on September 3 and 4, 2004, and September 6 and 7, 2005. Pastures were seeded at the rate of 134 kg/ha and were fertilized before planting according to soil tests. Nitrogen, P, and K were applied in amounts for production goals of 3,360 kg of forage DM/ha and a 3,360 kg/ha wheat grain crop. The five treatments were as follows: 1) negative control (NC), no mineral or any other supplement; 2) free-choice, nonmedicated mineral (MIN); 3) free-choice, medicated mineral containing 1,785 mg of monensin/kg (RMIN); 4) RMIN and soybean hulls (SH-RMIN); and 5) a monensin-containing energy supplement formulated to the Oklahoma Green Gold supplement specifications containing 165 mg of monensin/kg (GRNGOLD; Horn et al., 2005, 2006). Mineral mixtures in YR1 and YR2 (both MIN and RMIN) were manufactured by ADM Alliance Nutrition Inc., Quincy, IL, and North American Nutrition Companies Inc., Lewisburg, OH, respectively. Energy supplements were hand-fed at the rate of 1.81 kg/steer every other day to achieve a target average daily intake of 0.91 kg/steer. Both supplements were fed pelleted (0.5-cm pellet).

Each year, the pastures were blocked by location within the wheat field (4 blocks), and treatments were randomly assigned within block with the restriction that no treatments were in adjacent pastures. One block had only 3 pastures, and the RMIN, SH-RMIN, and GRNGOLD treatments were randomly assigned within that block. Steer BW gain was measured from November 5, 2004, to February 4, 2005 (91 d), and from November 15, 2005, to March 8, 2006, (113 d). During the YR1 grazing season, steers continued grazing until February 22, 2005, when the wheat reached the first-hollow stem stage of maturity, as is recommended in a dual-purpose winter wheat system (Redmon et al., 1996; Fieser et al., 2006a). However, due to low forage availability (the result of cumulative effects of wet weather and trampling of wheat by steers), steer growth performance after February 4, 2005, was not used in BW gain analysis in the YR1 data set.

Cattle

The Oklahoma State University Institutional Animal Care and Use Committee approved the use of animals and research procedures used in this study.

YR1. Two hundred fifty-three predominantly black, crossbred steers (initial BW 255 ± 25 kg) that originated from a single ranch in north central Nebraska (Ainsworth) grazed winter wheat pastures in YR1. All steers were shipped directly from the ranch of origin and had not been previously comingled with cattle of any other source. Within 24 h of arrival, all steers were weighed and vaccinated for infectious bovine rhinotracheitis, bovine virus diarrhea, parainfluenza 3, bovine respiratory syncytial virus (Titanium 5, Agri Laboratories Ltd., St. Joeseph, MO), as well as treated with an injectable dewormer (Ivomec, Merial Ltd., Duluth, GA). From arrival until turnout on wheat pasture, all steers were held in a drylot and fed Bermudagrass hay and a 40% CP, Deccox (Alpharma Inc., Fort Lee, NJ) containing supplement at the daily rate of 0.91 kg/steer. Steers were stratified by arrival BW and allotted to pastures to minimize differences in BW between pastures at the initiation of the experiment. All steers were weighed and implanted with Component E-S with Tylan (VetLife, West Des Moines, IA) on the day they were placed on wheat pasture (November 5, 2004). To minimize risk of bloat at turnout, the initial BW was taken when steers were full, and a 2% pencil shrink was used to determine initial BW. Subsequent BW measures were taken following an overnight withholding of feed and water on February 4 and 22, 2005. Eighteen steers (1 steer/pasture) were added on December 2, 2004, but were not included in BW gain determination. These additional steers were added to utilize the excess forage available before turn-out and during the early part of the grazing season, in accordance with forage clipping data (i.e., adjustments in stocking densities were made to maintain similar forage allowances for all pastures within a block). The weighted average stocking density for all pastures over the course of the 91-d experimental grazing period during YR1 was 1.74 steers/ha.

YR2. One hundred sixteen predominantly black, crossbred steers (initial BW = 287 ± 14 kg) that originated from a single ranch in northeast Colorado (Yuma) grazed winter wheat pastures in YR2. The cattle shipping, feeding, and vaccination protocol was the same as described previously for YR1. Steers were weighed full and implanted with Component E-S with Tylan (VetLife) at turnout (November 15, 2005). Initial BW was calculated with a 2% pencil shrink as described previously. Subsequent BW measures were taken on December 22, 2005, and February 10 and March 8, 2006, following an overnight withholding of feed and water. Originally, 155 steers were turned out on November 15, 2005, but 33 steers (approximately 2 steers/pasture) were removed on December 22, 2005, based on declining forage availability. Additionally, on February 10, 2006, two steers were removed from pastures 1, 9, and 18 based on clipping data indicating lower forage availability in these pastures than other pastures within their block. The weighted average stocking density for all pastures during the 113-d experimental grazing period of YR2 was 0.94 steers/ha.

Sample Collection and Preparation

Wheat forage mass was determined by hand-clipping forage to ground level inside 0.19-m^2 quadrants (10 random locations within each pasture). Clipping was done on 4 dates within each grazing season: October 28 and December 15, 2004, and January 25 and February 22, 2005, for YR1 and November 10 and December 14, 2005, and January 24 and March 7, 2006, for YR2. At collection, care was taken to ensure minimal soil contamination of the forage samples. Clipped samples were dried to a constant weight in a forced-air oven at 50°C and weighed for DM determination. Forage mass was calculated by taking the grams of DM per 0.19 m^2 from the clipped sample and extrapolating that to kilograms of DM on a per-hectare basis in each pasture. Forage allowance was calculated as kilograms of DM/steer and kilograms of DM/100 kg of BW. This was determined using the number and BW of steers in each pasture on the date of clipping or weigh date in closest proximity to the clipping date. The November 10, 2005, and March 7, 2006, forage samples were retained for characterization of forage quality. Forage samples were composited by pasture within clipping date. During each year, energy supplements and mineral mixtures were sampled weekly. All supplement and mineral mixture samples were composited monthy within each year and analyzed for monensin concentration at a commercial laboratory (Eurofins Scientific, Memphis, TN). At the end of each year, supplement samples were composited. Composited forage and supplement samples were ground to pass through a 2-mm screen in a Wiley mill (Thomas Scientific, Philidelphia, PA) for determination of DM, OM, CP, NDF, ADF, ether extract, neutral detergent insoluble CP, and acid detergent insoluble CP (**ADICP**), as well as macro- and microminerals. Total digestible nutrient value was determined according to the equations of Weiss et al. (1992).

Laboratory Analyses

Dry matter and ash content were determined by oven-drying at 100°C for 24 h, followed by ashing at 500°C for 6 h in a muffle furnace. A combustion method (Leco CN-2000, St. Joseph, MI) was used in accordance with AOAC (1996) to determine N content. Forage and supplement NDF, ADF, and ADL concentrations were determined sequentially, as described by Van Soest et al. (1991), without the addition of sodium sulfite, using an Ankom200 Fiber Analyzer and F57 filter bags (Ankom Technology, Macedon, NY). Neutral detergent insoluble CP and ADICP were determined by performing nonsequential NDF and ADF procedures and removing the residue from the filter bags and determining N concentration of the residue by the combustion method described above. Ether extract concentration was determined at a commercial laboratory (SDK Laboratories, Hutchinson, KS). Mineral content (Ca, P, Mg, K, S, Na, Zn, Fe, Mn, and Cu) of wheat forage, supplements, and mineral mixtures was also determined at a commercial laboratory (Servi-Tech Laboratories, Dodge City, KS).

Supplements and Mineral Mixtures

Ingredient and nutrient composition of the energy supplements (soybean hulls and GRNGOLD) are shown in Table 1. Rumensin 80 (Elanco Animal Health, Indianapolis, IN) was added to the GRNGOLD supplement to result in a target monensin concentration of 165 mg of monensin/kg of supplement on an as-fed basis. Actual analyzed concentration of monensin in the GRNGOLD supplement was 155 ± 4 mg of monensin/kg on an as-fed basis for YR1 and 150 ± 12 mg of monensin/kg in YR2. Formulated monensin concentration of RMIN was 1,785 mg of monensin/kg of mineral mixture (as-fed). Actual analyzed concentrations were 1,914 ± 225 and 1,680 ± 117 mg of monensin/kg of mineral mixture (as-fed) for YR1 and YR2, respectively. Because the analyzed monensin concentrations were considered to be within the analytical error for monensin determination, the formulated monensin concentrations from RMIN and GRNGOLD were used to calculate monensin intake for the RMIN, SH-RMIN, and GRNGOLD treatments.

Mineral composition of the mineral mixtures, soybean hulls, and GRNGOLD supplement is shown in Table 2. Mineral mixtures were fed in covered feeders (1 feeder per pasture), whereas energy supplements were fed in 3.7-m-long round-bottom feeders, with bunk space greater than 0.30 m/steer. Both mineral feeders and feed bunks were located near the water source in each pasture. Mineral mixture intake was determined weekly by weighing unconsumed mineral and adding fresh mineral mixture before returning the unconsumed mineral to the feeders.

Statistical Analyses

Individual steer growth performance measures were averaged by pasture (pasture = experimental unit) and analyzed as a randomized complete block design using the MIXED procedure (SAS Inst. Inc., Cary, NC), with pasture location within the field used as the blocking factor. The model included the main effect of treatment and used the Satterthwaite procedure to determine degrees of freedom. Due to the different environmental conditions between YR1 and YR2, each year was ana-

Table 1. Ingredient and nutrient composition of the energy supplements[1]

Item	Soybean hulls		GRNGOLD	
Ingredient composition,[2] %				
Soybean hulls	95.0		87.3	
Cane molasses	5.0		5.0	
Dicalcium phosphate	—		3.00	
Limestone	—		3.00	
Salt	—		1.25	
Magnesium oxide	—		0.25	
Copper sulfate	—		0.025	
Vitamin A-30,000	—		0.10	
Rumensin 80[3]	—		0.09	
	YR1		YR2	
Nutrient composition,[2] %	Soybean hulls	GRNGOLD	Soybean hulls	GRNGOLD
DM	91.0	92.3	90.9	92.2
OM	93.6	89.0	93.3	87.2
CP	14.1	12.8	13.3	12.6
NDF	58.7	55.1	61.7	56.6
ADF	48.2	41.6	47.1	42.9
ADL	4.1	3.8	4.0	3.8
EE[4]	2.2	1.9	2.2	1.8
NDICP[5]	2.9	2.8	3.3	3.3
ADICP[6]	1.1	0.9	1.1	0.9
TDN[7]	63.1	58.6	61.6	57.0
Monensin,[8] mg/kg	—	155 ± 4	—	150 ± 12

[1]Soybean hulls = soybean hulls fed at the rate of 1.81 kg/steer every other day; GRNGOLD = monensin-containing (165 mg of monensin/kg) energy supplement fed at the rate of 1.81 kg/steer every other day.
[2]All values expressed on a DM basis.
[3]Rumensin 80 (176 g of monensin/kg) added to result in a target monensin concentration of 165 mg of monensin/kg.
[4]EE = ether extract.
[5]NDICP = neutral detergent insoluble CP.
[6]ADICP = acid detergent insoluble CP.
[7]Calculated as described by Weiss et al. (1992).
[8]Monensin concentration analyzed on an as-fed basis.

lyzed independently using the following nonorthogonal contrast statements: 1) NC vs. MIN, 2) MIN vs. RMIN, 3) RMIN vs. average of SH-RMIN and GRNGOLD, and 4) SH-RMIN vs. GRNGOLD. Average daily gain least squares means were adjusted using a covariate ($P < 0.01$) of forage allowance on February 4, 2005, in YR1 (forage allowance at end of BW gain measures). Ending forage allowance was considered as a covariate during YR2 but was not used ($P = 0.44$). Forage allowance measures, nutrient concentrations, and supplement and mineral intakes are presented as means and SD without further statistical analysis.

Table 2. Mineral composition of the supplements[1]

	YR1				YR2			
Mineral	MIN	RMIN	Soybean hulls	GRNGOLD	MIN	RMIN	Soybean hulls	GRNGOLD
Ca, %	10.84	10.39	0.76	2.27	11.75	11.05	0.68	2.81
P, %	6.26	6.03	0.15	0.68	6.50	6.57	0.15	0.85
Mg, %	0.86	0.97	0.26	0.37	0.43	0.51	0.24	0.40
K, %	0.96	0.99	1.53	1.42	0.88	0.91	1.38	1.36
S, %	0.68	0.70	0.14	0.16	0.60	0.61	0.14	0.18
Na, %	10.13	9.83	0.02	0.51	9.18	9.28	0.01	0.49
Zn, ppm	3,961	4,710	46	44	2,958	3,078	42	47
Fe, ppm	5,290	5,227	661	885	4,332	4,479	612	1,090
Mn, ppm	6,166	6,627	40	55	2,083	2,474	37	67
Cu, ppm	899	1,438	5	45	767	817	5	79

[1]MIN = nonmedicated, free-choice mineral mixture; RMIN = free-choice mineral mixture with 1,785 mg of monensin/kg; soybean hulls = soybean hulls fed at 1.81 kg every other day; GRNGOLD = monensin-containing (165 mg of monensin/kg) energy supplement fed at 1.81 kg every other day. All values expressed on a DM basis.

Table 3. Monthly mean temperatures and total precipitation during the YR1 and 2 winter wheat growing seasons near Marshall, OK

	Mean temperature, °C			Total precipitation, mm		
Item	YR1	YR2	Normal[1]	YR1	YR2	Normal
August	25	27	27	100	262	66
September[2]	23	24	23	42	90	86
October	17	16	13	110	68	76
November	9	11	8	114	1	61
December	4	2	4	15	4	43
January	2	7	2	66	12	28
February	6	4	2	36	1	38
March	10	11	9	12	53	76
April	15	19	16	19	64	81
May	20	22	20	84	107	122
June	26	26	23	117	129	112
July	27	29	30	122	22	64

[1]Normal temperature and precipitation is the average from 1971 to 2000 for Marshall, OK (Logan Co., OK; Oklahoma Climate Data, http://climate.ocs.ou.edu/).
[2]Planting dates: September 3 and 4, 2004 and September 6 and 7, 2005.

RESULTS AND DISCUSSION

Forage Availability and Quality

Temperature and rainfall data for the 2 yr of this study, as well as normal temperatures and precipitation, are shown in Table 3. Monthly average temperature in each of the 2 yr was generally at or above the normal monthly average temperature. These 2 yr were drastically different concerning total precipitation. The first year was characterized by excessively wet conditions early in the growing season, whereas YR2 was one of the most significant drought seasons in Oklahoma history, with only 18 mm of precipitation from November through the end of February (most of the duration of the grazing season). In YR1, August, October, and November were particularly wet, with at least 100 mm of total precipitation in each month. However, the next 4 mo (remainder of grazing season) received only 129 mm of total precipitation.

Stocking rate, forage mass, and forage allowances are shown in Table 4. Forage mass averaged 849 kg of DM/ha during YR1 and just 644 kg of DM/ha in YR2. Rainfall before planting and following planting produced exceptional fall forage growth before turn-out in YR1. However, due to the cloudy and wet conditions, wheat growth was lethargic, and trampling due to wet soil conditions occurred, resulting in rapidly declining forage mass during YR1. Compounding this effect was that the wet conditions prevented timely gathering and removal of steers from pasture to reduce stocking rates and increase forage allowance. Therefore, forage allowance declined rapidly during this grazing season. The drought-like conditions that persisted from planting through cattle removal during YR2 prevented substantial growth of wheat forage during the grazing season. In contrast to YR1, we were able to remove steers in accordance with clipping data to maintain consistent forage allowances. Similar forage allowances were observed on average for the 2 yr (170 and 191 kg of DM/100 kg of BW for YR1 and YR2). Despite being able to manage forage allowance in YR2, neither year provided abundant available forage. Fieser et al. (2006b) found that peak individual steer performance (ADG) occurred at an average forage allowance of near 700 kg of DM/100 kg of BW, much above the forage allowances we were able to achieve during this 2-yr experiment.

Wheat forage nutrient composition from the beginning and end of the YR2 grazing season is shown in Table 5. Wheat was at stages 3 and 6 on Feekes growth scale (Large, 1954) at the time of the November and March clipping dates, respectively. Because of the low amount of available forage and the monoculture of wheat, steers had minimal opportunity for selective grazing. Therefore, despite the forage samples being whole plant, we think these samples provided a realistic estimation of diet quality. Crude protein declined from 28.6% in November to 22.8% in March. These values are typical of CP content of wheat forage, in which values of 25 to 30% are common (Horn, 1984). Our values are comparable at similar points in time with data reported by Reuter and Horn (2000) from before the grazing season and after approximately 100 d of grazing. All cell wall constituents (NDF, ADF, and ADL) increased numerically from the November to March clipping dates. With several cool-season grasses, Morrison (1980) found that both lignin and hemicellulose concentrations increased with advancing maturity. Also, our values are similar to cell wall component values reported by Horn (1984). No estimates of neutral detergent insoluble CP or ADICP were found in the literature for wheat forage. The calculated TDN values (67.2 and 62.5% for November and March, respectively) are less than reported by the beef cattle NRC (1996) for vegetative wheat forage (73% TDN) but are close to estimates for cool-season grasses in the dairy cattle NRC (2001; 66.6% TDN). Our measured TDN and CP values indicate a TDN:CP ratio of 2.3 and 2.7 for No-

Table 4. Standing forage DM and forage allowance during the 2004 to 2005 and 2005 to 2006 winter wheat grazing seasons

	Clipping date 2004 to 2005				
Item	October 28, 2004	December 15, 2004	January 25, 2005	February 22, 2005[1]	Average
Pastures, n	18	18	18	18	18
Stocking rate, steers/ha	1.65	1.77	1.65	1.65	1.74[2]
Forage mass, kg of DM/ha	1,506 ± 130	1,073 ± 316	566 ± 173	253 ± 66	849 ± 131
Forage allowance, kg of DM/steer	915 ± 79	605 ± 178	319 ± 97	156 ± 42	499 ± 72
Forage allowance, kg of DM/100 kg of BW	362 ± 32	—[3]	100 ± 27	50 ± 13	170 ± 15
	Clipping date 2005 to 2006				
	November 10, 2005	December 14, 2005	January 24, 2006	March 7, 2006	Average
Pastures, n	18	18	18	18	18
Stocking rate, steers/ha	1.11	0.87	0.83	0.83	0.94[2]
Forage mass, kg of DM/ha	619 ± 121	902 ± 152	498 ± 110	560 ± 108	644 ± 92
Forage allowance, kg of DM/steer	560 ± 108	816 ± 137	577 ± 142	676 ± 127	657 ± 91
Forage allowance, kg of DM/100 kg of BW	190 ± 38	258 ± 44	151 ± 36	165 ± 31	191 ± 27

[1]Steer performance measures were reported through February 4, 2005 due to insufficient forage after February 4, 2005.
[2]Weighted average stocking rate.
[3]No steer BW measure was taken to coincide with the December 15, 2004 clipping date.

Table 5. Nutrient composition of wheat forage at beginning (November) and end (March) of the 2005 to 2006 winter wheat grazing season

	Clipping date	
Nutrient[1]	November 2005[2,3]	March 2006[2,4]
DM, %	92.2 ± 1.0	93.5 ± 0.7
OM, %	86.4 ± 0.9	86.2 ± 2.4
CP, %	28.6 ± 0.5	22.8 ± 1.1
NDF, %	45.5 ± 1.4	50.0 ± 1.0
ADF, %	19.5 ± 1.9	23.7 ± 0.7
ADL, %	2.1 ± 0.2	2.9 ± 0.5
EE,[5] %	3.7 ± 0.1	3.2 ± 0.2
NDICP,[6] %	9.9 ± 0.8	8.9 ± 0.6
ADICP,[7] %	0.61 ± 0.15	0.70 ± 0.24
TDN,[8] %	67.2 ± 1.1	62.5 ± 3.4
Ca, %	0.55 ± 0.03	0.38 ± 0.02
P, %	0.22 ± 0.01	0.15 ± 0.02
Mg, %	0.33 ± 0.02	0.22 ± 0.01
K, %	3.22 ± 0.25	1.49 ± 0.16
S, %	0.31 ± 0.01	0.24 ± 0.01
Na, %	0.04 ± 0.02	0.04 ± 0.01
Zn, ppm	27 ± 2	23 ± 2
Fe, ppm	426 ± 75	1,016 ± 374
Mn, ppm	310 ± 52	254 ± 48
Cu, ppm	8.0 ± 0.7	5.7 ± 0.7

[1]All values expressed on a DM basis.
[2]n = 18 pastures per clipping date.
[3]Feekes growth scale 3.
[4]Feekes growth scale 6.
[5]EE = ether extract.
[6]NDICP = neutral detergent insoluble CP.
[7]ADICP = acid detergent insoluble CP.
[8]Calculated as described by Weiss et al. (1992).

vember and March, respectively. Based on the critical level of 7.0 determined by Moore et al. (1999), our values indicate a shortage of DE relative to CP.

All macrominerals measured declined (Ca, P, Mg, K, and S) or did not change (Na) in concentration from November to March. This pattern is consistent with Stewart et al. (1981), in which Ca, P, K, and Mg in winter wheat forage remained fairly constant or declined from October to March. Beck (1993) reported average mineral concentrations of 0.45% Ca, 0.31% P, 1.91% K, 0.26% Mg, 23 ppm Zn, 4.8 ppm Cu, and 0.20 ppm Se. Using the level 1 model of the beef cattle NRC (1996), a 287-kg Angus steer (similar BW and breed type to our steers at beginning of YR2) consuming 5.2 kg of wheat forage DM and gaining 1.0 kg daily has the following mineral requirements (relative to DMI): 0.64% Ca, 0.32% P, 0.10% Mg, 0.60% K, 0.04% Na, 0.15% S, 10 ppm Cu, 50 ppm Fe, 20 ppm Mn, and 30 ppm Zn. By comparing these requirements with our measured forage composition, all minerals are adequate without supplementation except Ca (–0.18%), P (–0.14%), Cu (–3 ppm), and Zn (–5 ppm). Because these requirements are expressed relative to DMI, if DMI is less than the estimated amount (5.2 kg of DMI), or ADG is greater than 1.0 kg, other mineral deficiencies could become evident.

Mineral Mixture and Supplement Intake

Intake of MIN is shown in Figure 1. Average daily intake of MIN was 193 g/steer during YR1 and 183 g/steer in YR2. During the last 4 wk of the YR1 grazing season, MIN was hand-fed daily at the rate of 181 g/steer. This was done to control increasing levels of MIN consumption, which had been increasing throughout

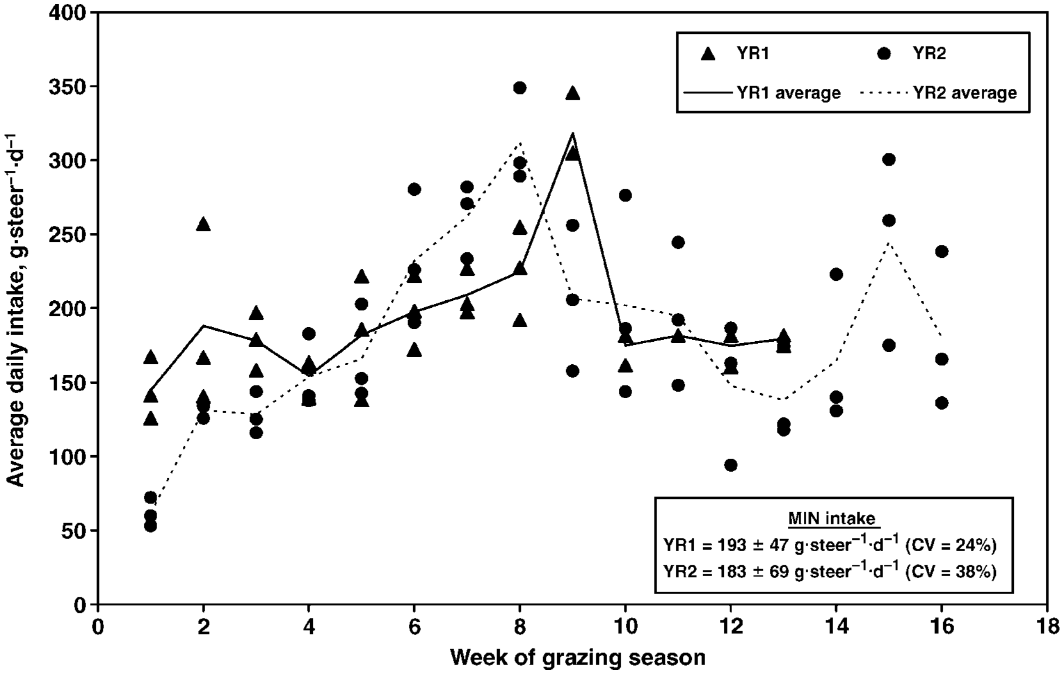

Figure 1. Average daily intake (mean ± SD) of free-choice, nonmedicated mineral mixture (MIN) as measured weekly during the 2004 to 2005 (YR1) and 2005 to 2006 (YR2) winter wheat grazing seasons.

the grazing season and topped 300 g·steer^{-1}·d^{-1} the previous week (wk 9). During YR2, steers had continuous access to MIN for the duration of the grazing season. In both years, MIN intake increased steadily from turnout until about 8 to 10 wk into the grazing season. Daily mineral mixture intake greater than 180 g/steer is likely more than economically feasible in production settings. Although intake of MIN was high, it is less than the 2-yr average daily intake of 227 g/steer reported by Gibson (2002) for a nonmedicated, free-choice mineral mixture. High MIN intake in our studies may be due to the location of the mineral feeder near the only water source in each pasture, as well as near a windbreak where steers spent time loafing. Additionally, pasture size ranged from 7.3 to 9.7 ha, so steers were in much closer proximity to mineral feeders than they might be in more extensive production environments.

Intake of RMIN is shown in Figure 2. For the monensin-containing mineral, intake was slightly greater in YR2 than YR1. Daily intake of RMIN averaged 72 g/steer in YR1 and 83 g/steer in YR2. Therefore, daily monensin intake averaged 129 and 147 mg/steer in YR1 and YR2, respectively. This is less than the target consumption of monensin from this mineral formulation, which was designed to provide 200 mg of monensin to each steer daily (112 g/steer of daily RMIN intake). Average daily intake of RMIN was generally greatest shortly after turn-out in each year and gradually declined through the remainder of the grazing season. The addition of monensin to the mineral mixture decreased daily intake of the mineral mixture by 121 g/steer in YR 1 (63% reduction) and 100 g/steer in YR2 (55% reduction). Steers on the RMIN treatment had the greatest variation in intake of the 3 treatments offered a free-choice mineral mixture with an average CV of 39% (43 and 35% in YR1 and YR2). Similar to our data, Gibson (2002) found that monensin included in a mineral mixture at 1,785 mg/kg decreased daily intake of the mineral mixture by 139 g/steer (62% reduction in intake).

Intake of RMIN when fed in conjunction with soybean hulls is shown in Figure 3. Average daily intake of RMIN was 90 g/steer in YR1 and 77 g/steer in YR2, when 1.81 kg of soybean hulls was also provided every other day. At these RMIN intakes, daily monensin intake averaged 161 and 137 mg/steer in YR1 and YR2, respectively. This indicates that when bunk-feeding soybean hulls every other day, intake for RMIN is essentially unchanged as compared with offering RMIN alone (18 g·steer^{-1}·d^{-1} difference in YR1 and 6 g·steer^{-1}·d^{-1} difference in YR2). However, the CV for monensin intake averaged 29.5% when soybean hulls were fed and 39.5% when RMIN was fed alone. Soybean hull intake is not shown graphically, because average daily intake did not deviate from the target of 0.91 kg/steer. The daily amount of soybean hulls fed was readily consumed in a single feeding bout.

Intake of the GRNGOLD supplement met our target daily intake of 0.91 kg/steer in each year. Based on visual observations, rate of consumption of GRNGOLD was slower than soybean hulls, but the entire amount of supplement offered was consumed on the same day, occasionally in more than a single feeding bout. With complete consumption of GRNGOLD, daily monensin intake was also at the target level of 150 mg/steer. This

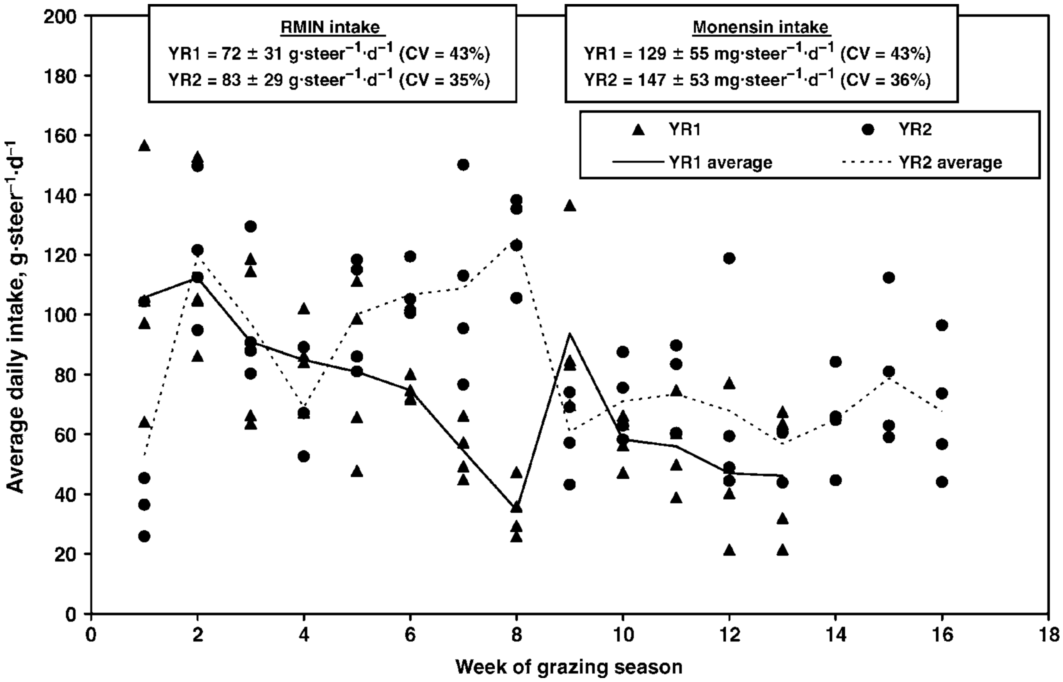

Figure 2. Average daily intake (mean ± SD) of free-choice, monensin-containing mineral mixture (RMIN; 1,785 mg of monensin/kg) as measured weekly during the 2004 to 2005 (YR1) and 2005 to 2006 (YR2) winter wheat grazing seasons.

is similar to the amount of monensin consumed in SH-RMIN (i.e., less than 13 mg of monensin·steer^{-1}·d^{-1} difference between SH-RMIN and GRNGOLD in either year). Therefore, similar intakes of supplemental energy and monensin were achieved whether fed as a single supplement or as separate packages. Fieser et al. (2003, 2005) fed energy supplements containing about 43% ground corn and 44% soybean hulls with increased

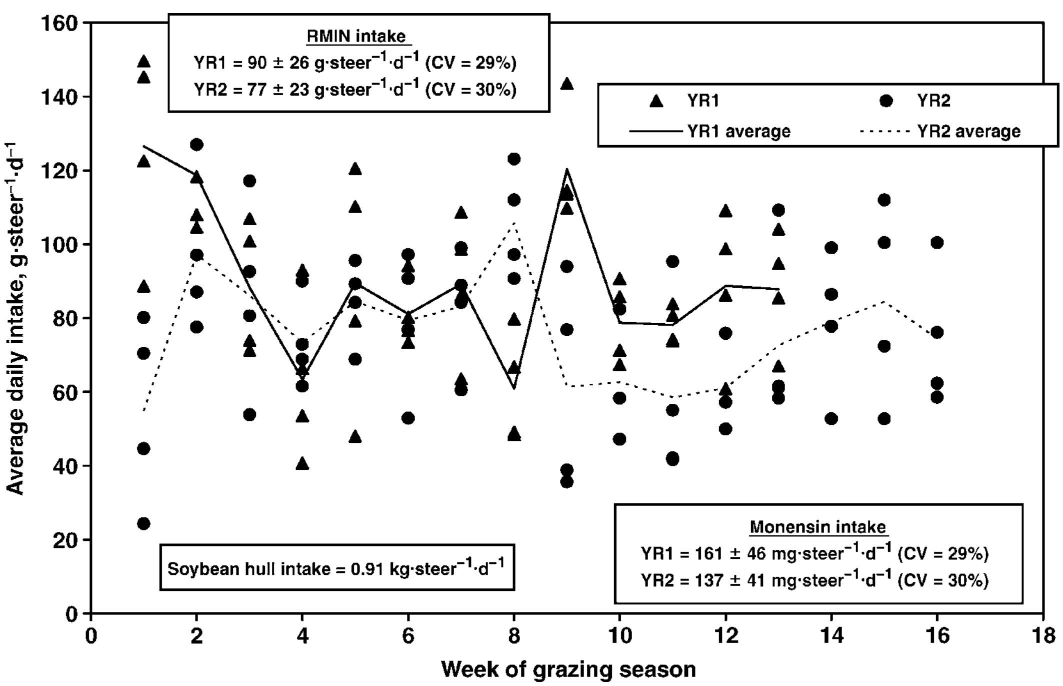

Figure 3. Average daily intake (mean ± SD) of free-choice, monensin-containing mineral mixture (RMIN; 1,785 mg of monensin/kg) when offered in conjunction with 1.81 kg of soybean hulls, as fed every other day during the 2004 to 2005 (YR1) and 2005 to 2006 (YR2) winter wheat grazing seasons.

Table 6. Steer growth performance and supplement conversions of steers grazing winter wheat pasture during the 2004 to 2005 and 2005 to 2006 winter wheat grazing season[1]

	Treatment[2]							Contrast[3]			
Item	NC	MIN	RMIN	SH-RMIN	GRNGOLD	SEM[4]	*P*-value[5]	NC vs. MIN	MIN vs. RMIN	RMIN vs. SH-RMIN and GRNGOLD	SH-RMIN vs. GRNGOLD
2004 to 2005											
Pastures, n	3	3	4	4	4						
Initial BW, kg	258	256	253	255	254	1.4					
Final BW, kg	304	305	320	327	325	8.9					
ADG, kg/steer	0.49	0.55	0.72	0.81	0.89	0.053	<0.01	0.38	0.03	0.05	0.24
Supplement conversion[6]				3.5	2.7						
2005 to 2006											
Pastures, n	3	3	4	4	4						
Initial BW, kg	287	288	287	286	287	2.5					
Final BW, kg	385	411	417	416	415	5.5					
ADG, kg/steer	0.87	1.09	1.15	1.15	1.13	0.048	<0.01	0.01	0.35	0.87	0.77
Supplement conversion[6]				14.7	20.5						

[1]Least squares means by treatment.
[2]NC = negative control; MIN = nonmedicated, free-choice mineral; RMIN = free-choice mineral mixture with 1,785 mg of monensin/kg; SH-RMIN = RMIN mineral mixture and soybean hulls fed at the rate of 1.81 kg/steer every other day; GRNGOLD = monensin-containing (165 mg of monensin/kg) energy supplement fed at the rate of 1.81 kg/steer every other day.
[3]Observed significance levels for comparison contrasts.
[4]Most conservative SEM.
[5]Observed significance level for the main effect of treatment.
[6]Calculated as kilograms of as-fed energy supplement per kilogram of additional gain compared with steers receiving MIN.

concentrations of monensin to decrease the amount of supplement fed as compared with the GRNGOLD. With monensin concentrations of 352 (Fieser et al., 2003) and 293 mg/kg of supplement (Fieser et al., 2005), supplement intakes averaged 89 and 95%, respectively, of the targeted amounts of 0.45 and 0.68 kg/d.

Steer Performance

Growth performance of steers is shown in Table 6. Initial BW of the steers was relatively large, and ADG during YR1 was substantially less than the 1.0 kg commonly observed for steers fed MIN at the Oklahoma State University Wheat Pasture Research Unit (Kaitibie et al., 2003). Treatment influenced ADG ($P < 0.01$) in both years. In YR1, MIN did not increase ADG ($P = 0.38$) as compared with the NC but did increase ADG ($P = 0.01$) by 0.22 kg in YR2. The increased ADG by MIN in YR2 is possibly due to correction of a slight mineral deficiency in wheat pasture as previously discussed. Because of the lower ADG in YR1, wheat forage alone may have adequately met the mineral requirements without MIN for the observed level of performance. A 2-yr wheat pasture study reported by Gibson (2002) also included the NC, MIN, and RMIN treatments. If data of that study are included with this study (i.e., combined 4-yr data set), MIN increased ADG ($P < 0.01$) of steers grazing wheat pasture from 0.71 to 0.82 kg (G. W. Horn; C. P. Gibson, Oklahoma State University, Stillwater; and B. G. Fieser, unpublished data).

Addition of monensin to the mineral mixture increased ($P = 0.03$) ADG by 0.17 kg (0.72 vs. 0.55 ± 0.053) in YR1 but did not influence ADG ($P = 0.35$) in YR2. In the study by Gibson (2002), addition of monensin to the mineral mixture increased ($P < 0.05$) ADG from 0.60 to 0.74 (±0.043) kg during the first year and from 1.16 to 1.22 (±0.02) kg during the second year. For the combined 4-yr data set, RMIN increased ADG ($P < 0.01$) by 0.10 kg (0.92 vs. 0.82 ± 0.017) as compared with MIN (G. W. Horn; C. P. Gibson, Oklahoma State University, Stillwater; and B. G. Fieser, unpublished data). Brazle and Laudert (1998) reported that a monensin-containing mineral mixture increased ($P < 0.05$) ADG of steers on native grass from 1.12 to 1.21 (±0.029) kg/steer as compared with a nonmedicated mineral mixture. These 2 studies (Brazle and Laudert, 1998; Gibson, 2002) and the current study suggest that adding monensin to a mineral mixture may be more effective when the achievable ADG under the given conditions is low or restricted. In contrast, when achievable ADG is greater (in excess of 1.0 kg/steer), indicative of greater forage and energy intake, the relative response to the addition of monensin to a mineral mixture is decreased.

Daily gains were increased ($P = 0.05$) by providing supplemental energy in addition to the monensin-containing mineral mixture (i.e., contrast of RMIN vs. SH-RMIN and GRNGOLD) in YR1; however, this contrast was not significant ($P = 0.87$) in YR2. An explanation for the lack of response to the additional energy as soybean hulls or GRNGOLD, which was predominantly soybean hulls, in YR2 could be an actual dilution of overall dietary energy intake due to supplementation. Because the calculated TDN value of the supplements was less than the calculated TDN of wheat forage (62.4, 57.8, and 64.9% average TDN for soybean hulls, GRNGOLD, and wheat forage, respectively), the supplements may have decreased overall dietary energy intake. However, the TDN of by-product feeds like soybean hulls is highly variable and often underestimated. Additionally, our calculated TDN for wheat forage is lower than other digestibility estimates for wheat forage (Reuter and Horn, 2000). Lippke et al. (2000) found that supplementing steers on wheat pasture with cottonseed hulls and cottonseed hulls plus corn decreased OM digestibility and did not increase OM intake. Cravey et al. (1992) reported substitution ratios for wheat pasture averaged 0.86 for high-starch and high-fiber monensin-containing energy supplements (i.e., each kg of supplement decreased forage DMI by 0.86 kg). In the studies conducted by Cravey et al. (1992), forage allowances were low and averaged 104 kg of DM/100 kg of BW. Fieser and Vanzant (2004) reported a substitution ratio of 0.61 for either cracked corn or soybean hulls for growing steers fed vegetative fescue hay (17.4% CP). The lack of a difference ($P > 0.24$) in ADG between steers that received SH-RMIN and GRNGOLD suggests that the method of delivery (separate packages vs. a single package) for energy, monensin, and mineral supplementation is unimportant.

Although not included in our contrasts, the GRNGOLD supplement increased ADG by 0.34 kg in YR1, as compared with MIN, but a similar response was not observed in YR2. In 3 of 4 studies reported by Horn et al. (2005), the monensin-containing energy supplements very consistently increased ADG of growing cattle on wheat pasture by about 0.18 kg as compared with MIN. Rouquette et al. (1982) reported that a monensin-containing ground corn supplement (220 mg of monensin/kg) fed at 0.91 kg/d to growing cattle on rye and ryegrass pastures increased ADG by 0.21 kg as compared with MIN. In our studies that lead to the GRNGOLD supplementation program, the energy supplements consisted of about 65% ground sorghum grain and 21% wheat middlings. A combination of energy feedstuffs may provide a more favorable synchrony concerning rates of ruminal starch, OM fermentation, or both, and the CP fractions of wheat forage. This may result in a more consistent BW gain response to supplementation as compared with a high-fiber commodity feedstuff like soybean hulls. Horn et al. (1995) supplemented growing cattle on wheat pasture with high-starch (79% ground corn) or high-fiber (47% soybean hulls and 42% wheat middlings) energy supplements, and type of supplement did not influence ($P > 0.45$) ADG. However, mean daily supplement consumption was 0.65% BW, which is much greater than the targeted intake for GRNGOLD.

Supplement Conversion

Supplement conversion (expressed as kg of as-fed supplement divided by kg of additional ADG compared with MIN) is shown in Table 6. Supplement conversions were excellent in YR1 and were 3.5 and 2.7 for SH-RMIN and GRNGOLD, respectively. Because of the much smaller ADG response to the energy supplements in YR2, these conversions were much greater. In previous work, conversions for the GRNGOLD supplement, containing about 65% ground sorghum grain and 21% wheat middlings and fed at the same rate as the current study, have been much more consistent and ranged from 4.4 to 5.2 (Horn et al., 2005). At similar supplement intakes to this study, calculated supplement conversions of 3.9 and 4.9, respectively, for 141 and 170 d grazing were observed by Rouquette et al. (1982). A modification of the GRNGOLD supplement in which the amount fed was cut in half (i.e., 0.91 kg every other day vs. 1.82 kg every other day, and monensin intake was similar to the current study) resulted in supplement conversion of 3.6 (Fieser et al., 2003). However, rate of consumption of the supplement was slowed, which would be of concern on days of inclement weather. Fieser et al. (2005) found that increasing daily monensin intake from 100 to 188 mg (target of 200) improved supplement conversion from 5.2 to 3.9. In 1 yr of the study reported by Horn et al. (1981), addition of 110 mg/kg of monensin to an energy supplement fed at a daily rate of 0.91 kg/head to light-BW heifers grazing wheat pasture decreased supplement conversion from 9.8 to 4.3. Additional data are needed relative to the effect of forage mass, allowance, or both on conversion of energy supplements fed to growing cattle on wheat pasture. However, in general, the data indicate that supplement conversion is improved as the amount of supplement fed is decreased and that the effect of monensin on supplement conversion is important in evaluating the economics of supplementation programs.

Delivery of efficacious amounts of technologies such as ionophores, antibiotics, and bloat-preventive compounds is a very real and important challenge in beef cattle grazing programs. Inherent with this challenge is development of specific supplementation programs that include amount and type of supplement to be fed. In this study, inclusion of monensin in a free-choice mineral mixture decreased intake of the mineral mixture by about 60%. Daily BW gain of RMIN steers was greater ($P < 0.05$) than MIN in YR1 (0.72 vs. 0.55 ± 0.053 kg/steer) but was not different ($P = 0.35$) in YR2. Three different delivery methods that included a free-choice monensin-containing mineral mixture, the same free-choice monensin-containing mineral mixture plus hand-fed soybean hulls (SH-RMIN), and a hand-fed monensin-containing, soybean hull-based energy supplement (GRNGOLD) resulted in monensin intakes of about 146 mg/d with very small differences for monensin intake among delivery methods. The absence of a difference ($P > 0.24$) in daily gain between steers that received SH-RMIN and GRNGOLD suggests that the method of delivery (separate packages vs. a single package) for energy, monensin, and mineral supplementation is not important. Relative cost of products, location, and accessibility of pastures, fuel costs, and opportunity cost for labor all influence decisions relative to method of delivery of technologies in grazing programs.

LITERATURE CITED

AOAC. 1996. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Beck, P. A. 1993. Development of a self-limited monensin-containing energy supplement for growing cattle on wheat pasture. MS Thesis. Oklahoma State Univ., Stillwater.

Brazle, F. K., and S. B. Laudert. 1998. Effect of feeding Rumensin in a mineral mixture on steers grazing native grass pastures. Pages 123–125 in 1998 Kansas State Cattlemen's Day Proc. http://www.oznet.ksu.edu/library/lvstk2/srp804.pdf Accessed Oct. 31, 2006.

Cravey, M. D., G. W. Horn, F. T. McCollum, and P. A. Beck. 1992. Effect of high-starch vs. high-fiber energy supplements on forage intake of steers grazing wheat pasture. J. Anim. Sci. 70(Suppl. 1):89. (Abstr.)

Fieser, B. G., G. W. Horn, J. T. Edwards, and E. G. Krenzer Jr. 2006a. Timing of grazing termination in dual-purpose winter wheat enterprises. Prof. Anim. Sci. 22:210–216.

Fieser, B. G., G. W. Horn, and J. R. Kountz. 2005. Effect of increasing levels of monensin in an energy supplement for cattle grazing winter wheat pasture. http://www.ansi.okstate.edu/research/2005rr/2005rr/18/18.htm Accessed Oct. 31, 2006.

Fieser, B. G., G. W. Horn, J. R. Kountz, and S. A. Schaefer. 2003. A modification of the Oklahoma Green Gold Supplementation Program: Supplement intake and performance of wheat pasture stocker cattle. http://www.ansi.okstate.edu/research/2003rr/01/01.htm Accessed Oct. 31, 2006.

Fieser, B. G., G. W. Horn, and E. G. Krenzer Jr. 2006b. Effects of planting date and forage allowance on steer growth performance and grain yield in a dual-purpose winter wheat system. Prof. Anim. Sci. 22:424–431.

Fieser, B. G., and E. S. Vanzant. 2004. Interactions between supplement energy source and tall fescue hay maturity on forage utilization by beef steers. J. Anim. Sci. 82:307–318.

Gibson, C. P. 2002. Mineral supplementation with or without ionophores and phosphorus accretion in growing beef cattle grazing winter wheat pasture. MS Thesis. Oklahoma State Univ., Stillwater.

Horn, F. P. 1984. Chemical composition of wheat pasture. Pages 47–54 in Natl. Wheat Pasture Symp. Proc. G. W. Horn, ed. Oklahoma Agric. Exp. Stn., Stillwater.

Horn, G. W. 2006. Growing cattle on winter wheat pasture: Management and herd health considerations. Vet. Clin. Food Anim. 22:335–356.

Horn, G. W., P. A. Beck, J. G. Andrae, and S. I. Paisley. 2005. Designing supplements for stocker cattle grazing wheat pasture. J. Anim. Sci. 83:E69–E78.

Horn, G. W., M. D. Cravey, F. T. McCollum, C. A. Strasia, E. G. Krenzer Jr., and P. L. Claypool. 1995. Influence of high-starch vs. high-fiber energy supplements on performance of stocker cattle grazing wheat pasture and subsequent feedlot performance. J. Anim. Sci. 73:45–54.

Horn, G. W., T. L. Mader, S. L. Armbruster, and R. R. Frahm. 1981. Effect of monensin on ruminal fermentation, forage intake, and weight gains of wheat pasture stocker cattle. J. Anim. Sci. 52:447–454.

Horn, G. W., and S. I. Paisley. 1999. Developments in the management and supplementation of stocker cattle on wheat pasture. Pages 48–54 in Proc. 1999 Plains Nutr. Counc. Spring Conf., San Antonio, TX. Texas A&M Res. Ext. Center, Amarillo.

Kaitibie, S., F. M. Epplin, G. W. Horn, E. G. Krenzer Jr., and S. I. Paisley. 2003. Dual-purpose winter wheat and stocker steer grazing experiments at the wheat pasture research unit, Marshall, Oklahoma. Bulletin B-816. Oklahoma Agric. Exp. Stn., Stillwater.

Large, E. C. 1954. Growth stages in cereals. Illustration of the Feekes scale. Plant Pathol. 3:128–129.

Lippke, H., T. D. A. Forbes, and W. C. Ellis. 2000. Effect of supplements on growth and forage intake by stocker steers grazing wheat pasture. J. Anim. Sci. 78:1625–1635.

Lusby, K. S., and G. W. Horn. 1991. Supplementation programs for high-intensity grazing systems and high-quality forages. A. Review. Prof. Anim. Sci. 7:43–48.

Moore, J. E., M. H. Brant, W. E. Kunkle, and D. I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility, and animal performance. J. Anim. Sci. 77(Suppl. 2):122–135.

Morrison, I. M. 1980. Changes in the lignin and hemicellulose concentrations of ten varieties of temperate grasses with increasing maturity. Grass Forage Sci. 35:287–293.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th ed. Natl. Acad. Press, Washington, DC.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Redmon, L. A., E. G. Krenzer Jr., D. J. Bernardo, and G. W. Horn. 1996. Effect of wheat morphological stage at grazing termination on economic return. Agron. J. 88:94–97.

Reuter, R. R., and G. W. Horn. 2000. Changes in growth performance of steers and nutritive value of wheat pasture from fall/winter grazing to graze-out. http://www.ansi.okstate.edu/research/2000rr/05.htm Accessed Oct. 25, 2006.

Rouquette, F. M., Jr., J. V. Davis, and M. J. Florence. 1982. Influence of monensin on gain of stocker calves grazing cool-season annual grasses. Pages 5–13 in Forage Research in Texas. Texas Agric. Exp. Stn., College Station.

Stewart, B. A., D. L. Grunes, A. C. Mathers, and F. P. Horn. 1981. Chemical composition of winter wheat forage grown where grass tetany and bloat occur. Agron. J. 73:337–347.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Weiss, W. P., H. R. Conrad, and N. R. St. Pierre. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. Anim. Feed Sci. Technol. 39:95–110.