THE EFFECTS OF MONENSIN AND MONENSIN-CONTAINING SUPPLEMENTS ON PERFORMANCE OF STEERS GRAZING WINTER WHEAT PASTURE

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Format of Dissertation

This Dissertation is presented in the Journal of Animal Science style and format, as outlined by the Oklahoma State University graduate college style manual. The use of this format allows the individual chapters to be suitable for submission to scientific journals. Two papers have been prepared from the data collected to partially fulfill the requirements for the Ph.D. degree. Each paper is complete with an abstract, introduction, materials and methods, implications, and literature cited section. These two papers are chapters III and IV.

Chapter I

Introduction

Wheat pasture is one of the most important forage resources in the southern Great Plains. Its importance is due to many factors, including the high forage quality that allows for exceptional ADG of stocker cattle grazing wheat, as well as a protein or energy supplement to dormant range or hay diets. Wheat forage is commonly grazed from approximately October or November, to early March (dual-purpose winter wheat) or as late as May if a grain crop is not desired. A popular ionophore, monensin sodium (trade name Rumensin®, Elanco Animal Health, Inc., Indianapolis, IN), has been shown to be effective in reducing bloat and improving ADG of stocker cattle grazing wheat pasture.

The goal of the research contained in this dissertation was to measure some the effects of monensin on site and extent of wheat forage digestion, as well as the evaluation of different delivery mechanisms for providing monensin to stocker cattle grazing wheat pasture. Chapter II provides a review of literature on intake and digestibility of wheat forage, and how supplements and monensin influence these variables. Additionally, an overview of the response to monensin-containing supplements on wheat pasture is included and attempts are made to find general trends in the data. Also, a novel analysis of two recent trials on wheat pasture is presented and discussed relative to mineral and monensin supplementation on wheat pasture. Chapter III investigates the effects of

energy and/or mineral supplements with and without monensin on supplement intake and conversion, and growth performance of steers grazing winter wheat pasture. Chapter IV investigates the effects of three levels of monensin on site and extent of forage digestion and utilization and rumen kinetics and fermentation. Chapter V provides a brief summary of the research reported in this dissertation.

Chapter II

Review of Literature

Introduction

Since 2001, between 1.8 and 3.7 million head of cattle grazed small grain pastures annually in Kansas, Oklahoma, and Texas (USDA-NASS, 2001 to 2007). Others have estimated that this number is much greater, with as many as 6 million head of cattle grazing wheat annually in the entire southern Great Plains region (Horn, 1984; Horn, 2006). Based on these numbers the importance of wheat pasture in the American beef cattle industry is obvious. It is a critical component in the staging of cattle in the feeding system, adding rapid gain to cattle outside the feedlot in preparation for fattening. Because of the high quality of wheat forage, it is a unique forage that poses special advantages and challenges. One advantage of wheat forage is its ability to sustain excellent ADG of stocker cattle and its occasional use as a protein supplement for cattle consuming lower quality forages. The primary health problem of stocker cattle grazing wheat pasture is frothy bloat. The effects of monensin on growth performance, intake and digestion, and metabolic disorders will be discussed.

Wheat Forage Composition and Quality

Forage quality can most accurately be assessed by the level of animal performance that is achieved when consuming a given forage. This premise is generally applied in situations where forage availability is not limiting and nutrients other than

protein and energy are supplied to correct known deficiencies. The ADG of cattle grazing wheat forage is a testament to its high quality, with ADG greater than 1.0 kg common with only mineral supplementation (Horn, 2006). The exceptional quality of wheat forage makes it unique compared with many forages. Wheat forage is generally high in CP, commonly ranging from 20 to 30 % (Horn, 1984; Croy, 1984; Reuter and Horn, 2000). Based on figures reported by Horn (1984) and Reuter and Horn (2000), the CP content of wheat forage is not static, but rather it is high early in the grazing season, decreases during the dormant phase in the middle of the winter, and then increases as the plant resumes growth in early spring. If followed to maturity, the forage portion of wheat declines in quality as grain is produced and the plant repartitions nutrients from stems and leaves into grain production. This quadratic shape to wheat forage CP is characteristic of many other nutrients in the wheat plant, including digestibility (measured in-vitro), NDF, and ADF (Horn, 1984; Reuter and Horn, 2000). Wheat forage is typically very digestible. In-vitro measures by Reuter and Horn (2000) suggest that wheat forage is upwards of 80 % digestible. Horn (1984) reported in-vitro digestibilities that differed in magnitude from Reuter and Horn (2000), but were still excellent with values in excess of 70 %.

Mineral content of wheat forage is also variable. Stewart et al. (1981) found that the macro minerals (Ca, P, K, Mg) either held constant or increased from December to March. In contrast to native range forages, or even perennial forage crops, wheat pastures are typically fertilized annually at planting and again later in the growing season if necessary. Because of the short term nature of the crop (annual wheat), fertilization schemes potentially impact the mineral content of wheat forage. Therefore, it is

recommended that actual mineral analyses be conducted on wheat forage that is to be grazed. This is probably a good management practice for other nutrients as well, especially in the case of formulating specific supplements for given locations and conditions.

Supplementation of Cattle Grazing Wheat Forage

Despite the high quality of wheat forage, and excellent ADG with cattle grazing wheat forage, supplementation of wheat forage is potentially beneficial to balance nutrients and improve efficiency of forage utilization. Hogan (1982) reported that when the digestible OM (DOM) to CP ratio (DOM:CP) was greater than 3, there is a need for additional energy to improve efficiency of ruminal ammonia utilization. A common DOM:CP for wheat forage would be 3.6 (assuming DOM = 80 % and CP = 22 %). Moore et al. (1999) approached this nutrient imbalance with slightly different variables. Moore et al. (1999) found that forage TDN:CP ratios less than 7 indicate a deficit of energy in relation to N. With a wheat forage TDN of 73 % (NRC, 1996) and CP of 22 %, wheat forage has a TDN:CP ratio of 3.3. Regardless of the approach taken, it is apparent that some form of supplemental energy is needed to better utilize the excess CP in wheat forage. For this reason, a great deal of research has been conducted to investigate the effects of energy supplementation on growth performance of cattle grazing winter wheat pasture (Horn et al., 2005; Horn, 2006).

Richardson et al. (1976) found that monensin had a protein sparing effect in concentrate diets. Bergen and Bates (1984) and Schelling (1984) also indicate that monensin can spare protein from degradation in the rumen, and allow more true feed N to reach the small intestine. This is one of the mechanisms by which monensin is believed

to improve efficiency when included in diets. Because of its potential for impacting N utilization, the effects of monensin inclusion in supplements for cattle grazing wheat pasture has been extensively examined. An overview of these results is presented later in this review.

As with most forages, the mineral profile of wheat forage is not in ideal balance for production. Horn (2006), using the mineral concentrations reported by Stewart et al. (1981), found that wheat pasture was marginally adequate for phosphorus and magnesium, excessive for potassium, and deficient for calcium (based on a 225 kg steer gaining 1.0 kg/d). For the less studied micro minerals, evidence suggests that copper should be included in wheat pasture mineral supplements as well (Horn, 2006). It is a good animal husbandry practice to provide a free-choice mineral supplement to cattle grazing wheat pasture. This supplement should be high in Ca, and relatively low in P and K. Mineral supplements also provide a means for delivery of feed additives such as monensin or poloxalene. A database presented later in this review will give an indication of the importance of feeding supplemental minerals to cattle grazing wheat pastures, as well as additional advantages that can be gained by including monensin in the mineral supplement.

Forage Intake

Many factors influence the amount of forage an animal will consume. Mertens (1994) posed the following question regarding forage intake: "Does intake determine animal performance (intake as an input) or does animal performance determine intake (intake as a response)?" Most likely forage intake is a convergene of these two

dichotomies. Therefore, when assessing forage intake, we must account for physiological animal factors, as well as physical and chemical composition of the plant material.

Animal Factors Affecting Forage Intake. Mertens (1994) discussed in great detail many non-forage factors that influence intake. One point of emphasis was that intake is regulated both in the short- and long-term. Short-term regulation involves mechanisms to initiate and cease meals, while long-term regulation of intake involves BW regulation and performance of the animal over its entire lifetime. Obviously, the culmination of many short-term signals leads to the long-term outcome. Citing numerous studies, mostly from the early 1970's, Mertens (1994) stated that over the long-term, animals will balance energy comsumed with energy expenditures in order to maintain relatively constant BWs. Evidence of this is that mature animals with low production requirements maintain a fairly constant BW, rather than gaining weight indefinitely. As a "safety buffer", animals have the capacity to store energy reserves in the form of glycogen and fat to be utilized when intake restrictions occur. As nutritionists, we formulate rations to meet long-term production goals, therefore, the long-term factors of intake are what we focus on. Mertens (1994) considered three mechanisms to be of greatest importance relative to non-forage factors controlling intake: physiological regulation, physical limitation, and psychogenic modulation.

Many animal factors contribute to the physiological regulation of intake. These factors include the species, sex, physiological state (maintenance, growth, pregnancy, and lactation), size, body shape, and health status (Mertens, 1994). Many of these factors are inputs in the NRC (1996) intake prediction models. Mertens (1994) indicated that physiological regulation of intake involves equilibrating energy input with the animal's

energy demand. Other factors must come into play to determine intake. Without any further qualification, an animal would continue to consume a given feedstuff indefinitely to match its energy needs. Obviously there is a physical limit to how much an animal can consume. For example, as energy demand increases with increasing milk production, a feed of higher energy content must be provided or maximal production cannot be achieved. Eventually, body energy reserves will be utilized and eventually other physiological processes, such as reproduction, will cease, so that nutrients can be used for essential metabolic functions. The concept of eating to meet energy demands is believed to be the dominanant response when feeding energy dense, concentrate-based rations, such as those fed in feedlots. These diets typically have high grain content and little physical bulk, allowing voluntary intake to be greater than would be expected with forages.

It is generally accepted that physical distention of the reticulorumen is the major factor limiting intake of forages (Campling and Balch, 1961; Balch and Campling, 1962; Allen, 1996). It is believed that while many forages are readily accepted by the animal, due to the low energy content and bulky nature of forages, animals are physically unable to consume and digest bulky forages at levels sufficient to achieve desirable levels of performance.

If ruminal fill or distention limits intake of a low energy, bulky feedstuff, the rate at which ruminal contents are passed through the rumen becomes vitally important for the initiation of another meal. A decrease in retention time is a result of increased particulate passage rate, which tends to increase with increases in feed intake (Owens and Goetsch, 1988; Allen, 1996). While rumen contents are comprised of both liquid and particulate

matter, the rate at which each fraction leaves the rumen is different (Owens and Goetsch, 1988). The liquid passage rate, generally referred to as “dilution rate”, ranges from 4 to 10 %/h. Mean particulate passage rates for roughages generally range from 1 to 6 %/h. An early indication of the relationship between passage rate and voluntary intake came from Campling et al. (1961). In their study, total tract retention time of stained particles decreased as daily intake of hay increased.

Wheat forage is of minimal physical bulk, and high in water content (Horn, 1984; Reuter and Horn, 2000). Therefore, physical bulk is likely not a major contributor to intake regulation of wheat forage. In this regard, wheat forage is likely most similar to a concentrate diet, in which energy balance factors contribute to regulating intake. Other authors have found that high quality pastures are similar to concentrate feeds and intake may be limited by nutrient balance (Fisher et al., 1990; Poppi et al., 1990). Horn et al. (1981) found that wheat forage intake averaged nearly 3.0 % BW. Branine and Galyean (1990) found that wheat forage intake ranged from 2.4 to 3.5 % BW throughout the grazing season. Supporting these high intakes are high passage rates. Branine and Galyean (1990) measured liquid dilution rates in excess of 10 %/h. Estimating the forage intake of free grazing animals is so difficult that all of the commonly used methods have limitations and consist of various compromises that may introduce error (Minson, 1990; Owens and Hanson, 1992). Horn et al. (1981) found that a factor contributing to the complication of measuring wheat forage intake is fecal ash contamination. Fecal ash content of steers grazing wheat pasture were in excess of 40 %, indicating a significant amount of soil consumed while grazing, and a need to express wheat forage intakes on an OM basis, rather than a DM basis (Horn et al., 1981).

Forge allowance influences how much wheat forage an animal will consume. Redmon et al. (1995) found that wheat forage intake declined rapidly as forage allowance fell below a plateau level (20 to 24 kg DM·100 kg BW^{-1}·d^{-1}. Fieser et al. (2006) found that ADG of steers declined rapidly below a plateau of around 700 kg DM/100 kg BW. Regardless of whether intake is an input or a response, these reports indicate that forage allowance is a major factor that influences wheat forage intake. However, it is unclear if this is an animal factor (animals cease grazing when the return of energy consumed is not greater than energy expended), or a plant factor of mass where forage mass influences grazing time.

The third intake regulation factor discussed by Mertens (1994) is psychogenic modulation. This is defined as the regulation of food intake involving the animal's behavioral response to inhibitory or stimulatory factors in the feed or feeding environment. While psychogenic responses probably play a vital role in the regulation of intake, the effects are difficult to quantify. Factors associated with the psychogenic regulation include such things as palatability of the feedstuff, social behaviors, or responses to external stimuli. An example of this is when an animal that appears to be extremely distended begins a meal when fresh feed is offered, despite the visual appearance that intake should have ceased.

Plant Factors Affecting Forage Intake. Because of the importance of physical fill and energy consumption on voluntary intake of forages, plant composition plays a critical role. Due to ease of measurement relative to animal factors, much effort has been directed at predicting intake based on forage composition. Blaxter et al. (1961) found that when feeding three different qualities of hay, voluntary intake decreased with

increasing crude fiber content. From similar studies, Van Soest (1965) also concluded that voluntary intake was inversely related to the fiber content of the forage. Van Soest (1965) showed that voluntary intake decreased quadratically with increasing cell wall content (NDF). This correlation was especially strong with grasses. Lippke (1980) found that DM and OM intakes were negatively correlated ($R^2 = 0.86$) with ADF content of the forage.

This relationship between fiber values and intake supports the idea that bulk density does not play a major role in intake regulation of wheat forage. Low levels of NDF and ADF in wheat forage (Reuter and Horn, 2000) agree with the previously mentioned high forage intakes, and are in agreement with the exceptional ADG observed in cattle grazing wheat pasture.

Effect of Monensin on Wheat Forage Intake. Bergen and Bates (1984) found that part of the mechanism by which monensin works is to reduce intake of the diet without sacrificing performance, thereby improving efficiency. However, that conclusion was based on grain-based diets. Monensin does not appear to affect forage intake of cattle grazing wheat pasture (Horn et al., 1981; Davenport et al., 1989, Branine and Galyean, 1990). Schelling (1984) suggested that depressed intake due to monensin is either not present or much more subtle in cattle on forage-based diets than high-concentrate diets.

Forage Digestibility

Forage Digestion in the Ruminant. As discussed with intake, forage digestion also relies on both animal and plant factors. Microbial activity in the rumen has a more direct influence on digestibility than on intake. Across a wide variety of forage types and maturities, the rumen is the major site of fiber digestion (Galyean and Owens, 1991).

After reviewing numerous studies, Merchen and Bourquin (1994) concluded that ruminal digestion is responsible for at least 90 % of total tract cellulose digestion. While the majority (60 %) of hemicellulose digestion takes place in the rumen (Merchen and Bourquin, 1994). The remainder of fiber digestion takes place postruminally, as essentially no fiber digestion takes place in the small intestine (Merchen and Bourquin, 1994).

Fermentation in the rumen is the result of microbial activity, which converts components of the diet to products that are useful (volatile fatty acids, microbial protein, B-vitamins) and useless or potentially harmful (CH_4, CO_2, ammonia, nitrate) to the host animal (Owens and Goetsch, 1988). The bacterial species responsible for digestion of roughages and concentrates differ, and have different optimal ruminal environments. One critical aspect of the rumen environment is the pH. Typically the rumen maintains a slightly acidic pH, in the range of 5.5 to 7.2 (Owens and Goetsch, 1988). Concentrate-based diets result in pH values on the low end of that range due to the large amount of fermentable material, while forage diets generally support pH values closer to the upper end of that range. Cellulolytic bacteria can be inhibited whenever the pH falls below 6.0 (Owens and Goetsch, 1988). In this regard, wheat forage is more similar to concentrates that forages. Rumen pH of cattle grazing wheat forage is typically around 6.0 (Davenport et al., 1989; Branine and Galyean, 1990).

Ruminants are able to derive energy from forage-based diets in the form of by-products of microbial digestion. According to Owens and Goetsch (1988), VFAs provide 50 to 85 % of the metabolizable energy used by the animal when consuming a forage

based diet. Typically, rumen pH and VFA concentrations are inversely related, i.e. low rumen pH indicates high VFA concentrations.

Another desirable product of microbial fermentation is microbial protein flowing out of the rumen and into the small intestine where it is metabolized. Maximizing the amount of microbial protein flowing out of the rumen will minimize the amount of microbial protein that is necessary to meet particular animal requirements. Maximization of microbial protein synthesis is also particularly important because it is a high quality protein, with a well-balanced amino acid profile (Merchen and Titgemeyer, 1992). Forages of lower digestibility will produce lower levels of microbial protein, because microbial production is a function of the amount of OM digested in the rumen (Merchen and Bourquin, 1994). Wheat forage has been reported to result in very high microbial efficiency, with Vogel (1988) reporting microbial efficiency values as high as 38.9 (g of bacterial N/kg of OM truly fermented it the rumen) in early spring. Beever et al. (1987) also reported high microbial efficiency values for a high quality forage (white clover), near 30 (g of bacterial N/kg of OM truly fermented it the rumen) for primary growth and regrowth.

Plant Factors Affecting Forage Digestibilty. The primary plant factors affecting forage digestibility are protein and the cell wall constituents. Van Soest (1965) concluded that chemical composition of the plant is much more closely related to digestibility than to voluntary intake. Lippke (1980) showed that as forages increased in physiological maturity the NDF and ADF fractions increased correspondingly. Merchen and Bourquin (1994) stated that this increase in plant maturity and fiber content is indicative of a reduction in leaf to stem ratio. In wheat forage, NDF and ADF increase in

the fall with advancing age of the plant (Horn, 1984). The slowing of growth during winter, coupled with continuous defoliation by grazing results in an increased proportion of stem, prior to an increase in wheat plant growth as temperatures rise in spring and stimulate tillering which reduces fiber again (Horn, 1984). Blaxter et al. (1961) found that apparent digestibility of forages decreased as crude fiber content increased. This negative relationship between fiber content and digestibility is widely accepted (Merchen and Bourquin, 1994).

Effect of Monensin on Wheat Forage Digestibility. The rumen is the primary site where monensin effects digestibility. Monensin generally does not effect in-vitro digestibility of wheat forage (Davenport et al., 1989; Branine and Galyean, 1990). In one trial reported by Horn et al. (1981), monensin had no effect on apparent wheat forage digestibility, and in the other trial monensin reduced OM digestibility by less than 2 %. Two of the most classic and consistent effects of monensin are reduced methane production and increased proportions of propionate in the rumen (Bergen and Bates, 1984; Schelling, 1984). Methane and CO_2 are useless products of microbial fermentation that serve as lost energy and propionate is the most energetically efficient VFA produced in the rumen (Owens and Goetsch, 1988). Monensin has been shown to reduce gas and methane production in wheat forage diets (Horn et al., 1981; Min et al., 2005). Horn et al. (1981) and Davenport et al. (1989) reported that monensin increases the molar proportion of propionate of cattle grazing wheat pasture. These two factors (reduced gas production and increased propionate) result in retention of more feed energy by the animal.

Effect of Monensin on Wheat Pasture Bloat

Frothy bloat is a major cause of mortality (2 to 3 %) in wheat pasture stocker cattle (Horn et al., 1977). The specific cause of wheat pasture bloat has not been identified (Horn, 2006). Min et al. (2005) suggest that dietary protein and low ruminal pH are critical factors in the etiology of wheat pasture bloat. Most of the research relative to wheat pasture bloat has focused on feed additives that reduce bloat, such as poloxalene and ionophores. Monensin has been shown to improve ADG of cattle grazing wheat pasture (Horn et al., 2005; Horn, 2006) and decrease incidence and severity of wheat pasture bloat (Grigsby, 1984; Branine and Galyean, 1990; Paisley and Horn, 1998). Often the only evidence of bloat on wheat pasture is a dead animal. Monensin appears to reduce the incidence of sub-clinical (or non-lethal) cases of bloat, which may result in more normal metabolic function and allow for normal intake and digestibility of wheat forage.

Overview of Monensin-Containing Supplements for Steers Grazing Winter Wheat Pasture

A large database was constructed of the known trials involving monensin supplementation of steers grazing wheat pasture. All studies were conducted at Oklahoma State University. The individual experiments date back to 1990, and include self-limiting, monensin-containing energy supplements, hand-fed, monensin-containing energy supplements, and monensin-containing mineral mixtures. The studies and the pertinent details of each are summarized in **Table 1**. Supplement intakes ranged from essentially zero (no energy supplement, mineral mixture intakes less than 0.2 $kg \cdot hd^{-1} \cdot d^{-1}$) to almost 2.25 $kg \cdot hd^{-1} \cdot d^{-1}$ for self-limiting energy supplements. Inclusion criteria for the

database included properly designed controls, generally a non-medicated mineral compared with a monensin-containing energy supplement. In some cases negative controls (no supplementation) were included, but studies were only included in the database if a positive control (free-choice mineral mixture) was also included. Energy supplement intake ranged from 0.40 to 2.28 $kg \cdot hd^{-1} \cdot d^{-1}$. Mineral mixture intake ranged from 45 to 236 $g \cdot hd^{-1} \cdot d^{-1}$, and was strongly influenced by monensin inclusion in the mineral mixture. For steers receiving monensin-containing supplements (either energy or mineral mixtures), monensin intake averaged 152 $mg \cdot hd^{-1} \cdot d^{-1}$, and ranged from 83 to 258 $mg \cdot hd^{-1} \cdot d^{-1}$. Daily gains were increased an average of 13.3 % by energy and/or mineral supplementation with monensin. Supplement conversion (kg of supplement/kg of additional ADG compared with positive control) averaged 13.7, but was highly variable (standard deviation = 15.7). However, the median value (where as many observations were above as below) was just 7.5, indicating the often excellent conversion of monensin-containing energy supplements on wheat pasture. Because of the production oriented nature of this database, further statistical analysis could not be performed due to the confounding nature of the treatments (lack of energy supplements without monensin and vice-versa within the same study). However, a scatter plot was constructed (**Figure 1**) to visualize the change in ADG (percent change in ADG compared with the non-medicated mineral mixture). **Figure 2** is the same data, but a surface plot was constructed using the G3GRID procedure of SAS (SAS Inst., Inc., Cary, NC). These figures provide a visual basis for evaluating the different supplementation programs. The smoothed surface plot (Figure 2) indicates that higher levels of monensin increase the improvement in ADG. Additionally, the highest increases in ADG appear to be at a

moderate level of energy supplement, around 0.91 kg·hd^{-1}·d^{-1}. However, caution must be exercised when evaluating this figure because of the confounded nature of the experiments.

Non-Medicated and Monensin-Containing Mineral Mixtures for Steers Grazing Winter Wheat Pasture

A four year database consisting of data collected by Gibson (2002) and data from Chapter III of this dissertation was constructed and analyzed to determine the effects of non-medicated and monensin-containing mineral mixtures on mineral mixture intake and growth performance of steers grazing winter wheat pasture. Pasture means from 4 experiments (2 years from Gibson (2002); 2 years from the present dissertation) were first combined to one data set, and observations for treatments besides the negative controls (no supplementation; NC), free-choice, non-medicated mineral mixture (MIN), and the free-choice, non-medicated mineral mixture with monensin added at a rate of 1,785 mg/kg (RMIN) were deleted. The NC and MIN treatments were represented in 14 pastures across the 4 experiments, while RMIN was represented in 16 pastures. This resulted in 148 steers on NC, 126 steers receiving MIN, and 143 steers receiving RMIN. Initial BW of steers across all 4 experiments was 254 ± 22 kg. All experiments were conducted at the Oklahoma State University Wheat Pasture Research Unit near Marshall, OK. The data were then analyzed using the MIXED procedure of SAS (SAS Inst., Cary, NC) with a model statement that included the main effect of treatment and the Satterthwaite procedure was used to determine degrees of freedom. For the data set combining all 4 experiments, the random statement included the effect of experiment and block nested in experiment. Protected ($P \leq 0.05$) Fisher's LSDs were used to separate

treatment LS means. Mineral mixture and monensin intakes are presented (**Table 2**) as raw means and standard deviations without further statistical analysis.

Addition of monensin to MIN reduced mineral mixture intake by 67% (from 209 to 68 $g \cdot steer^{-1} \cdot d^{-1}$), and by at least 100 $g \cdot steer^{-1} \cdot d^{-1}$ in each year. Averaged across the four experiments, monensin intake from RMIN was 121 $mg \cdot steer^{-1} \cdot d^{-1}$.

The free-choice mineral mixtures had an effect ($P < 0.01$) on ADG **(Table 3).** Across these four separate experiments, MIN increased ($P < 0.01$) ADG by 0.11 kg/steer (15 % increase) compared with NC. The addition of monensin to the mineral mixture (at 1,785 mg/kg) further increased ($P < 0.01$) ADG by 0.10 kg/steer (12 % increase) compared with MIN. Therefore, the additional ADG realized when offering a free-choice, monensin-containing mineral as compared with no supplement was 0.21 kg/steer (30 %). This increase in ADG was even more impressive given that mineral intake was reduced by two-thirds with monensin. These data indicate that providing supplemental minerals free-choice to steers grazing wheat pasture improves performance. The degree to which ADG is improved is dependent on the mineral content of the forage and the amount of available forage to sustain a given level of ADG. The effects of monensin appear to act independent of this possible correction in mineral balance, as ADG is improved by the same amount above MIN, that MIN improved ADG compared with NC. Additionally, this data set shows that despite the variability encountered in wheat pasture grazing from year to year (lack of difference in ADG in 2004-2005), mineral and monensin supplementation increased ADG during most years.

Conclusions

Wheat forage is a tremendous forage resource that is unique among forages. However, the high quality nature of wheat pasture does make its use challenging. In many regards, the digestion of wheat forage is more similar to concentrates than forages. Despite its high quality, supplementation of wheat pasture with energy sources, mineral mixtures, and monensin has improved performance of cattle grazing winter wheat forage. Mineral supplementation appears to be critical to balancing a wheat forage diet and allowing for optimal growth. Additonally, mineral supplements make an ideal carrier for monensin and other additives because of their ease of handling and regular intake. Despite the negative effect that monensin has on intake of mineral mixtures, the improvement in ADG from monensin appears to be additive to that of the non-medicated mineral mixtures. All of the individual effects of monensin, such as increased forage digestibility, reduced methane loss, increased ruminal propionate concentrations, and reduced incidence and severity of bloat work in concert to produce the consistent improvements in ADG of cattle on wheat pasture.

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Table 1. Effects of energy, mineral, and monensin supplementation on ADG and supplement conversions

Reference	Treatments[1]	Energy Supp. Intake[2]	Mineral Mixture Intake[3]	Monensin Intake[4]	ADG, kg	Delta ADG, kg[5]	Delta ADG, %[6]	Supp. Conversion[7]
Horn et al., 1990	MIN	·	54	0	0.80	·	·	·
	Energy + Monensin	1.65	·	258	1.04	0.24	30.1	6.49
Horn et al., 1992	MIN	·	95	0	1.10	·	·	·
	Energy + Monensin	1.47	·	244	1.32	0.22	19.8	4.44
Beck et al., 1993	MIN	·	109	0	1.05	·	·	·
	Energy + Monensin	0.91	·	150	1.25	0.20	19.5	4.44
Horn et al., 1995 (Exp. 1)	MIN	·	N/A	·	0.97	·	·	·
	Starch-based Energy + Monensin	1.91	·	168	1.00	0.03	2.8	70.10
	Fiber-based Energy + Monensin	1.94	·	170	1.07	0.10	10.3	19.44
	Fiber-based Energy + Monensin (Free-choice)	2.26	·	199	1.02	0.05	5.1	45.23
Horn et al., 1995 (Exp. 2)	MIN	·	N/A	0	0.89	·	·	·
	Energy + Monensin	1.76	·	155	1.07	0.19	21.0	9.46
Horn et al., 1995 (Exp. 3)	MIN	·	N/A	0	0.99	·	·	·
	Starch-based Energy + Monensin	1.08	·	95	1.11	0.12	12.4	8.81
	Fiber-based Energy +	1.66	·	146	1.16	0.17	17.4	9.63

Table 1 cont.

	Monensin							
Paisley and Horn, 1996	Energy	2.28	·	0	1.36	·	·	·
	Energy + Monensin	0.65	·	108	1.41	0.05	3.7	·
Horn et al., 1997	MIN	·	N/A	0	1.04	·	·	·
	Milo + Monensin	0.93	·	124	1.09	0.06	5.7	15.85
	Midds/Hulls + Monensin	1.06	·	140	1.07	0.04	3.5	29.13
Paisley et al., 1998	MIN	·	136	0	1.15	·	·	·
	Energy + Monensin	0.83	·	183	1.33	0.18	15.4	4.69
Gibson, 2002 (Year 1)	NC	·	·	0	0.55	·	·	·
	MIN	·	213	0	0.60	0.05	·	·
	RMIN	·	45	83	0.74	0.14	22.6	·
Gibson, 2002 (Year 2)	NC	·	·	0	1.04	·	·	·
	MIN	·	236	0	1.16	0.12	·	·
	RMIN	·	68	125	1.23	0.07	5.9	·
Fieser et al., 2003	MIN	·	132	0	1.33	·	·	·
	Energy + Monensin	0.40	·	143	1.45	0.11	8.5	3.56
Fieser et al., 2005 (early period)	MIN	·	122	0	1.18	·	·	·
	Energy	0.68	·	0	1.28	0.10	8.9	6.52
	Energy + Monensin	0.68	·	100	1.37	0.20	16.6	3.49
	Energy + Monensin	0.68	·	184	1.36	0.19	15.8	3.66

Table 1 cont.

Fieser et al., 2005 (late period)	MIN	·	195	0	1.00	·	·	·
	Energy	0.68	·	0	1.09	0.09	9.1	7.50
	Energy + Monensin	0.68	·	100	1.05	0.05	5.5	12.50
	Energy + Monensin	0.66	·	194	1.13	0.13	13.2	5.03
Fieser et al., 2007 (Year 1)	NC	·	·	0	0.49	·	·	·
	MIN	·	195	0	0.55	·	·	·
	RMIN	·	73	129	0.72	0.11	19.8	·
	Energy + RMIN	0.91	91	160	0.81	0.14	25.6	6.45
	Energy + Monensin	0.91	·	150	0.89	0.21	38.0	4.35
Fieser et al., 2007 (Year 2)	NC	·	·	0	0.87	·	·	·
	MIN	·	186	0	1.09	·	·	·
	RMIN	·	82	146	1.15	0.22	5.8	·
	Energy + RMIN	0.91	77	137	1.15	0.06	5.8	14.29
	Energy + Monensin	0.91	·	150	1.13	0.05	4.6	18.18
Average[8,9]		1.14	124	152			13.3	13.7
Standard Deviation		0.55	60	42			8.9	15.7
Minimum		0.40	45	83			2.8	3.5
Maximum		2.28	236	258			38.0	70.1
Median		0.91	109	148			11.3	7.5

[1]MIN = free-choice, non-medicated mineral mixture; Energy + Monensin = monensin-containing energy supplement, generally corn, milo, wheat middling, or soybean hull based; NC = negative control, no supplemental nutrients; RMIN = monensin-containing free-choice mineral mixture.
[2]$kg \cdot hd^{-1} \cdot d^{-1}$.

Table 1 cont.

[3]$g \cdot hd^{-1} \cdot d^{-1}$.
[4]$mg \cdot hd^{-1} \cdot d^{-1}$.
[5]Change in ADG compared with positive control (MIN).
[6]Change in ADG expressed as a percentage of the positive control (MIN).
[7]Supplement Conversion = kg of as-fed supplement/kg of additional gain compared with MIN.
[8]Average ADG of MIN = 0.98.
[9]Monensin intake of monensin-containing supplements.

Table 2. Intake of free-choice mineral mixtures with and without monensin, and monensin intake from the monensin-containing mineral of steers grazing winter wheat pasture in 4 separate years and overall[1]

Year	MIN[2]	RMIN[2]	Monensin[3]
2000-01[5]	213 ± 50	45 ± 9	83 ± 17
2001-02[5]	236 ± 59	68 ± 9	125 ± 16
2004-05[6]	195 ± 14	73 ± 14	129 ± 22
2005-06[6]	181 ± 27	82 ± 9	148 ± 18
Combined	209 ± 45	68 ± 18	121 ± 29

[1]means ± SD
[2]MIN = non-medicated, free choice mineral mixture; RMIN = free-choice mineral mixture with 1,785 mg monensin/kg; MIN and RMIN intake $g \cdot steer^{-1} \cdot d^{-1}$
[3]Monensin intake from RMIN, $mg \cdot steer^{-1} \cdot d^{-1}$.
[4]from Gibson (2002).
[5]from Fieser et al. (2007).

Table 3. Effect of mineral supplementation and mineral supplementation with monensin on ADG of steers grazing winter wheat pasture in 4 separate years and overall[1]

Year	NC[2]	MIN[2]	RMIN[2]	SEM[3]	P-value[4]
2000-01[5]	0.31[b]	0.41[ab]	0.54[a]	0.060	0.04
2001-02[5]	1.09[c]	1.18[b]	1.23[a]	0.012	< 0.01
2004-05[6]	0.56	0.60	0.75	0.085	0.09
2005-06[6]	0.86[b]	1.09[a]	1.15[a]	0.043	0.01
Combined	0.71[c]	0.82[b]	0.92[a]	0.173	< 0.01

[1]lsmeans for each individual year and combined.
[2]NC = negative control; MIN = non-medicated, free choice mineral; RMIN = free-choice mineral mixture with 1,785 mg monensin/kg.
[3]n = 12 for Gibson, 2002; n = 10 for Fieser et al., 2007.
[4]Observed significance level for the main effect of treatment.
[5]calculated from data of Gibson, 2002.
[6]calculated from data of Fieser et al., 2007.
[a,b,c]Means within a row with different superscripts differ (P < 0.05).

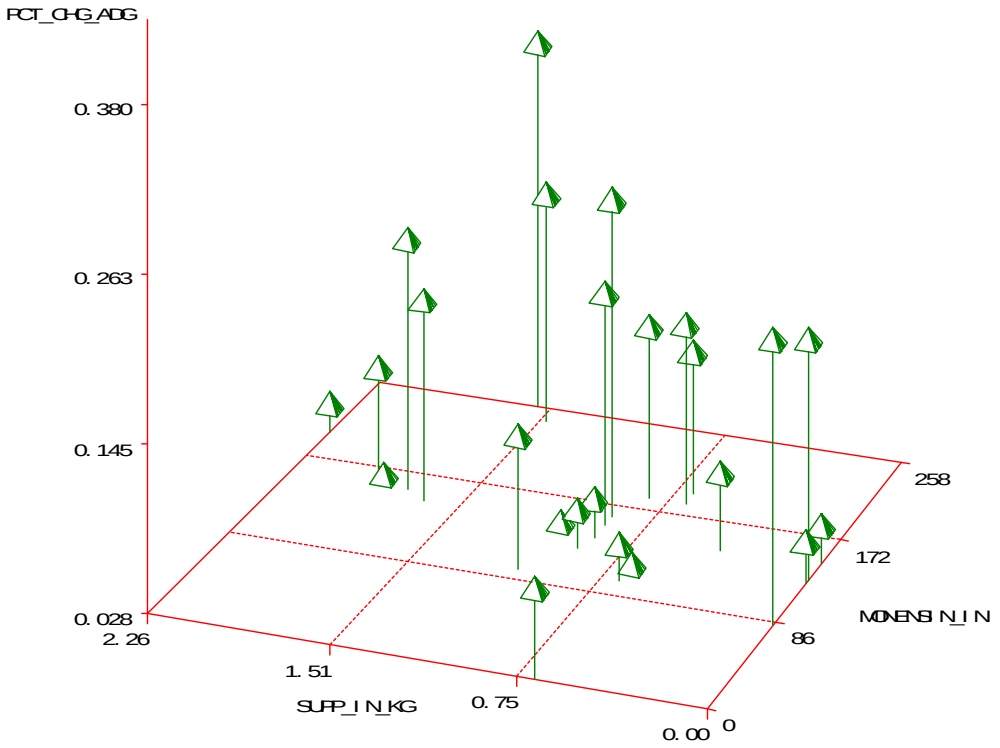

Figure 1. Scatter plot of 16 trials showing the percent change in ADG compared with the control, in which a monensin-containing supplement was fed to cattle grazing wheat pasture. PCT_CHG_ADG = percent change in ADG; SUPP_IN_KG = amount of energy supplement consumed (kg·head^{-1}·d^{-1}; 0 SUPP_IN = mineral supplement); MONENSIN_IN = daily monensin intake (mg·head^{-1}·d^{-1}).

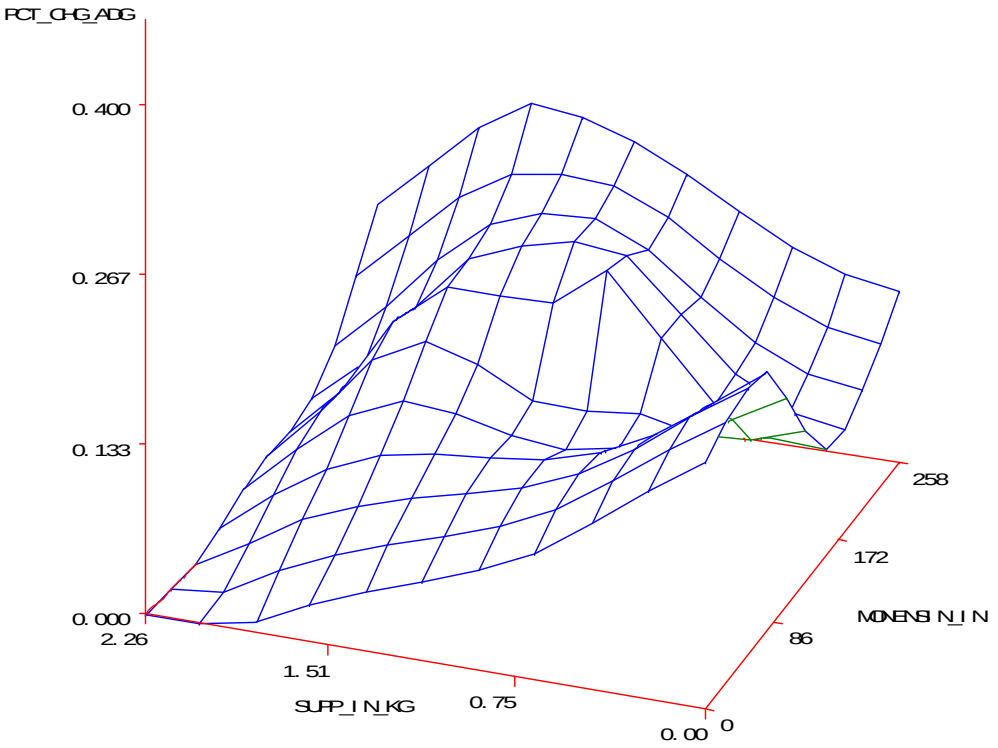

Figure 2. Smoothed surface plot of 16 trials showing the percent change in ADG compared with the control, in which a monensin-containing supplement was fed to cattle grazing wheat pasture. PCT_CHG_ADG = percent change in ADG; SUPP_IN_KG = amount of energy supplement consumed (kg·head^{-1}·d^{-1}; 0 SUPP_IN = mineral supplement); MONENSIN_IN = daily monensin intake (mg·head^{-1}·d^{-1}).

Chapter III

Effects of Energy and/or Mineral Supplementation in Combination with Monensin on Performance of Steers Grazing Winter Wheat Pasture

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ABSTRACT: A 2-yr study was conducted during the 2004-2005 (**YR1**) and 2005-2006 (**YR2**) winter wheat grazing seasons to determine the effects of different supplementation strategies and delivery methods on supplement intake and growth performance of steers grazing winter wheat pasture (YR1: n = 253, initial BW 255 ± 25 kg; YR2: n = 116, initial BW 287 ± 14 kg). Five treatments were 1) negative control (**NC**), no supplemental nutrients; 2) free-choice, non-medicated mineral (**MIN**); 3) free-choice, medicated mineral with 1,785 mg monensin/kg mineral mixture (**RMIN**); 4) RMIN and soybean hulls (**SH/RMIN**); 5) a soybean hull-based energy supplement containing 165 mg 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 between 129 and 161 mg monensin/steer on average, while GRNGOLD provided 150 mg

monensin/day. Compared to 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 MIN 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 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 was excellent in YR1, resulting in an additional 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

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 6-7 million cattle grown on wheat pasture annually. 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, and(or) bloat preventatives, 3) substitute for forage to increase stocking rate or stretch available forage supplies; and 4) enhance cattle management (Lusby and Horn, 1991; Horn and Paisley, 1999; Horn et al., 2005; Horn, 2006). Because of the large amounts of rumen degradable N in wheat forage

and to decrease the incidence/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 higher fuel and labor costs, our recent 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 with regard to supplement intake and steer growth 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 an energy commodity feedstuff (soybean hulls) was investigated.

Materials and Methods

Study Site and Treatments

One hundred forty ha of clean-tilled winter wheat at the Oklahoma State University Wheat Pasture Research Unit near Marshall, OK (OSUWPRU) was divided into 18 pastures during the winter wheat grazing seasons of 2004-2005 (**YR1**) and 2005-2006 (**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 prior to planting according to soil test results. Nitrogen, P, and K were applied in amounts for production goals of 3360 kg of forage DM/ha and a 3360 kg/ha wheat grain crop. Five treatments were: (1) negative control (**NC**), no mineral or any other supplement; (2) free-

choice non-medicated mineral (**MIN**[1]); (3) free-choice, medicated mineral containing 1,785 mg monensin/kg (**RMIN**); (4) RMIN and soybean hulls (**SH/RMIN**); (5) a monensin-containing, energy supplement formulated to the Oklahoma Green Gold supplement specifications containing 165 mg monensin/kg (**GRNGOLD**; Horn et al., 2005; Horn, 2006). 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 in pelleted form (0.5 cm pellet). Each year 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 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 (result of cumulative effects of very wet weather and tromping of wheat by steers), steer growth performance after February 4, 2005 was not used in BW gain analysis in the YR1 dataset.

Cattle

YR1. Two hundred fifty-three predominantly black, crossbred steers (initial BW 255 ± 25 kg) originating from a single ranch in north-central Nebraska (Ainsworth), grazed winter wheat pastures in YR1. All steers were shipped directly from the ranch of

[1] Mineral mixtures in 2004-2005 and 2005-2006 (both MIN and RMIN) were manufactured by ADM Alliance Nutrition, Inc., Quincy, IL, and North American Nutrition Companies, Inc., Lewisburg, OH, respectively.

origin and had not been previously co-mingled 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 de-wormer (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 weight 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 prior to 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) originating from a single ranch in northeast Colorado (Yuma), grazed

winter wheat pastures in YR2. 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, West Des Moines, IA) 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 g DM per 0.19 m^2 from the clipped sample and extrapolating that to kg DM on a per hectare basis in each pasture. Forage allowance was calculated as kg DM/steer and kg DM/100 kg 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, EE, neutral detergent insoluble CP (NDICP), and acid detergent insoluble CP (ADICP), as well as macro- and micro-minerals. 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 non-sequential 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) is 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 monensin/kg supplement on an as-fed basis (AF). Actual analyzed concentration of monensin in the GRNGOLD supplement was 155 ± 4 mg monensin/kg on an as-fed basis for YR1, and 150 ± 12 mg monensin/kg in YR2. Formulated monensin concentration of RMIN was 1,785 mg monensin/kg mineral mixture (AF). Actual analyzed concentrations were 1,914 ± 225 and 1,680 ± 117 mg monensin/kg mineral mixture (AF) 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 (one 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 prior to returning to 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 of SAS (SAS Inst., 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 very different environmental conditions between YR1 and YR2, each year was analyzed independently using the following non-orthogonal 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 not used ($P = 0.44$). Forage allowance measures, nutrient concentrations, and supplement and mineral intakes are presented as means and standard deviations without further statistical analysis.

Results and Discussion

Forage Availability and Quality

Temperature and rainfall data for the 2 years of this study, as well as "normal" temperatures and precipitation, are shown in **Table 3.** Monthly average temperature in each of the 2 years was generally at or above the "normal" monthly average temperature. These 2 years were drastically different with regard to total precipitation. The first year (YR1) was characterized by excessively wet conditions early in the growing season, while 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 months (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 DM/ha during YR1, and just 644 kg DM/ha in YR2. Rainfall prior to planting and following planting produced exceptional fall forage growth prior to 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 two years (170 and 191 kg DM/100 kg 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 DM/100 kg BW, much above the forage allowances we were able to achieve during this two-year 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 Feeke's 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 selectivity grazing. Therefore, despite the forage samples being "whole plant" we feel 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 days 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 NDICP 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 November and March, respectively. Based on the critical level of 7.0 determined by Moore et al. (1999), our values indicate a shortage of digestible energy relative to CP.

All macro-minerals 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/d 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 DMI), or ADG is greater than 1.0 kg/steer, other mineral deficiencies could exist.

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 weeks 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 the grazing season and topped 300 $g \cdot steer^{-1} \cdot d^{-1}$ the previous week (week 9). During YR2, steers had continuous access to MIN for the duration of the grazing season. In both years, MIN intake increased steadily from turn-out until about 8 to 10 weeks into the grazing season. Daily mineral mixture intake greater than 180 g/steer is likely more than economically feasible in production settings. While 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 non-medicated, 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 wind break

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 monensin to each steer daily (112 g/steer daily RMIN intake). Average daily intake of RMIN was generally greatest 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 three 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 $g \cdot steer^{-1} \cdot d^{-1}$ difference

in YR1 and 6 g·steer^{-1}·d^{-1} difference in YR2). However, the coefficient of variation 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 is similar to the amount of monensin consumed in RMIN/SH (i.e., less than 13 mg 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 and 2005) fed energy supplements containing about 43% ground corn and 44% soybean hulls with increased concentrations of monensin in order 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 OSUWPRU (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 two-year wheat pasture study reported by (Gibson, 2002) also included the NC, MIN, and RMIN treatments. If data of that study is included with this study (i.e., combined four-year data set), MIN increased ADG ($P < 0.01$) of steers grazing wheat pasture from 0.71 to 0.82 kg (Horn et al., unpublished data).

Addition of monensin to the mineral mixture increased ($P = 0.03$) ADG by 0.17 kg 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 ADG ($P < 0.05$) by 0.14 kg (from 0.38 to 0.52 kg/steer) during the first year, and by 0.06 kg (from 1.16 to 1.22 kg/steer, $P <0.05$) during the second year. For the combined four-year data set, RMIN increased ADG by 0.10 kg ($P < 0.01$) as compared with MIN (Horn et al., unpublished data). Brazle and Laudert (1998) reported that a monensin-containing mineral mixture increased ($P < 0.05$) ADG of steers on native grass by 0.09 kg (from 1.12 to 1.21 kg/steer) as compared with a non-medicated mineral mixture. These three studies (Brazle and Laudert, 1998; Gibson, 2002; and the present 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 higher (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 byproduct feeds like soybean hulls is highly variable and often under estimated. 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 DM/100 kg 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 not important.

While 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 three out 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 monensin/kg) fed at a level of 0.91 kg/d to growing cattle on rye/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 with regard to rates of ruminal starch and(or) OM fermentation and the crude protein fractions of wheat forage. This may result in a more consistent weight 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 higher 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 higher. 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 present 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 days 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 (target of 200) improved supplement conversion from 5.2 to 3.9. In one year 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 weight heifers grazing wheat pasture decreased supplement conversion from 9.8 to 4.3. Additional data is needed relative to the effect of forage mass and(or) allowance 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.

Implications

Delivery of efficacious amounts of technologies such as ionophores, antibiotics, bloat-preventive compounds, etc. is a very real and important challenge in beef cattle

grazing programs. Inherent with this challenge is the development of specific supplementation programs which include amount and type of supplement to be fed. In this study, inclusion of monensin in a free-choice mineral mixture reduced intake of the mineral mixture by about 60%, while increasing ADG by an average of 0.12 kg/steer. 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 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. 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.

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Table 1. Ingredient and nutrient composition of energy supplements

Item	Soybean hulls[1]	GRNGOLD[1]
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

	2004-2005		2005-2006	
Nutrient composition[2]	Soybean hulls[1]	GRNGOLD[1]	Soybean hulls[1]	GRNGOLD[1]
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, %	2.2	1.9	2.2	1.8
NDICP, %[4]	2.9	2.8	3.3	3.3
ADICP, %[5]	1.1	0.9	1.1	0.9
TDN, %[6]	63.1	58.6	61.6	57.0
Monensin, mg/kg[7]	-	155 ± 4	-	150 ± 12

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

Table 2. Mineral composition of supplements[1,2]

	2004-2005				2005-2006			
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]Supplements: MIN = non-medicated, free-choice mineral mixture; RMIN = free-choice mineral mixture with 1,785 mg monensin/kg; Soybean Hulls = soybean hulls fed at 1.81 kg every other day as part of SH/RMIN; GRNGOLD = monensin-containing (165 mg monensin/kg) energy supplement fed at 1.81 kg every other day.
[2]All values expressed on a DM basis.

Table 3. Monthly mean temperatures and total precipitation during the 2004-2005 and 2005-2006 winter wheat growing seasons near Marshall, OK

	Mean temperature, °C			Total precipitation, mm		
Item	2004-2005	2005-2006	"Normal"[1]	2004-2005	2005-2006	"Normal"[1]
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 average from 1971-2000 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.

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

Clipping Date 2004-2005					
Item	October 28, 2004	December 15, 2004	January 25, 2005	February 22, 2005[1]	Average
No. pastures	18	18	18	18	18
Stocking Rate, steers/ha	1.65	1.77	1.65	1.65	1.74[2]
Forage mass, kg DM/ha	1,506 ± 130	1,073 ± 316	566 ± 173	253 ± 66	849 ± 131
Forage allowance, kg DM/steer	915 ± 79	605 ±178	319 ± 97	156 ± 42	499 ± 72
Forage allowance, kg DM/100 kg BW	362 ± 32	-[3]	100 ± 27	50 ± 13	170 ± 15
Clipping Date 2005-2006					
	November 10, 2005	December 14, 2005	January 24, 2006	March 7, 2006	Average
No. pastures	18	18	18	18	18
Stocking Rate, steers/ha	1.11	0.87	0.83	0.83	0.94[2]
Forage mass, kg DM/ha	619 ± 121	902 ± 152	498 ± 110	560 ± 108	644 ± 92
Forage allowance, kg DM/steer	560 ± 108	816 ± 137	577 ± 142	676 ± 127	657 ± 91
Forage allowance, kg DM/100 kg BW	190 ± 38	258 ± 44	151 ± 36	165 ± 31	191 ± 27

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

Table 5. Nutrient composition of wheat forage at beginning (November) and end (March) of the 2005-2006 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, %	3.7 ± 0.1	3.2 ± 0.2
NDICP, %[5]	9.9 ± 0.8	8.9 ± 0.6
ADICP, %[6]	0.61 ± 0.15	0.70 ± 0.24
TDN, %[7]	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	1016 ± 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]Feeke's growth scale 3.
[4]Feeke's growth scale 6.
[5]NDICP = neurtal detergent insoluble CP.
[6]ADICP = acid detergent insoluble CP.
[7]Calculated as described by Weiss et al. (1992).

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

	Treatment[2]							Contrast[3]			
Item	NC	MIN	RMIN	SH/RMIN	GRN GOLD	SEM[4]	P-value[5]	NC vs. MIN	MIN vs. RMIN	RMIN vs. SH/RMIN & GRNGOLD	SH/RMIN vs. GRNGOLD
2004-2005											
No. of pastures	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
Supp. conversion[6]				3.5	2.7						
2005-2006											
No. of pastures	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
Supp. conversion[6]				14.7	20.5						

[1]Least squares means by treatment.
[2]NC = negative control; MIN = non-medicated, free-choice mineral; RMIN = free-choice mineral mixture with 1,785 mg 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 monensin/kg), energy supplement fed at the rate of 1.81 kg/steer every other day.
[3]Observed significance levels for comparison contrasts.

Table 6 cont.

[4]Most conservative standard error of the mean.
[5]Observed significance level for the main effect of treatment.
[6]Calculated as kg of as-fed energy supplement per kg of additional gain over steers receiving MIN.

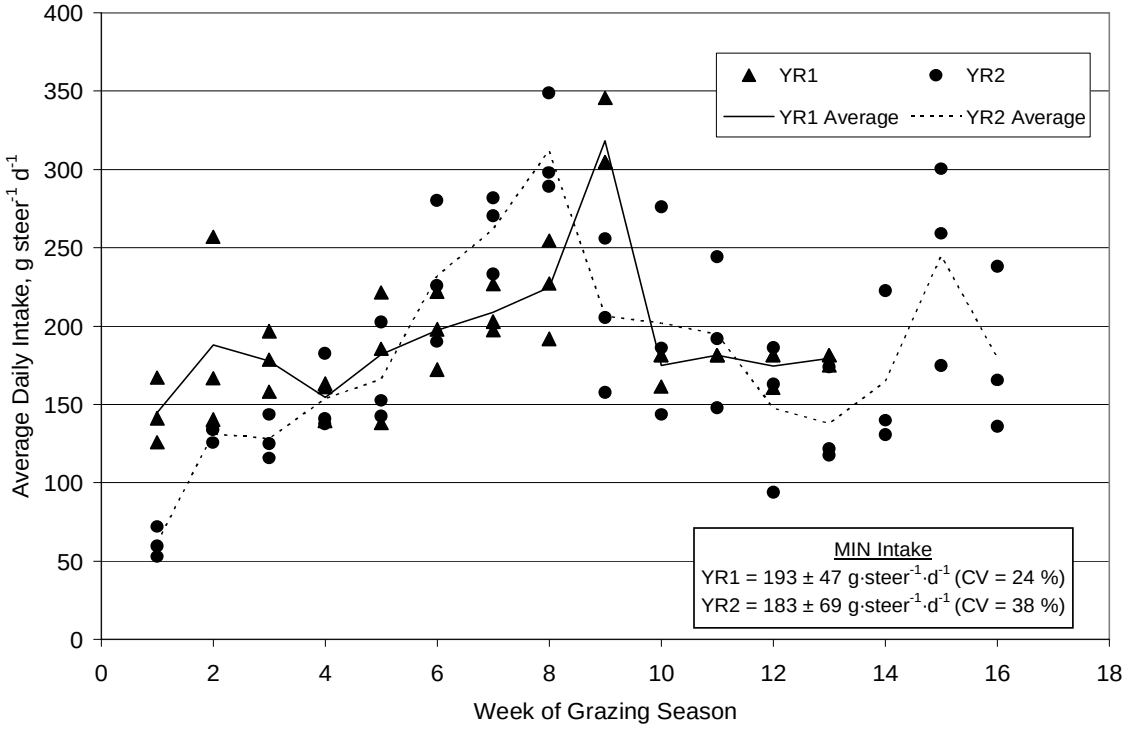

*Figure 1. Average daily intake (mean ± SD) of **MIN** (free-choice, non-medicated mineral mixture), measured weekly during the 2004-2005 (**YR1**) and 2005-2006 (**YR2**) winter wheat grazing seasons.*

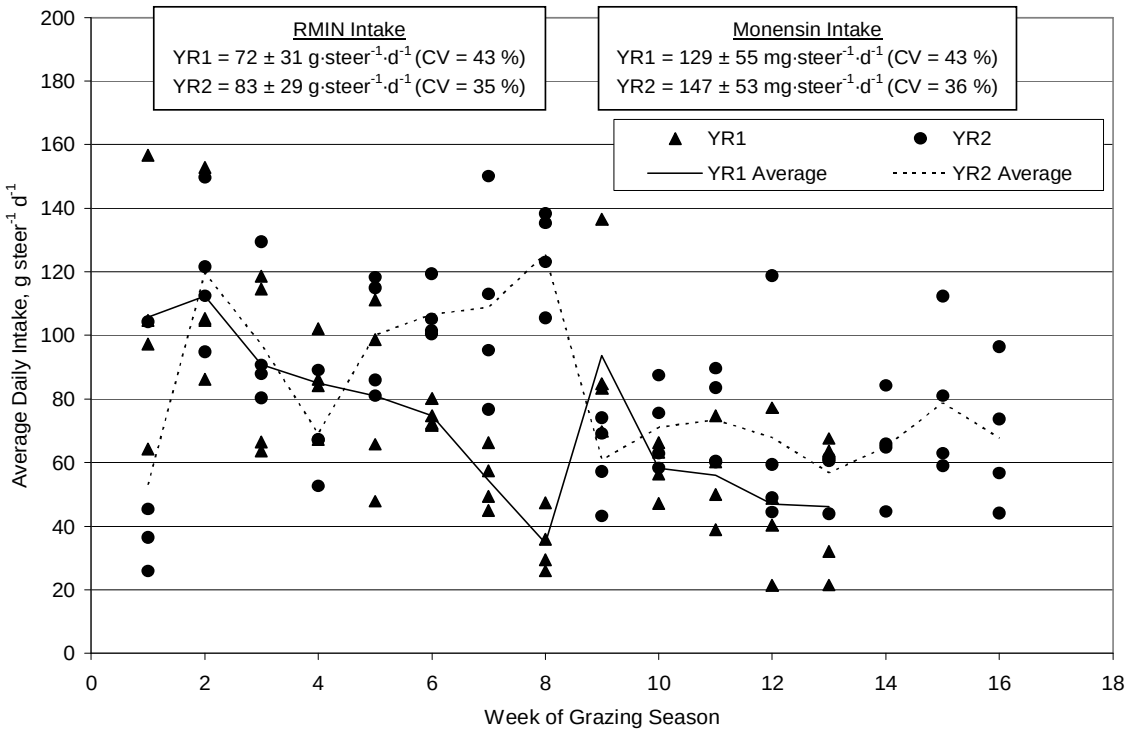

*Figure 2. Average daily intake (mean ± SD) of **RMIN** (free-choice, monensin-containing mineral mixture; 1,785 mg monensin/kg), measured weekly during the 2004-2005 (**YR1**) and 2005-2006 (**YR2**) winter wheat grazing seasons.*

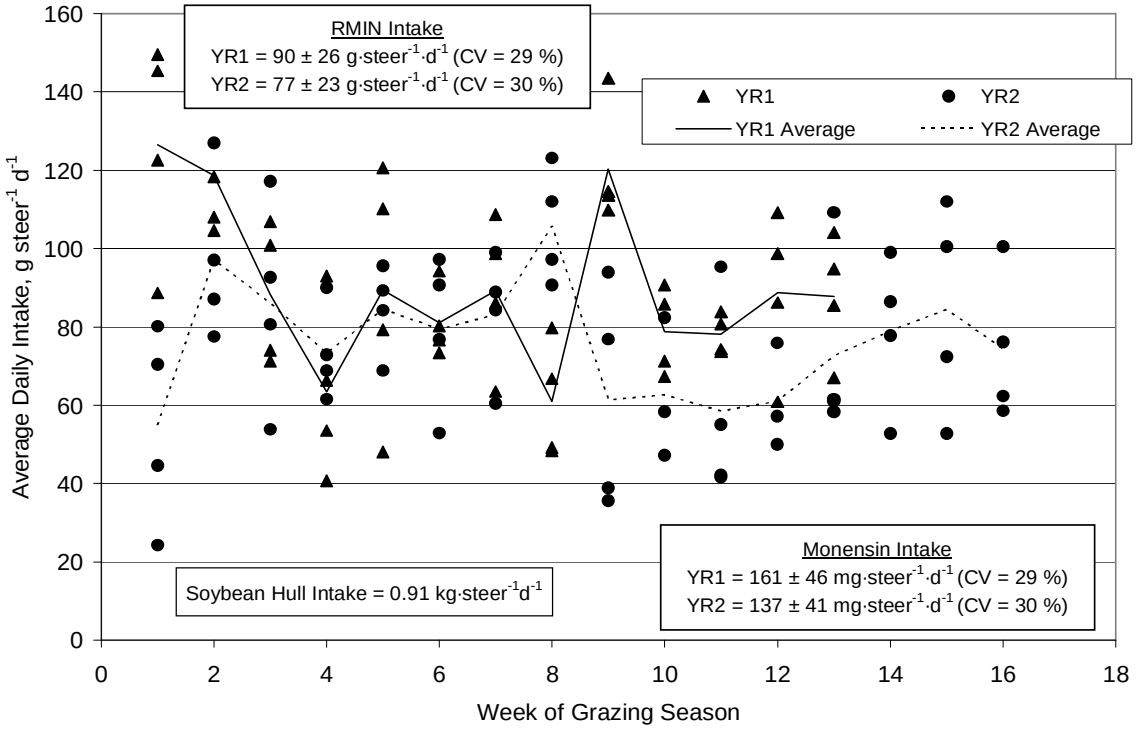

*Figure 3. Average daily intake (mean ± SD) of **RMIN** (free-choice, monensin-containing mineral mixture; 1,785 mg monensin/kg),when offered in conjunction with 1.81 kg soybean hulls fed every other day during the 2004-2005 (**YR1**) and 2005-2006 (**YR2**) winter wheat grazing seasons.*

Chapter IV

Effect of Monensin on Intake, Digestibility, Nutrient Flow, and Rumen Kinetics of Steers Grazing Winter Wheat Pasture

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ABSTRACT: This study was conducted to determine the effects of monensin on intake, digestibility, rumen kinetics, and VFA concentrations of steers grazing winter wheat pasture. Fifteen ruminally and duodenally cannulated crossbred steers (initial BW 227 ± 21 kg) were used in a crossover design. The three treatments were: (1) control (0 mg monensin·steer^{-1}·d^{-1}; **0**); (2) 100 mg monensin·steer^{-1}·d^{-1} (**100**); and (3) 200 mg monensin·steer^{-1}·d^{-1} (**200**). Monensin was delivered daily in gelatin capsules via rumen cannula. Forage intake, digestibility, and nutrient flows were determined using marker based techniques (Cr_2O_3 as an external marker and indigestible NDF as an internal marker). Wheat pasture samples were of characteristically high quality (CP = 25 %, NDF and ADF = 39.6 and 17.4 %, respectively). Stocking density was fixed at 1.79 steers/ha, and forage allowance averaged 935 kg DM/100 kg BW. Organic matter intake (OMI) and digestible OMI were not affected ($P \geq 0.64$) by monensin, and averaged 2.57 and 2.15 % BW, respectively. Duodenal flow of OM, microbial OM, NDF, ADF, total N, non-ammonia N, microbial N, and feed N were all not affected ($P \geq 0.21$) by treatments.

True ruminal OM digestion was increased (P = 0.05) from 54.2 % to 62.3 % by monensin. Ruminal NDF digestion increased (P = 0.04) from 73.4 % to 81.3 % with monensin. Ruminal ADF digestion was also increased (P = 0.04) with monensin (72.2 vs. 79.7 %, for control and monesin, respectively). Level of monensin did not affect (P ≥ 0.74) ruminal OM, NDF, or ADF digestibility. Monensin tended (P = 0.10) to increase ruminal forage N digestion, from 67.5 % to 75.2 % and 74.5 % for 0, 100, and 200, respectively). Microbial efficiency averaged 25.5, and was not affected (P = 0.68) by treatment. Total tract digestion of OM, NDF, ADF, and N were minimally affected (P ≥ 0.07) by treatment. Ruminal methane production tended (P = 0.09) to be decreased by monensin, while the acetate:propionate ratio was reduced (P = 0.04) by monensin. Molar proportion of propionate was not different (P = 0.25) between 0 and 100 mg monensin·steer^{-1}·d^{-1}. However, 200 mg monensin·steer^{-1}·d^{-1} increased (P ≤ 0.04) the ruminal molar proportion of propionate. These data indicate that increased NDF and ADF digestion, with lower methane production and higher ruminal propionate concentrations from monensin dosing are at least partially responsible for the improved energy status and growth performance of cattle receiving monensin and grazing winter wheat pasture.

Key Words: wheat pasture, monensin, intake, digestibility

Introduction

As many as 6 million head of cattle graze winter wheat pasture in the southern Great Plains annually (Horn, 1984; Horn, 2006). These cattle represent a significant number of cattle being prepared for entry into feedlots for finishing. Wheat pasture is characterized by high moisture content, and highly digestible and fermentable

carbohydrates and protein (Horn, 1984). Due to the high quality of wheat forage, ADG of cattle grazing wheat pastures is often excellent, assuming adequate forage allowances. Unfortunately, metabolic disorders such as bloat can be problematic when grazing wheat pasture. Horn et al. (2005) and Fieser et al. (2007) have shown monensin to be an effective additive to supplement programs to improve ADG in cattle grazing wheat pasture, and improve the utilization of supplements fed on wheat pasture. Additionally, monensin has been shown to be effective in reducing the incidence and severity of bloat in cattle grazing wheat pasture (Branine and Galyean, 1990; Paisley and Horn, 1998; Min et al., 2005). Horn et al. (1981) reported that monensin increases rumen molar proportion of propionate, as is characteristic of monensin in feedlot diets (Richardson et al., 1976). One of the possible mechanisms for the effectiveness of monensin in improving performance of cattle grazing wheat pasture is improved N utilization, as monensin has been shown to do in concentrate based diets (Bergen and Bates, 1984; Schelling, 1984). However, to this point, the effect of monensin on N degradation, and site and extent of other nutrients, has not been investigated in cattle grazing wheat pasture. Therefore, the objective of this study was to characterize the site and extent of digestion of OM, N, NDF, and ADF, as well as microbial efficiency of steers grazing wheat pasture. Additionally, ruminal fluid kinetics and VFA concentrations were measured.

Materials and Methods

Animals, Study Site, and Treatments

Experimental and surgical protocols were approved by the Oklahoma State University Animal Care and Use Committee (protocol number AG50372). Fifteen Angus crossbred steers (initial BW 227 ± 21 kg) were used in a crossover design. Ruminal and

double-L duodenal cannulas (Streeter et al., 1991) had been surgically placed in each steer prior to the study. The steers continuously grazed one winter wheat (*Triticum aestivum*; variety 2174) pasture (8.94 ha) at the Oklahoma State University Wheat Pasture Unit in Stillwater, OK, for 127 d, from November 5, 2003, to March 11, 2004. The wheat field was planted on September 9, 2003, at a seeding rate of 134 kg/ha, with 97 kg N/ha applied as anhydrous ammonia immediately prior to planting. The study consisted of three 18-d periods. The first period began on November 17, 2003, with subsequent periods starting on January 12 and February 23, 2004.

The 3 treatments were: (1) control, no monensin (**0**); (2) 100 mg monensin·steer^{-1}·d^{-1} (**100**); and 200 mg monensin·steer^{-1}·d^{-1} (**200**). A pre-mix was created using 1.29 kg Rumensin® 80 (Elanco Animal Health, Indianapolis, IN; 17.6 % monensin activity), and 5.51 kg ground corn. Calculated monensin concentration of the pre-mix was 33.5 mg/g of pre-mix. Actual analyzed monensin concentration of the pre-mix was 32.3 ± 2.4 mg /g, which is within the analytical error of the procedure (Woodson-Tenent Laboratories, Memphis, TN). The pre-mix was weighed into gelatin capsules, 3.0 g pre-mix/capsule 100 and 6.0 g/capsule for 200. Steers were hand-fed a non-medicated mineral mixture formulated for cattle grazing winter wheat pasture (Wheat Pasture Pro Mineral, Land O'Lakes Farmland Feed, LLC., Shoreview, MN)[2] at a rate of 113 g mineral mixture·steer^{-1}·d^{-1}.

Sampling Procedures

Days within each period were broken down as follows: d 1 to 7, adaptation to monensin dosing (monensin administered daily during each period); d 8 to 14, adaptation

[2] Wheat Pasture Pro Mineral; Land O'Lakes Farmland Feed, LLC. Shoreview, MN. Guaranteed analysis: Ca 15.0 – 17.0%; P 4.0%; NaCl 18.5 – 22.0%; Mg 5.5%; K 0.1%; Zn 2350 ppm; Mn 2000 ppm; Cu 650 ppm; I 65 ppm; Se 22 ppm; Vit. A 220,462 IU/kg.

to chromic oxide (Cr_2O_3, 10 g·steer^{-1}·d^{-1}; Cr_2O_3 dosed daily from d 8 to 18); d 15 to 17, fecal grab and duodenal sample collection; d 18 rumen fluid sampling. During the sample collection time (d 15 to 18) steers were confined to the 2.87 ha nearest the barn to facilitate gathering and minimize interruptions in grazing. Monensin and Cr_2O_3 were administered via rumen cannula daily at 0800 and 1600 (Cr_2O_3 only) in a gelatin capsule (monensin capsule described above; 5 g Cr_2O_3/capsule). Duodenal (approx. 300 g/sample) and fecal (approx. 400 g/sample) samples were collected twice daily, at 12-h intervals, with the collection time advanced 4-h each day. This resulted in a duodenal and fecal sample obtained every 4-h of a 24-h period. At 0800 on d 18, each steer was dosed with Co-EDTA (500 ml; Uden et al., 1980) via rumen cannula for determination of rumen fluid kinetic measures. Rumen fluid was collected on d 18 at 0, 4, 8, 12, 16, and 24-h after dosing. Also on d 18, prior to dosing and 12-h post-dosing, 500 g samples of ruminal contents were collected from each steer, combined with 500 ml of a solution of cold, 10% formalin in physiological saline and frozen for subsequent isolation of ruminal bacteria.

On d 14, forage mass and diet quality samples were collected from 6 random locations within the pasture. Wheat forage mass was determined by hand clipping forage to ground level inside 0.19 m^2 quadrants. Diet quality samples were obtained by hand plucking the upper portion of the plant, in an effort to simulate the forage steers were consuming. This was considered an accurate estimation due to the homogenous nature of the clean tilled wheat field. Forage 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 g DM per 0.19 m^2 from the clipped sample and extrapolating that to kg DM/ha. Forage allowance was calculated as kg DM/steer and kg DM/100 kg BW.

From each fecal grab sample, 200 g of wet fecal matter was sub-sampled, transferred to a convection drying oven, and dried to a constant weight at 50°C. Diet quality and fecal samples were ground to pass through a 2-mm screen in a Wiley Mill (Arthur A. Thomas, Philadelphia, PA). Duodenal samples were blended (Waring Pro® WPB05 Blender, Waring Consumer Products, East Windsor, NJ) to achieve a homogeneous sample, and 200 g sub-samples from each collection time were composited within period and frozen for later lyophilization. Ruminal fluid samples were collected from the center of the rumen and strained through 8 layers of cheesecloth. A portable pH meter (Orion Model 720, Thermo Electron Corporation, Beverly, MA), with a combination electrode, was used to determine pH immediately after the sample was strained. Following pH measurement, rumen fluid samples (100 ml) were acidified with 1 ml of 7.2 N H_2SO_4 and frozen for later analyses.

Laboratory Procedures

Forage, fecal, and duodenal samples were analyzed in duplicate for DM and OM 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 of forage, fecal, duodenal samples, and rumen bacteria isolates. Neutral detergent fiber and ADF were determined sequentially according to Van Soest et al. (1991), with the exclusion of sodium sulfite and decalin from the procedure, using an Ankom200 Fiber Analyzer (Ankom Technology, Macedon, NY). Ash-free, indigestible NDF (**INDF**) was used as an internal marker to calculate

digestibility of wheat forage and determined by an in-situ method. Indigestible NDF was determined by weighing 1.2 g of forage sample or 1.0 g of fecal sample (sample size:surface area = 10 to 12 mg/cm^2; Vanzant et al., 1998) into heat-sealed, nitrogen-free polyester in-situ bags (5 x 10 cm, 50 ± 15 m pore size, Ankom Technology, Macedon, NY). Bags were placed in a large nylon mesh bag and weighted to prevent floating above the rumen mat of the in-situ steer. The in-situ steer was fed a ground alfalfa and prairie hay diet (50:50) blended to ensure nitrogen would not be limiting in the diet. Bags remained in the rumen for 96-h, at which time they were removed and rinsed with tap water until rinse water ran clear. Bags were then processed for NDF determination as described previously. Isolation of rumen bacteria was accomplished by processing thawed, formalin-preserved rumen contents through a blender, and then strained through 2 layers of cheese cloth prior to centrifugation. Ruminal bacteria were isolated and prepared for analysis by differential centrifugation as described by Bock et al. (1991). Ruminal bacteria and duodenal samples were analyzed for purine concentration as a marker for the calculation of microbial N flow to the small intestine and efficiency of microbial protein synthesis, using high pressure liquid chromatography (HPLC; Hewlett-Packard Series II 1090 Liquid Chromatograph, Agilent Technologies, Palo Alto, CA), as described by Makkar and Becker (1999). Ruminal VFA concentrations were determined by deproteinizing 4 ml of ruminal fluid with 1 ml of 25% meaphosphoric acid (Erwin et al., 1961) and centrifuging at 20,000 x g for 15 min. Individual VFA were separated by gas chromatography (Perkin Elmer Autosystem, 9000 series, Norwalk, CT) with 8 ml/min flow rate of ultrahigh-purity He as a carrier gas and 2-ethylbutyric acid as an internal standard. Rumen fluid ammonia N concentration was determined

colorimetrically as described by Broderick and Kang (1980). Lyophilized duodenal samples were reconstituted to 3% DM in 0.1 N HCl, mixed, and centrifuged at 20,000 x g for 20 min. (Hannah et al., 1991). The supernatant was analyzed for ammonia N by the procedure of Broderick and Kang (1980). Chromium concentrations of fecal and duodenal samples were quantified by inductively coupled plasma spectrometry (ICP; Spectro Ciros ICP Spectrometer, Spectro Analytical Instruments, Kleve, Germany) using the sample digestion procedure described by Williams et al. (1962). Rumen fluid samples were centrifuged (15,000 x g for 10 min.) and analyzed for Co concentration by ICP.

Calculations

Forage OM intake and digestibility were calculated using a dual-phase marker method with Cr_2O_3 as an external marker and INDF as the internal marker. Fecal OM output and duodenal flow of OM was calculated based on marker ratios using Cr. Forage digestibility was calculated as described by Hungate (1966), and intake was expressed as the ratio of fecal output to forage indigestibility. Microbial OM and microbial N leaving the abomasum were calculated using purines as a microbial marker (Zinn and Owens, 1986). Organic matter fermented in the rumen was considered equal to OM intake minus the difference between the amounts of total OM reaching the duodenum and microbial OM reaching the duodenum. Apparent feed N that escaped to the small intestine was considered equal to total N leaving the abomasum minus NH_3-N and microbial N, and included endogenous contributions. Rumen fluid dilution rate was calculated by regressing the natural logarithm of Co concentrations against sampling times (Warner and Stacy, 1968). Fluid volume was calculate by extrapolating the log curve to time zero,

taking the inverse natural log, and dividing by initial Co dose. Fluid flow rate (L/h) was calculated by multiplying fluid dilution rate by volume, and ruminal fluid turnover time was calculated as the inverse of fluid dilution rate (Galyean, 1997). Methane production was calculated based on the theoretical fermentation balance of Wolin (1960), as described by Owens and Goetsch (1988).

Statistical Analyses

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for a crossover design. A variable was constructed to identify the sequence in which treatments were applied to steer (6 sequences) across periods. The model included terms for sequence, treatment, and period, and the Kenward-Roger method was used to calculate degrees of freedom. Steer within sequence was treated as a random effect. Fermentation characteristics were analyzed using a model including the above terms and random effects, as well as period*steer within sequence as a repeated measure, and grouped within period. The error covariance of repeated measures was modeled with an autoregressive correlation structure. Despite period being a significant ($P \leq 0.01$) effect, least squares means are reported by treatment, and pooled across periods. This was done because dosing took place at 0800 during each period, but grazing times and day length were changing across periods. Protected ($P \leq 0.05$) Fisher's LSD were used to separate treatment means. Nutrient composition and forage allowance data are presented as raw means and standard deviations, with no further statistical analysis.

Results and Discussion

Wheat Forage Composition and Forage Allowance

Nutrient composition of wheat forage is shown in **Table 1**. Standing wheat forage DM was between 25.3 and 31.8 % (average 28.2 ± 3.1 %) during the grazing season. This low DM content is characteristic of wheat pasture during fall and winter grazing (Horn, 1984). Reuter and Horn (2000) observed similar DM content of standing forage, ranging from 17.5 to 40.6 % between mid-November and mid-March. Forage OM concentration ranged from 90.0 % in period 3 to 91.2 % in period 1 (average 90.7 ± 0.7 %). Forage CP content ranged from a low of 22.0 % during period 2 to a high of 29.3 % in period 3, with an average CP concentration of 25.6 ± 3.7 %. Crude protein values of 20 to 30 % in wheat pasture are common (Croy, 1984; Horn, 1984; Reuter and Horn, 2000). Ash-free NDF and ADF averaged 39.6 ± 2.7 and 17.4 ± 0.6 %, respectively. Horn (1984) noted a similar pattern where NDF and ADF increased in the late fall with advancing maturity of the plant. Slowed plant growth, combined with grazing defoliation, increases the proportion of stem in wheat plants during the winter. Upon resumption of rapid forage growth as spring temperatures increased (around February) a subsequent reduction in NDF and ADF concentration is expected until tillering and seed head development (Horn, 1984). Other cool season annual small grain forages, such as barley and oats, have similar NDF (37.6 to 39.5 %) and ADF (22.8 to 24.3 %) values (Francia et al., 2006).

Stocking density and forage allowance during the three grazing periods are shown in **Table 2**. Stocking density was held constant across the grazing season at 1.79 steers/ha. Forage allowance averaged 935 ± 339 kg DM/100 kg BW. The lowest forage

allowance was observed during period 3, with a forage allowance of 692 kg DM/100 kg BW. Fieser et al. (2006) found that maximum individual animal ADG occurred at a forage allowance of 709 kg DM/100 kg BW on winter wheat pasture. The forage allowance observed during the present study was sufficient to allow for ad-libitum intake of grazed wheat forage.

Forage and Nutrient Intake and Digestibility

Forage and nutrient intake, duodenal nutrient flow, and site and extent of digestion data are shown in **Table 3**. Organic matter intake (OMI) was not affected (P = 0.74) by monensin, and averaged 2.57 % BW. Similarly, digestible OMI was not affected (P = 0.64) by monensin, with an average of 2.15 % BW. Horn et al. (1981) and Branine and Galyean (1990) also found that monensin did not alter wheat forage intake (with monensin dosage of 200 and 170 mg monensin·steer^{-1}·d^{-1}, respectively). Additionally, Davenport et al. (1989) reported no change in forage intake of steers grazing winter wheat pasture using a monensin ruminal delivery device that provided 100 mg monensin·steer^{-1}·d^{-1}. Gallardo et al. (2005) found that dairy cows grazing alfalfa pastures also did not reduce intake in response to monensin (335 mg monensin·cow^{-1}·d^{-1} from a controlled release capsule). Potter et al. (1986) reported an average reduction of 3.1 % (average of 12 trials) in intake of harvested forages when monensin was fed. However, this reduction in intake is not reported relative to BW. In a classic monensin study, Dinius et al. (1976) found no effect of monensin on forage (orchardgrass hay) intake across a range of monensin intakes (0, 11, 22, and 33 ppm in the total diet). As suggested by the preceding publications, Schelling (1984) reported that depressed intake

due to monensin is either not present or much more subtle in cattle on forage-based diets than high-concentrate diets.

Absolute intakes (g/d) of OM, digestible OM, NDF, ADF, and N were not affected by monensin ($P \geq 0.39$). Similarly, no differences ($P \geq 0.21$) attributable to monensin were detected for OM, microbial OM, NDF, ADF, total N, NH_3-N, microbial N, or feed N flows to the duodenum (g/d). In addition, fecal excretion of OM, NDF, ADF, and N were not different ($P \geq 0.57$) among treatments. However, true ruminal OM digestibility (**OMD**) was increased ($P = 0.05$) with monensin. True ruminal OMD was 54.2 % for the control steers, and was increased ($P \leq 0.05$) by 15 % with inclusion of monensin (62.3 % with monensin). No difference ($P = 0.74$) was detected between the 100 or 200 mg monensin/d treatments, 61.7 vs. 62.9 %. Andersen (1988) reported true ruminal OMD of mature wheat forage to be 54.9 %, and immature wheat forage of 77.9 %. Ruminal OMD of perennial ryegrass ranged from 65 to 67 %, across a variety of harvest dates (Beever, 1984). Beever et al. (1987) found that inclusion of monensin (250 mg/d) to a diet of fresh-cut perennial ryegrass did not affect ruminal OMD (55.6 and 53.6 for control and monensin treatments, respectively).

Ruminal NDF digestibility (**NDFD**) was also increased ($P = 0.04$) by monensin. Ruminal NDFD was 73.4 % for steers receiving no monensin, and was increased ($P \leq 0.03$) nearly 11 % by including monensin. No difference ($P = 0.92$) was observed between the two monensin levels relative to ruminal NDFD, averaging 81.3 % for 100 and 200. Ruminal ADF digestibility (**ADFD**) responded similarly to ruminal NDFD. Addition of monensin increased ($P \leq 0.03$) ruminal ADFD by 10 % over no monensin (0 = 72.2 % ruminal ADFD). No difference ($P = 0.97$) was observed between monensin

levels for ruminal ADFD, averaging 79.7 % for monensin treatments. In agreement with our observed increase in ruminal NDFD, Deswysen and Ellis (1988) found that monensin (100 mg·heifer^{-1}·d^{-1}) increased ruminal NDFD in corn silage-based diets. Conversely, Faulkner et al. (1985) found no influence of monensin on ruminal NDFD when included in a corn stalk-based diet at levels up to 36.6 mg monensin/kg diet. To emphasize the variation in ruminal fiber digestion response to monensin, Fredrickson et al. (1993) reported decreased 96-h NDF disappearance in steers grazing native blue grama range with a monensin ruminal delivery device (100 mg·heifer^{-1}·d^{-1}). Monensin has been shown to have no effect on ruminal cellulose digestion (Beever et al., 1987) or rate of ruminal cellulose disappearance (Ricke et al., 1984), in cattle grazing perennial ryegrass and sheep on an alfalfa-based diet, respectively. Spears (1990) suggested that the chemical and/or physical properties with different diets influence the effect of ionophores on fiber digestibility. Increased ruminal fiber digestion could be explained by recent work from our laboratory, in which *Prevotella* sp. and *Bacillus* sp. were the predominant microbial populations when supplementing monensin (200 mg·steer^{-1}·d^{-1}) on wheat pasture (Fernando et al., 2005). Both of these species of bacteria have been shown to have a demonstrated activity on xylan (*Prevotella* sp.) or xylanase activity (*Bacillus* sp.; Collins et al., 2005). Using dairy cows fed a timothy hay and soybean meal diet, Yang and Russell (1993) found that the number of carbohydrate fermenting bacteria was not significantly altered by monensin. However, monensin did numerically increase the estimated number of carbohydrate fermenting bacteria and inhibit highly active amino acid fermenting bacteria (Yang and Russell, 1993).

Ruminal feed N digestibility tended (P = 0.10) to be increased with monensin. This numerical increase was about 7.4 percentage units. Our ruminal feed N digestibility with monensin (average 74.9 %) is similar to the DIP values reported by Reuter and Horn (2000) for wheat forage using a *Streptomyces griseus* 48-h in vitro procedure (76.9 ± 2.4 %). We did not observe the classical "protein sparing" effect of monensin in which dietary protein degradation in the rumen is reduced (Bergen and Bates, 1984; Schelling, 1984). Bergen and Bates (1984) observed increased ruminal escape of feed protein by feeding monensin. However, these studies utilized concentrate- or corn silage-based diets (Bergen and Bates, 1984). In other work on a high CP forage (white clover; *Trifolium repens* cv. Blanca; 25 % CP), Beever et al. (1987) found that monensin did not alter rumen degradability of feed N (average 84.0 % rumen degraded). It is possible that when grazing forages with CP values in excess of 25 %, that are highly ruminally degraded, but have a short rumen retention time, the protein sparing effect of monensin is minimized by the abundance of ruminally available N.

Microbial efficiency (g bacterial N/kg of OM truly fermented in the rumen) was not affected (P = 0.68) by monensin. These microbial efficiency estimates were relatively high, averaging 25.5 across all treatments. This high microbial efficiency value is common in high quality forages. Vogel (1988) reported microbial efficiency values as high as 38.9 in steers grazing wheat pasture in the early spring. Beever et al. (1987) found microbial efficiency of white clover diets to be 30.4 when unsupplemented. Additionally, Beever et al. (1987) did not find an impact of monensin on microbial efficiency. In contrast to our observations, Van Nevel and Demeyer (1977) found that monensin reduced microbial efficiency in vitro. In our in vivo data, monensin shifted

both factors that contribute to microbial efficiency, bacterial N and OM truly fermented in the rumen. Because both of these values moved in the same direction and similar amounts, no net effect was observed relative to microbial efficiency.

Postruminal OM and N digestibility tended ($P = 0.09$) to be reduced with monensin addition. This is likely a function of these factors having higher ruminal digestion, allowing for the possibility of greater postruminal fermentation. No effect ($P \geq 0.84$) was seen on postruminal NDFD or ADFD. Mean posturminal ADFD values were negative. However, these negative values were not different from zero ($P \geq 0.27$). While NDFD means were positive, they were also not different from zero ($P \geq 0.10$). This suggests that essentially no postruminal NDF or ADF digestion was taking place.

Apparent total tract digestion of OM and N were not influenced ($P \geq 0.73$) by monensin supplementation, and averaged 81.8 and 80.4 % for OM and N, respectively. Conversely, monensin tended ($P \leq 0.10$) to increase total tract digestion of NDF and ADF. This is likely a residual effect of the increased NDFD and ADFD observed ruminally with monensin, because, as stated previously, essentially no NDF or ADF digestion was detected posturminally. Poos et al. (1979) found that apparent digestibility of DM and ADF was reduced by monensin when added to a ground corn cob-based diet supplemented with concentrates. Similarly, Deswysen and Ellis (1988) did not find evidence of a monensin effect on apparent NDF digestion. Faulkner et al. (1985) observed increases in apparent DM and NDF digestibility at low levels (6.1 to 12.2 ppm) of monensin, and at higher levels (36.6 ppm) values were similar to the control treatment. Dinius et al. (1976) found no effect of monensin (up to 33 ppm) on DM, CP, or fiber digestibility. In contrast to our study, Ruiz et al. (2001) found no effect of monensin on

apparent digestibility of DM, and a tendency of increased apparent N digestibility with monensin in dairy cows consuming a fresh orchardgrass diet. However, Ruiz et al. (2001) did not see an effect of monensin on NDF digestibility. Similar to our findings, Poos et al. (1979) did not observe an alteration in apparent N digestibility with monensin. As discussed previously, the extreme variation in intake and chemical composition of forages likely contributes to the variation observed in response to monensin effects on nutrient digestion.

Rumen Fluid Kinetics and Fermentation Products

Rumen fluid characteristics are shown in **Table 4**. Rumen fluid dilution rate was extremely rapid, with an average of 14.9 %/h, and was not influenced by monensin ($P = 0.35$). Monensin has been shown previously to have no effect on liquid dilution rate on wheat pasture (Davenport et al., 1989; Branine and Galyean, 1990). Fluid dilution rates of between 8.3 and 11.1 %/h (Davenport et al., 1989) and 7.9 and 11.1 %/h (Branine and Galyean, 1990) have been reported on wheat pasture. On a lower quality forage (corn stalks and supplement), Faulkner et al., 1985 were also unable to detect a change in liquid dilution rate due to monensin. The rapid liquid dilution rates are indicative of the high microbial efficiency values we measured. Prigge et al. (1978) found that microbial protein synthesis increased as liquid dilution rate increased. This relationship is confirmed by Owens and Goetsch (1988). Monensin also did not alter ($P \geq 0.20$) rumen liquid flow rate, liquid volume, or liquid turnover time.

All time dependent measures (pH, NH3-N, total VFA, acetae:propionate ratio, methane production, and molar proportions of individual VFA) failed to show a treatment*time interaction ($P \geq 0.09$). While these variables were sensitive to time ($P <$

0.01), the time factor was based on our initial dosing time and did not account for timing of grazing bouts. Additionally, the effects of time were generally a degree of magnitude, and did not affect treatment ranking (lack of treatment*time interaction). Therefore, effects for these variables are reported as lsmeans across time for each of the dietary treatments (**Table 4**). Monensin influenced (P = 0.01) rumen pH. However, the range in mean rumen pH values was from 5.9 to 6.1, meaning it was probably of little biological consequence. Because of its high rumen degradability and solubility, low rumen pH is characteristic of cattle grazing wheat forage. Davenport et al. (1989) and Branine and Galyean (1990) reported rumen pH of wheat pasture cattle ranging from 5.7 to 6.3. Branine and Galyean (1990) found that monensin increased rumen pH (from 6.0 to 6.3) in one of three time periods they investigated. Similarly, Horn et al. (1981) reported an increase in rumen pH from 6.22 to 6.75 (at 4-h post dosing) with the addition of monensin. However, by 24-h post-dosing this effect was not significant. Min et al. (2005) found no effect of monensin on rumen pH out to 22 d of feeding monensin to steers on wheat pasture.

One of the classic modes of action for monensin is reduced rumen N digestibility, generally characterized by reduced rumen NH_3-N concentrations (Bergen and Bates, 1984; Schelling, 1984; Russell and Strobel, 1989). Our results were somewhat inconclusive, with 100 increasing rumen NH_3-N, compared to either 0 or 200. This is consistent with the tendency we observed for monensin to increase feed N digestion in the rumen. Neither Horn et al. (1981) nor Davenport et al. (1989) observed an impact of monensin on rumen NH_3-N in steers grazing wheat pasture. In agreement with our data, Branine and Galyean (1990) observed increased ruminal ammonia 2 and 8 h after feeding

monensin to steers grazing wheat pasture in late April. Conversely, at 2- and 23-h post feeding, steers receiving monensin had reduced ruminal ammonia (Branine and Galyean, 1990). At all other collection times there was no effect of monensin on ruminal ammonia (Branine and Galyean, 1990). With perennial ryegrass and white clover, Beever et al. (1987) were unable to detect a reduction in ruminal NH_3 with monensin. Ruiz et al. (2001) found a similar pattern, with a numerical reduction in rumen ammonia. Similarly, Poos et al. (1976) reported numerical reductions in rumen ammonia with monensin. These reports not only provide evidence for the potential of monensin to reduce ruminal ammonia values, but also the variable nature of the rumen ammonia concentrations, with numerous reductions observed, but significance not detected due to high variance. Yang and Russell (1993) found that monensin reduced ruminal ammonia concentrations as well as the number of amino acid fermenting bacteria in the rumen. However, the daily monensin dose for cows used by Yang and Russell (1993) was 350 mg·steer^{-1}·d^{-1} (0.51 mg monensin/kg BW). In the present study, the 200 mg·steer^{-1}·d^{-1} dose provided only 0.40 mg monensin/kg BW. At our levels, 100 and 200 mg monensin·cow^{-1}·d^{-1}, the monensin may not be able to counteract the load of rumianlly degradable N from wheat forage.

Another classic response to monensin is reduced losses to methane gas (Bergen and Bates, 1984; Schelling, 1984). Monensin tended ($P = 0.09$) to decrease methane production, which ranged from 0.62 mol methane/mol of glucose equivalent fermented for control steers, to 0.60 for steers receiving 200 mg monensin·steer^{-1}·d^{-1}. Based on our values, 200 mg monensin·steer^{-1}·d^{-1} reduced methane production by 3.2 %. Horn et al. (1981) found that monensin reduced gas production ($CO_2 + CH_4$) in steers grazing wheat

pasture by between 5 and 8 %. The reduction in gas production specific to methane was between 8 and 15 % (Horn et al., 1981). Min et al. (2005) found that monensin reduced methane production per g or forage by roughly 50 % in-vitro. Additionally, Min et al. (2005) showed that cumulative hourly gas production for monensin after 3-h was less than the control.

Our highest dose of monensin tended ($P = 0.06$) to reduce total VFA concentration, compared with 0 and 100. Other studies on wheat pasture have failed to show an effect of monensin on total VFA concentration (Davenport et al., 1989; Branine and Galyean, 1990). Horn et al. (1981) found that monensin reduced total VFA 4 h post-dosing, but at 24 h post-dosing this reduction was no longer significant. Ruiz et al. (2001) also found a small numerical reduction in total VFA by adding monensin to the diet. Acetate:propionate ratio (**A:P**) responded to out treatments ($P = 0.04$). The highest dose of monensin reduced ($P = 0.01$) A:P compared with 0. The 100 treatment was intermediate ($P \geq 0.11$) between the control and 200. Horn et al., (1981) also found reduced A:P when monensin was fed to steers grazing winter wheat pasture. Acetate:propionate ratios calculated from the data of Davenport et al. (1989) indicate that monensin reduced A:P of steers on wheat pasture from 3.2 to 3.0. The theoretical fermentation balance equations developed by Wolin (1960) suggest that a reduction in A:P, results in a reduction in methane production. Based on the direct measures of Horn et al. (1981) it appears that this balance holds true on wheat pasture.

Molar proportions of acetate, valerate, isobutyrate, and isovalerate were unaffected ($P \geq 0.32$) by treatment. The only individual VFA influenced by monensin was propionate ($P = 0.01$). Molar proportion of propionate was not different ($P = 0.25$)

between 0 and 100, but was increased ($P \leq 0.04$) by 200. The increase in propionate apparently came at the expense of butyrate, which tended ($P = 0.17$) to decrease with monensin dosing. Perhaps the most consistent and important response observed with including monensin in ruminant diets is a shift in molar proportions of VFA toward greater amounts of propionate (Dinius et al., 1976; Richardson et al., 1976; Ipharraguerre and Clark, 2003). Horn et al. (1981) reported increased ruminal molar proportions of propionate of steers grazing wheat pasture with 200 mg monensin·steer^{-1}·d^{-1}. This increase in propionate was more distinct 4-hr after feeding, but still detectable 24-h after feeding monensin. Davenport et al. (1989) reported increased propionate proportions (from 19.2 to 20.3 mol/100 mol) with 100 mg monensin·steer^{-1}·d^{-1} for steers grazing wheat pastures from early February through early April. This small, but significant ($P < 0.05$), increase is comparable to what we observed in the present study, and at similar molar proportions of propionate. Conversely, Branine and Galyean (1990) did not report any alteration in molar proportion of propionate for steers on wheat pasture (170 mg monensin·steer^{-1}·d^{-1}). However, in 2 out of 3 periods, butyrate was reduced ($P < 0.05$), and a numerical increase in propionate was observed (Branine and Galyean, 1990).

Implications

Monensin increased ruminal OM, NDF, and ADF digestibility of cattle grazing winter wheat pasture, without a reduction in OM intake or liquid dilution rate. Monensin dosage (100 or 200 monensin·steer^{-1}·d^{-1}) did not affect these variables. However, higher monensin dosage may be necessary to alter some fermentation products, as only 200 mg monensn·steer^{-1}·d^{-1} effected the acetate:propionate ratio and the molar proportion of propionate. These digestion and fermentation effects are indicative of monensin

improving the energy status of cattle, and are possible mechanisms for the improved performance of cattle fed monensin on wheat pasture.

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Table 1. Dry matter and nutrient composition of wheat forage

	Period[1]			
Nutrient composition[2]	1	2	3	Average
Standing forage DM[3]	25.3 ± 0.83	31.8 ± 2.57	28.1 ± 1.42	28.2 ± 3.10
OM	91.2	90.9	90.0	90.7 ± 0.7
CP	25.6	22.0	29.3	25.6 ± 3.7
NDF, ash-free	37.2	42.5	39.2	39.6 ± 2.7
ADF, ash-free	16.8	18.0	17.4	17.4 ± 0.6

[1]Pasture clipping done on d 15 of each period. Period 1 = Dec. 1, 2003. Period 2 = Jan. 26, 2004. Period 3 = March 8, 2004.
[2]Expressed as a percentage of the DM.
[3]Expressed as a percentage on an as-fed basis.

Table 2. Stocking density and standing forage characteristics

Item	Period[1]			Average
	1	2	3	
No. of steers[2]	16	16	16	
Stocking density, steers/ha	1.79	1.79	1.79	
Forage mass, kg DM/ha	5,361 ± 547	4,082 ± 676	4,225 ± 440	4,556 ± 707
Forage allowance, kg DM/steer	2,996	2,280	2,361	2,546 ± 392
Forage allowance, kg DM/100 kg BW	1,322	790	692	935 ± 339

[1]Pasture clipping done on d 15 of each period. Period 1 = Dec. 1, 2003. Period 2 = Jan. 26, 2004. Period 3 = March 8, 2004.
[2]Number of steers includes 15 steers on treatment and 1 "extra" steer.

Table 3. Effect of monensin on nutrient intake, duodenal flow, microbial efficiency, and site and extent of digestion of steers grazing winter wheat forage

	Monensin dosage, mg·steer^{-1}·d^{-1}				
Item	0	100	200	SEM[1]	P-value[2]
OMI, % BW	2.57	2.52	2.63	0.151	0.74
Digestible OMI, % BW	2.14	2.09	2.22	0.138	0.64
Intake, g/d					
OM	7,564	7,293	7,955	513.4	0.43
Digestible OM	6,374	6,104	6,762	468.0	0.39
NDF	3,009	2,904	3,175	203.8	0.40
ADF	1,321	1,274	1,391	89.7	0.41
N	353.3	337.0	371.6	25.15	0.42
Flow to duodenum, g/d					
OM	2,932	2,679	2,575	169.1	0.22
Microbial OM	12.5	10.9	11.2	0.69	0.21
NDF	588.7	479.8	471.1	52.61	0.21
ADF	265.2	227.1	219.0	21.63	0.27
Total N	219.6	195.5	194.9	13.14	0.25
Nonammonia N	206.2	182.2	182.4	12.42	0.23
Microbial N	119.8	106.9	108.2	6.87	0.34
Feed N	86.3	75.3	74.2	7.43	0.39
Ruminal digestion, %					
OM, true	54.2[b]	61.7[a]	62.9[a]	2.69	0.05
NDF	73.4[b]	81.5[a]	81.1[a]	2.55	0.04
ADF	72.2[b]	79.6[a]	79.8[a]	2.33	0.04
Feed N	67.5	75.2	74.5	2.78	0.10
Microbial efficiency[3]	24.7	24.8	27.1	2.77	0.68
Fecal excretion, g/d					
OM	1,183	1,190	1,193	66.7	0.99
NDF	413.0	403.4	385.3	24.50	0.57
ADF	247.6	236.4	232.6	14.81	0.62
N	56.3	57.0	56.7	3.11	0.98
Postruminal digestion, %					
OM	58.9	53.3	52.0	2.32	0.09
NDF	15.8	9.3	15.5	9.50	0.84
ADF	- 7.4	- 10.6	- 8.9	9.79	0.97
N	73.8	69.8	69.8	1.46	0.09
Total tract digestion, %					
OM	81.5	81.9	82.1	0.58	0.73
NDF	83.8	84.4	85.3	0.53	0.07
ADF	77.6	79.0	79.6	0.73	0.10
N	80.0	80.3	80.8	0.79	0.76

[1]n = 44.
[2]Probability of a greater *F*-value for the main effect of treatment (monensin dosage).
[3]Microbial efficiency = g of bacterial N/kg of OM truly fermented in the rumen.

Table 3 cont.

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

Table 4. Effect of monensin on ruminal fluid kinetics, fermentation products, and VFA of steers grazing winter wheat pasture

	Monensin dosage, mg·steer^{-1}·d^{-1}				
Item	0	100	200	SEM[1]	P-value[2]
Ruminal fluid kinetics					
Liquid dilution rate, %/h	15.2	15.3	14.2	0.87	0.35
Liquid flow rate, L/h	6.5	5.9	6.0	0.31	0.20
Liquid volume, ml/kg BW	147.0	132.2	140.4	9.83	0.48
Liquid turnover time, h	6.9	6.8	7.2	0.43	0.54
pH	6.0^{ab}	5.9^{b}	6.1^{a}	0.04	0.02
NH_3-N, mM	22.5^{b}	26.3^{a}	23.4^{b}	0.98	0.01
Methane production[3]	0.62	0.61	0.60	0.005	0.09
VFA concentration, mM	111.7	111.6	105.3	2.71	0.06
Acetate:propionate	3.4^{a}	3.2^{ab}	3.1^{b}	0.08	0.04
	mol/100 mol				
Acetate	64.1	63.9	63.4	0.51	0.52
Propionate	19.5^{b}	20.0^{b}	20.8^{a}	0.33	0.01
Butyrate	12.7	12.3	12.1	0.26	0.17
Valerate	1.3	1.3	1.3	0.04	0.32
Isobutyrate	1.1	1.1	1.0	0.03	0.76
Isovalerate	1.4	1.4	1.5	0.05	0.37

[1]n = 44.
[2]Probability of a greater *F*-value for the main effect of treatment (monensin dosage).
[3]Methane production = mol methane/mol of glucose equivalent fermented.
[a,b]Within a row, means without a common superscript letter differ ($P \leq 0.05$).

Chapter V

Summary and Conclusions

A major goal of stocker cattle producers is to maximize ADG while maximizing the utilization of available forage. Energy and mineral supplementation with monensin is one of the methods that has been investigated to accomplish this goal. The research reported in this dissertation was conducted to evaluate supplementation programs and the specific effects of monensin on site and extent of wheat forage digestion.

A performance study was conducted over two grazing seasons to determine the effects of different supplementation programs on supplement intake and steer growth performance of stocker calves on wheat pasture. Five treatments were evaluated, a negative control, a free-choice, non-medicated mineral mixture, a monensin-containing, free-choice mineral mixture, soybean hulls and a monensin-containing, free-choice mineral mixture offered separately, and a monensin-containing, energy supplement. Steer growth response due to treatment was not consistent between years. In the first year the non-medicated mineral mixture did improve ADG compared with steers on the negative control. However, the monensin-containing mineral mixture did improve ADG compared with the non-medicated mineral mixture and negative control. The separate package supplement was not different from the monensin-containing, energy supplement, but they did out perform the monensin-containing mineral mixture treatment. In year two, the non-medicated mineral mixture improved ADG compared with the negative

control. The monensin-containing supplements (mineral and energy) did not improve ADG compared to the non-medicated mineral mixture.

In addition to the performance study, a companion digestion study was conducted to determine the effect of monensin on site and extent of digestion and nutrient flow of steers grazing wheat forage. Three treatments were evaluated: control (no monensin), 100 mg·steer^{-1}·d^{-1}, and 200 mg·steer^{-1}·d^{-1} were dosed via rumen cannula daily. Intake and apparent digestibility was not altered by dosing with monensin. However, ruminal digestion of NDF and ADF was improved with monensin, but no differences were observed between monensin levels. Microbial protein flow to the duodenum and microbial efficiency were not affected by monensin. Monensin decreased acetate:propionate ratio compared with the control treatment. Rumen molar proportion of propionate was increased with the highest dose of monensin compared with the control.

In conclusion, steers gained better when receiving monensin in one of two years. Based on the literature, this increased ADG response to monensin (observed in the one year) is typical of monensin in steers grazing wheat pasture. Lack of a response to monensin supplementation is not unprecedented, but is rarely observed. There does not appear to be a difference in the delivery method of monensin, in an energy supplement or fed in a mineral mixture and a separate energy supplement. Monensin seems to improve the growth performance of cattle grazing wheat pasture by improving fiber digestion, and increasing the amount of propionate in the rumen fermentation, while also tending to reduce the amount of energy lost as methane gas.

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