

BACKGROUNDING METHODS FOR GROWING BEEF CATTLE AND
STRATEGIES FOR INCORPORATING ALTERNATIVE FEEDSTUFFS INTO DIETS
OF FINISHING BEEF CATTLE

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“Never limit yourself because of others’ limited imagination; never limit others because of your own limited imagination.” ~ Mae Jemison

Dedication

I dedicate this dissertation to the most important people in my life, my family. Without the continued love and support you give me, I would not be where I am today. You are always there to strengthen me during the difficult times; you are always there to share in my joy during the happy times; but most importantly, you are always *there*. That means more to me than words can express.

“When you allow your best self to shine through and have the courage to believe in unlimited possibilities, you will discover how wonderfully magnificent you truly are.”

~ Elizabeth Hyland

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Abstract

Volatile commodity and cattle markets present challenges for profitable beef production. Four experiments were conducted to evaluate backgrounding methods for growing cattle and utilizing alternative feedstuffs in finishing diets to improve feedlot performance and efficiency. Experiment 1 evaluated the effectiveness of grazing stockpiled and swathed annual ryegrass as backgrounding systems on forage quality and beef stocker cattle performance. Results of experiment 1 suggest grazing stockpiled and swathed annual ryegrass may be viable backgrounding systems; however, forage maturity and winter weather conditions may reduce forage quality and accessibility to levels that can limit stocker cattle performance. Experiment 2 evaluated the effects of reproductive status (spayed vs. intact heifers supplemented with melengestrol acetate) and terminal implant strategy (moderate vs. aggressive) on beef feedlot heifer performance during backgrounding and finishing phases and on carcass characteristics. Results of experiment 2 suggest intact heifers supplemented with melengestrol acetate had greater performance during backgrounding; however, use of moderate or aggressive terminal implant strategies may allow similar performance during finishing and comparable carcass characteristics between spayed and intact beef feedlot heifers. Experiment 3 evaluated the effects of partially replacing dry-rolled corn in traditional corn-based finishing diets with either 35% conventional dried distillers grains plus solubles or 35% high protein dried distillers grains on beef steer feedlot performance and carcass characteristics. Results of experiment 3 suggest that although overall feed intake tended to be reduced,

high protein dried distillers grains may successfully replace conventional dried distillers grains plus solubles or up to 35% of dry-rolled corn in finishing beef cattle diets.

Experiment 4 evaluated effects of supplemental manganese in high-sulfur feedlot diets containing dried distillers grains plus solubles on *in vitro* and *in vivo* ruminal fermentation and hydrogen sulfide gas production. *In vitro* results of experiment 4 suggest that 1,000 ppm manganese in high-sulfur diets appeared to release less total hydrogen sulfide gas than 0 or 500 ppm manganese; whereas *in vivo* results suggest beef steers consuming 1,000 ppm manganese may have a less acidic ruminal environment prior to feeding to result in a tendency for reduced average ruminal hydrogen sulfide concentration.

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Chapter 1

Review of Literature

Introduction

Volatile commodity prices and the cyclic nature of the cattle market result in frequent tight profit margins for beef producers. Price signals and demands from consumers have challenged cattle producers to reduce costs of production, and perhaps even change production practices, while still providing consumers with high-quality, affordable beef products (Clary, 1992). Beef producers are not able to control cattle markets, but they can exert more control over input costs throughout the production phase in an attempt to sustain or increase profitability. In most beef cow/calf production settings, weaning is highly stressful on calves and increases susceptibility to pulmonary-related diseases and reduced performance. Preconditioning to new environments and vaccinating against respiratory diseases prior to feedlot entry promote achievement of genetic potential and improved lifetime performance of weaned stocker calves. Improving lifetime performance throughout the production phase may lead to overall profitability of raising cattle. Additionally, producers may implement alternative cost-effective strategies during growing and finishing phases of beef production to reduce input costs. Cattle producers must be willing to be flexible, take risks, and implement appropriate strategies in all phases of beef production to remain competitive in the rapidly evolving beef industry.

Backgrounding Beef Stocker Cattle

Beef cow/calf producers may choose to background calves for a period of time following weaning. Backgrounding calves offers marketing options that may provide incentives to the producer and is often an overlooked segment of the beef industry. Not only does backgrounding add weight and frame size to calves in an efficient manner, it also helps to maintain a steady supply of cattle for feedlots. Most beef calves in the United States are weaned in the fall months and are sent to feedlots; thus, there is opportunity for higher prices and greater profits if calves enter feedlots in the spring months. Selling price of feeder cattle follows a seasonal trend, with higher prices recorded in the spring months of February, March, and April and lower prices recorded in late summer and fall months of August, September, and October (Barham and Troxel, 2007). If producers are able to retain ownership of feeder calves and grow them economically as groups through a backgrounding phase, they may capture additional value and take advantage of improved profitability (Troxel et al., 2002; Barham and Troxel, 2007).

Backgrounding is generally known as a management system that uses mainly pastures, crop residues, or harvested forages with little or no grain to efficiently develop muscle mass and frame size on stocker cattle during the period between weaning and feedlot entry. Commonly, a backgrounding phase will last 60 to 90 days, and cattle should gain between 45 and 180 kg depending on forage availability, diets fed, and number of days on feed (DOF) in the system. Typically, energy intake will be restricted by either feeding low-energy diets or limit-feeding cattle to reduce ruminal passage rates

and increase rumen retention time for improved nutrient utilization and enhanced feed conversion ratios (Galyean, 1999). Maximum feed efficiency does not occur at maximum feed intake because the two factors are not linearly related, so there are both economic and performance benefits to controlling energy intake at various growth phases (Ferrell and Jenkins, 1998). Calves entering a backgrounding system may either be grazed on pastures or crop-residues or confined in a dry lot and fed high-roughage feedstuffs. There is opportunity to induce compensatory gain during the feedlot phase when grazing stocker calves in a backgrounding system. Stocker calves that were energy-restricted to a low rate of body weight (BW) gain during grazing may experience greater rates of BW gain at feedlot entry when restriction of dietary energy is removed (Phillips et al., 2001; Choat et al., 2003).

Backgrounding Beef Stocker Cattle in a Fall Grazing System

In the upper Midwest, cattle are typically limited to grazing pastures when forage growth occurs and high quality forage is available. Typically, the forage growing season in the upper Midwest is limited to approximately six months, from late April to late October. However, forage availability is often unreliable due to variable growing conditions that create fluctuation in pasture growth throughout the course of the growing season. In the lower Midwest, the period of time when forage is most unreliable and inadequate is from mid-December through March (Matches and Burns, 1995). While pastures offer an inexpensive source of high-quality forage, anytime forage is not available in pastures, cattle must be fed stored or harvested forages (Matches and Burns,

1995). Feeding harvested and stored forages is one of the greatest expenses incurred by cattle producers; thus, producers continue to search for effective methods to reduce winter feeding expenses.

Prior to feedlot entry, over three-fourths of the beef calves born in the United States will be grazed as stocker cattle (Peel, 2000). If producers desire to background calves, net farm income may be improved if high-quality forage is available when forage is typically not available and when weaned calves are available at seasonally low prices (Coulibaly et al., 1996). According to Beck et al. (2005), cattle producers in Missouri who retained ownership of feeder calves and added BW by grazing during fall and winter months had greater profits than solely grazing in spring. During spring, there is more forage available and thus, stocking rates must be increased to efficiently utilize all of the available forage. Beck et al. (2005) concluded BW gains in the fall and winter were more profitable than BW gains in the spring, which was also suggested by Coulibaly et al. (1996) when grazing stocker calves on winter wheat pasture in Oklahoma. In the upper Midwest, there is opportunity to reduce typical costs of production associated with feeding stored forages by up to 20% via increasing beef production on pastures using high-quality, cool-season forages in grazing systems (Bishop-Hurley and Kallenbach, 2001).

Options for Fall Grazing Systems in the Upper Midwest

Winter feeding cattle in the upper Midwest can be very expensive, as stored, harvested, or purchased forages may be required for 150 to 200 days when pastures are

not productive (Entz et al., 2002). Grazing longer over the normal grazing period would allow for reduced forage and feed input cost during the winter months. Two grazing systems used to extend the duration of the grazing season into fall and winter include stockpiling and swath grazing forages. Stockpiling, or deferred grazing, is more commonly implemented than swath grazing throughout the United States. Winter annual grazing programs have been tested in various locations throughout the United States with highly variable results. In addition to stand establishment, soil fertility, and competition for nutrients from other plant species, forage yield is dependent on climate, rainfall, and adaptability of the forage to the area where it is grown. Many studies have reported a large year to year variation in forage yield, nutrient value, and subsequent animal performance when grazing stockpiled or swathed forages into the fall or winter months; thus, implementing these systems in place of the conventional practice of feeding stored, harvested, or purchased forages carries more risk (Kallenbach et al., 2003).

Stockpiled Forage Fall Grazing System

Because few beef producers located in the north central United States depend on pasture forages throughout the extended winter months, little research on stockpiling forages exists for this region. In contrast, there are numerous studies evaluating effectiveness of stockpiled ryegrass or tall fescue in the southeastern United States. Stockpiling forages is the practice of allowing forage mass to accumulate for grazing after the growing season is complete. Therefore, the grazing season is extended later into the fall or winter months to reduce costs, labor, and time associated with harvesting and

storing forages, feeding conserved forage, and manure removal (Riesterer et al., 2000). By eliminating these processes, the producer may be able to reduce labor by as much as 25% of that typically needed for conventional methods of wintering beef cattle (Van Keuren, 1970).

Most producers who implement stockpiled forages for fall grazing generally begin accumulating either pure or mixed stands of forage as early as July, either following harvest of one cutting of hay or after light grazing throughout early summer. Proper forage maturity and grazing management can help minimize forage loss and maximize forage utilization when stockpiling forages. Forage yield of stockpiled forages will be greater the earlier the forage is stockpiled in the summer; however, maturity of the accumulated forage will also increase to reduce forage quality later into the grazing period. As forages mature, major losses occur in forage yield and quality, mainly as a result of translocation of nutrients out of senescing leaves, respiration processes that affect yield as growth rates decline, and loss and decay of leaves (Matches and Burns, 1995).

Nitrogen fertilization is important when stockpiling forages to increase the amount and quality of standing forage dry matter (DM) for all grass species, but especially for orchardgrass and tall fescue (Riesterer et al., 2000). To optimize the balance between forage quality and yield, it is recommended to begin stockpiling forages following fertilization application in August in more northern and cooler environments or in September in more southern and warmer environments to support a winter feeding strategy that is more economical than a traditional hay feeding program (Poore et al.,

2000). Grazing is stressful on forages, particularly due to effects of trampling, waste excretion, and potential daily plant defoliation (Smith et al., 1989). When grazing perennial forages later into the fall or winter months, rotational grazing or strip grazing forages may be useful in reducing forage losses by efficiently allocating and utilizing available forage while reducing potential negative effects of continuous grazing (Poore et al., 2000).

Quality and Loss of Forages in a Stockpiled Fall Grazing System

Generally, quality of cool-season annual forages can be considered adequate to support gains by growing calves throughout the grazing season. However, seasonal differences were reported in southeastern regions of the United States for forage concentrations of crude protein (CP), neutral detergent fiber (NDF), and also acid detergent fiber (ADF; Beck et al., 2007). When growth of annual forages is reduced in winter, either due to cool or dry weather, forage CP concentrations may decrease while fiber concentrations may increase with senescence of leaves (Beck et al., 2007). When forage regrowth is initiated again during the spring months, an accumulation of new growth increases CP concentrations and reduces fiber concentrations through March and April. However, as forage matures later into spring, forage quality is further reduced as CP concentration decreases and fiber concentrations increase (Beck et al., 2007).

The NDF concentration is inversely related to the dry matter intake (DMI) potential of the forage while the ADF concentration is inversely related to the total digestible energy concentration and digestibility of the forage (NRC, 1996). Total

digestible nutrient (TDN) concentration is an estimate of feedstuff digestible energy on a per-unit and nutrient requirement-basis (NRC, 1996). Thus, a TDN to CP ratio ranging from 5:1 to 7:1 is likely sufficient to capture adequate energy and protein to meet the requirements of both the animal and rumen microorganisms while allowing for variables of forage management and seasonal growing conditions (NRC, 1996; Moore et al., 1999). When this ratio falls below 5:1, there may be an excess of herbage nitrogen which may lead to inefficiencies in utilization of available nitrogen (Mayland et al., 2000).

Generally, most grass species follow similar patterns in forage quality changes during fall and into the winter months. Tall fescue, as well as most other grass species, typically follows a general pattern of increasing water soluble carbohydrates into the fall months which then generally decrease over the winter months (Taylor and Templeton, 1976; Burns and Chamblee, 2000; Baron et al., 2004). The proportion of dead foliage increases as forages mature over the winter season. As dead foliage increases, sugar concentrations in leafy material of swards are reduced. Sugars in plants are soluble and easily leach from leaves and also are rapidly respired and translocated from leaf material as maturity increases (Ocumpaugh and Matches, 1977). As sugar concentrations leave the plant sward, *in vitro* digestibility of sward organic matter also decreases since sugar concentration represents a portion of the cell soluble material (Ocumpaugh and Matches, 1977).

Baron et al. (2004) reported CP decreased in all grass species from September to October in western Canada. However, between October and April, CP concentrations decreased for alfalfa and meadow brome grass, remained the same for crested wheatgrass

and Kentucky bluegrass, and increased for smooth brome grass, orchardgrass, timothy, common quackgrass, and creeping red fescue (Baron et al., 2004). As the proportion of dead leaf material increases in swards, the total concentration of non-structural carbohydrates decreases by up to seven-fold (Taylor and Templeton, 1976; Burns and Chamblee, 2000). As winter progresses, differential leaching of nutrients occurs in dead leaf foliage. Crude protein is more resistant to leaching, so concentrations may actually increase in dead leaf foliage over time and be higher in spring (Taylor and Templeton, 1976; Baron et al., 2004).

As winter progresses and forages mature, forage NDF and ADF concentrations may change and be different across forage species. Averaged over a three-year study by Baron et al. (2004), NDF concentrations in September were lowest for alfalfa compared to grass species. Creeping red fescue was lower in NDF concentration than meadow brome grass, smooth brome grass, orchardgrass, and Kentucky bluegrass, but creeping red fescue had similar NDF concentrations to timothy and crested wheatgrass (Baron et al., 2004). Between the months of September and October in western Canada, NDF concentrations increased for alfalfa and smooth brome grass but remained the same for all other species. Decreases in forage NDF concentration during the fall may be attributed to dilution as leaf carbohydrate concentrations increase. Between September and October, smooth brome grass, meadow brome grass-alfalfa, and quackgrass increased in ADF concentration while other grasses maintained ADF concentration. However, from October to the following April, all species increased in ADF concentration (Baron et al., 2004). It has been reported that both green and dead leaf foliage remain relatively

constant in NDF and ADF concentrations over winter; therefore, differences in forage fiber concentrations across species at different stages of harvest may be a result of the proportion of leaf soluble and cell wall entities as well as the proportion of live and dead leaf foliage in the plant (Burns and Chamblee, 2000; Baron et al., 2004).

While stockpiled forages are effective at reducing winter feeding expenses, high forage DM loss may occur, particularly in late winter during snow accumulation and after snowmelt (Baron et al., 2004). Beef producers in the upper Midwest may graze stockpiled forages well into December and possibly even later if forage is still available and snow or ice accumulation does not hinder grazing. Even though cattle and sheep will learn to graze through snow, forage quality losses will escalate after a hard frost and snow accumulation in the northern Midwest (Riesterer et al., 2000). With adequate forage available, cattle and sheep are able to graze through fresh snow as deep as 0.5 m (Decker, 1988). However, if snow becomes trampled or forms a hard crust, grazing by livestock can be severely limited or prevented. Rain and snowmelt occurring after a frost, as well as lodging under the weight of accumulated snow and ice, and freeze-thaw cycles, intensify forage decay and organic matter losses by inducing rapid leaf rot and leaching of cell solubles (Ocumpaugh and Matches, 1977). Thus, forage palatability and nutritional value is rapidly reduced (Burns and Chamblee, 2000).

Success of Fall Grazing Stockpiled Forages

Success of fall grazing systems depends on several factors, including environment, forage species, rest period allowed for forage accumulation, and nutrient

management of the soil (Matches and Burns, 1995). Forages, particularly perennial and annual grasses which are adapted to specific climate and soil conditions, are most successful for stockpiling. Cattle, particularly stocker calves, have improved performance when grazing cool-season rather than warm-season forages later into the grazing period (Vendramini et al., 2007). Typically, legume forages are not used in stockpiled fall grazing systems due to their rapid decline in leaf nutritive value following frost damage or maturity (Matches and Burns, 1995). Established warm-season grass pastures will often be interseeded with cool-season grasses to increase the amount of forage available for late-season grazing, but success of seasonal forage production is highly variable (Moyer and Coffey, 2000). The vigor of the sward, the adaptability of the interseeded forage to the particular region, and the amount and distribution of precipitation will dictate the success of interseeded forages (Haferkamp et al., 2005). Therefore, the forage type most effective for a stockpiling system will vary depending on location and regional differences and class of cattle intended for grazing.

Several grass and small grain forage species are used widely throughout the United States to increase forage quality and availability for grazing livestock. Primarily in southeastern United States, interseeding small grains into existing warm-season sod pastures is commonly practiced for increasing forage yield during times of the year when forages are not traditionally available (Nelson et al., 1993). Bermudagrass is normally grazed by beef and dairy cattle in southeastern United States and is effective for grazing weaned beef calves due to its high productive and nutritive value potential (Taliaferro et al., 2004). Climate conditions will determine which winter annuals to interseed into

existing Bermudagrass pastures, but the ultimate goal for choosing the species is to maximize animal performance, animal BW gain per hectare, and overall profitability (Beck et al., 2007). Providing forage maturity is managed appropriately, winter annuals are high quality forages (Lippke et al., 2000). However, there may be rapid decreases in CP concentration as winter annuals mature or as the grazing season progresses (Branine and Galyean, 1990).

Successfully establishing winter annual forages interseeded into Bermudagrass sod pastures to improve efficiency of land use and provide high-quality forage for grazing may be challenging. However, one method to improve the success of this grazing strategy may include disking pastures and using annual ryegrass (*Lolium multiflorum*) alone or in combination with small grains, such as rye or wheat. Interseeding with these forages may provide ideal winter grazing for fall-weaned calves, thus allowing producers to retain ownership and reduce hay and grain consumption while improving gains in stocker cattle over winter (Coffey et al., 2002). Not only did the addition of ryegrass to small grains interseeded into Bermudagrass pastures increase final BW and average daily gain (ADG) of stocker calves grazing in the spring months, but it also increased the number of animal grazing days and animal BW gain per hectare compared to calves grazing small grains only (Beck et al., 2007). Additionally, the amount of forage DM was increased by 17% in the spring which increased pasture net return per hectare when ryegrass was interseeded with small grains into Bermudagrass pastures (Beck et al., 2007). Winter grazing, as well as spring grazing, of small grains-based pastures in areas of southeastern United States may be extended with the addition

of annual ryegrass due to its high percentage of growth throughout the winter months and also later into the spring with favorable warm and moist weather conditions (Beck et al., 2005). However, during cold periods of grazing, the addition of wheat or rye with annual ryegrass may increase forage productivity when seeded into clean-tilled crop fields (Beck et al., 2005).

Coffey et al. (2002) reported BW gains of stocker calves over a three-year period in southeastern Arkansas ranged from 0.20 to 0.89 kg/d during December through January and were similar when grazing ryegrass alone or when grazing blends of ryegrass with wheat or rye. Additionally over a three-year period, stocker calves grazing wheat, Italian ryegrass, or combinations of cereal rye with Italian ryegrass seeded in clean-tilled fields had ADG of 0.85 to 1.56 kg and similar BW gains per hectare during the winter months (Beck et al., 2005). In southern Georgia, calves grazing ryegrass or oats had similar ADG and BW gain per hectare (Utley et al., 1976). However, Beck et al. (2007) suggested the addition of ryegrass in grazing programs effectively increased forage availability for improved animal performance, BW gain per hectare, and overall profitability of the grazing program. The ADG reported by Beck et al. (2007) for calves grazing winter annual forages was generally lower than ADG reported for calves grazing cool-season grasses that had been seeded into dedicated crop fields (Horn et al., 1995; Beck et al., 2005) but were similar to ADG observed by calves grazing interseeded forages (Coffey et al., 2002; Gadberry et al., 2004). Beef heifers supplemented with corn and de-oiled rice bran at 1% of BW while grazing wheat or annual ryegrass interseeded into Bermudagrass pastures from December through March gained an average of 0.74 kg

of BW daily (Gadberry et al., 2004). Nonetheless, calves grazing high-quality, cool-season annual grasses interseeded into Bermudagrass pastures in Arkansas should realize daily winter gains of at least 0.91 kg providing adequate forage is available (Beck et al., 2007).

Forage Species Implemented in Stockpiled Fall Grazing Systems

In the southern United States, tall fescue is well-suited and commonly used as a dominant forage in stockpiled grazing systems. The upright growth pattern characteristic of tall fescue enables the plant to maintain its biomass above an 8 cm height, thus reducing the number of leaves that exist at ground level for reduced overall leaf rot and forage quality decay as winter progresses (Riesterer et al., 2000). Other research suggests that orchardgrass is suitable for stockpile grazing because of its consistently high autumn forage yields and tolerance to freezing conditions (Premachandra et al., 1993). Orchardgrass has increased cell membrane stabilization, decreased leaf water and osmotic potential, and increased turgor pressure as temperatures decrease in autumn, thus making the grass plant more tolerable to cold conditions (Premachandra et al., 1993). Additionally, Riesterer et al. (2000) suggested that the stiff sheath of orchardgrass and the jointed stems of reed canarygrass may be effective in preventing the grasses from becoming flattened under the weight of snow. If forage remains more vertical, it is more accessible for grazing through snow and may be more effective for stockpiling in northern climates (Riesterer et al., 2000).

Based on forage availability and forage utilization, Riesterer et al. (2000) states quackgrass and smooth brome grass are not suitable for stockpiling in southern Wisconsin. Smooth brome grass and quackgrass have low standing forage accumulation in late fall, regardless if fertilized with nitrogen, and therefore would not be effective forages in winter grazing systems. However, tall fescue, reed canarygrass, and early-maturing orchardgrass are more adapted as effective stockpiled forages for grazing during the Wisconsin winter season. Additionally, it is appropriate to graze late-maturing orchardgrass and timothy following a frost but before snow cover limits forage accessibility by livestock (Riesterer et al., 2000). Riesterer et al. (2000) reported average forage losses over winter of 22% and 31% for stockpiled cool-season forages in Wisconsin. The authors concluded that most losses in forage DM occur over winter due to lodging and freezing under heavy snow, and leaf losses and biomass losses occur due to rainfall either in fall or spring in Wisconsin (Riesterer et al., 2000). Rainfall must also be considered when choosing which forage type to implement in a stockpiled fall grazing system. Baron et al. (2004) reported with above average rainfall, timothy, crested wheatgrass, and orchardgrass had greater forage DM accumulation, whereas in years lacking adequate moisture, bromegrasses were able to produce adequate forage accumulation. However, alfalfa and meadow bromegrass-alfalfa mixtures are best suited for early fall grazing because of their large forage DM losses over the winter months (Baron et al., 2004).

Use of Annual Ryegrass in Stockpiled Fall Grazing Systems

Although not widely researched in the upper Midwest, annual ryegrass (*Lolium multiflorum*) is a high quality forage that may be viable for stockpiling in the lower Midwest (Kallenbach et al., 2003). With continuous grazing, CP concentration of Marshall ryegrass was reported to range from 11 to 26%, with lower concentrations likely due to inadequate nitrogen fertilization or time of harvest relative to nitrogen fertilization (Hafley, 1996). Even with apparent low CP concentrations, most ryegrass contains CP concentrations that are sufficient to meet requirements of growing beef cattle (NRC, 2000). In the vegetative state, annual ryegrass may have CP concentrations greater than 20% DM, while NDF and ADF concentrations may remain less than 40% and 22%, respectively (Mooso et al., 1990). Maximum NDF and ADF concentrations reported by Kallenbach et al. (2003) for annual ryegrass were 45.5% and 25.2%, which is likely acceptable quality for most classes of beef cattle (NRC, 2000). Due to potentially low fiber concentrations in annual ryegrass, the forage may be highly digestible and enable stocker calves to gain from 0.5 to 1.5 kg of BW daily (Sladden and Bransby, 1992).

In southern and southeastern United States, annual ryegrass is the most commonly grown cool-season forage (Evers et al., 1997) and is often interseeded into warm-season perennial grass pastures to increase forage production and quality (Rouquette et al., 1997). Additionally, annual ryegrass is a highly productive forage with high nutritive value, is easily established, and is tolerant to different stocking rates and defoliation intervals (Rouquette et al., 1997). In southern and southeastern United States, annual ryegrass is most productive from March to May; thus, producers in these regions may

interseed small grains with annual ryegrass to increase forage production of pastures during late December to mid-February (Evers et al., 1997). In more northern climates, annual ryegrass is useful in fall grazing systems because of its hardiness and tolerance to colder weather. While adequate precipitation during April, May, and June is essential to maximize forage production in the upper Midwest, tolerance to climate conditions will also enable forages to be productive later into the growing season (Haferkamp et al., 2005).

When grazing later into the fall months in the upper Midwest, it is important to utilize forages that not only increase the amount of forage DM but also improve forage quality available to cattle. Growth rates of annual ryegrass in the lower Midwest have been as high as 49 kg per hectare per day during the autumn months (Cuomo et al., 1999). Additionally, annual ryegrass may continue to grow following the first killing frost in the fall. It has been reported that annual ryegrass lacks true dormancy, thus allowing it to continue growth and maximize forage accumulation even after a frost if warm weather periods occur into late autumn or early winter (Keatinge et al., 1980; Hoveland et al., 1991). Some cold tolerant cultivars of annual ryegrass may continue growth even when average daily temperatures are less than 6°C (Keatinge et al., 1980; Cherney and Robinson, 1985). In Louisiana, approximately 40% of the total forage growth of annual ryegrass cultivars occurs in December through February, with the remaining 60% growth occurring from March to May (Redfearn et al., 2002). Regional differences in climate and growing season will affect when particular forages can be effectively grazed by cattle. Because nitrogen is the first-limiting nutrient for cool-

season forage growth and quality, proper soil nutrient management, as well as rainfall and soil water status, is necessary to ensure optimum nitrogen fertilizer response to maximize grazing animal performance (Sheehy et al., 1996). Although there are often decreases in forage CP and increases in forage fiber concentrations over the winter for stockpiled annual ryegrass, the loss in forage quality over time is generally not severe enough to restrict animal performance. Thus, with proper management, producers may have the option of grazing stockpiled annual ryegrass rather than feeding hay or silage to growing beef cattle (Kallenbach et al., 2003). Traditionally, backgrounding cattle on pasture is not commonly practiced in Minnesota due to the short growing season, but annual ryegrass fall grazing systems may provide opportunities for beef producers to consider backgrounding in Minnesota.

Managing Forages in Stockpiled Fall Grazing Systems

Grazing stockpiled forages can be an effective strategy for growing stocker calves. However, this class of cattle requires higher CP and energy concentrations in forage to allow maximum performance, so forages used in these grazing systems may require more management than forages grazed by mature beef cows. Management practices to optimize efficiency of the forage system and performance of weaned calves on stockpiled pastures include using appropriate stocking rates, managing forage DM production, understanding the relationship among herbage maturity, total production, and nutritive value, and implementing appropriate supplementation programs when necessary (Vendramini et al., 2006). For weaned beef calves grazing wheat pastures in Oklahoma,

the threshold level of forage allowance or available forage mass is 20 to 24 kg of DM per 100 kg of BW or 1,243 to 1,339 kg of DM per hectare to allow optimal forage DMI, organic matter digestibility, and ADG (Redmon et al., 1995). In contrast, Lippke et al. (2000) reported 850 kg of forage DM per hectare was the minimum quantity to support maximum ADG of stocker calves grazing wheat pasture.

When preparing forage for grazing calves, it is important to maximize forage accumulation and forage quality. Forage maturity is the major factor that affects plant morphology, thus contributing to reduced forage quality of standing forages over the duration of the grazing period (Nelson and Moser, 2004). Forage maturity can be managed by altering forage regrowth interval, either by period grazing or mowing for hay production. Awareness of variation in herbage mass and accumulation rate of ryegrass during optimal periods of growth for cool-season annuals will enable appropriate pasture management decisions (Vendramini et al., 2008b). During periods of rapid growth of cool-season annuals, a shorter forage regrowth interval is important to maintain nutritive value that will support BW gains by stocker calves (Vendramini et al., 2008b). Due to a smaller body size and rumen capacity compared to mature cattle, stocker calves grazing stockpiled annual forages will have improved performance with forage that is less mature. A longer regrowth interval results in advanced maturity of forage available for grazing because the proportion of total herbage as leaves decreases while the stem to leaf ratio increases (Vendramini et al., 2008b). Due to the increased structural carbohydrate concentration of forage stems, there is a linear decrease in *in vitro* digestibility of organic matter, which reduces DMI by grazing stocker calves; therefore, a

less mature forage sward will have greater digestibility and will support improved intake and ADG of stocker calves (Vendramini et al., 2008*b*). Stocker calves grazing seeded pastures also had improved ADG due not only to increased forage quality, but also to decreased energy expenditure compared to calves grazing native rangeland (Haferkamp et al., 2005).

Swathed Forage Fall Grazing System

A second fall grazing strategy used to reduce winter feeding expenses is swath, or windrow, grazing. The objective of this grazing system is to provide forage stored in swaths that will meet the nutrient requirements of a certain class of grazing beef cattle. Allowing the animal to harvest forages by grazing hay in windrows may preserve forage quality while reducing the need for baling, moving, stacking, feeding, and removing hay and manure waste after feeding; thus reducing the associated expenses of harvesting forages for winter (Munson et al., 1999). Additionally because cattle are grazing on pasture, they are in an environment that promotes animal health because it is clean and animals are able to exercise (McCaughey, 1997). Another advantage of swath grazing is the potential for livestock to select high quality, green regrowth between the windrowed forage for grazing (Volesky et al., 2002). There has been research on the effectiveness of grazing swathed forages with mature beef cows, pregnant beef heifers, and growing beef calves.

Managing Forage Quality in a Swathed Fall Grazing System

Allowing beef calves to graze forage stored as windrows over the winter months has been an effective management strategy for growing calves in some regions of the United States. Management of forage maturity prior to swathing may need to be more intense to ensure forage quality can meet nutritional requirements of this class of livestock. Volesky et al. (2002) reported forage quality remained relatively constant and high enough throughout the fall and early winter to allow beef calves to gain BW while grazing mixed forage (predominately cool-season species) stored in windrows. Calves grazing forage stored in windrows in western Canada had greater ADG than calves fed baled hay during November and December; however, ADG was similar between both groups of calves during January (Volesky et al., 2002). In the experiment, forage quality of standing forage, baled forage, and forage stored in windrows was monitored over time from September through February. When tested in September, CP concentration of standing forage, baled forage, and forage stored in windrows was similar and averaged 10.6%. While CP in both baled and swathed forage remained the same, CP in standing forage decreased to 5.7% by February (Volesky et al., 2002). Forage fiber concentrations increased in standing forage and forage in swaths over time. Initial forage NDF was similar and averaged 63.6% across standing forage, baled forage, and forage stored in windrows. Over time, NDF concentrations averaged 73.1% between standing and swathed forage and remained higher than baled forage (65.7%) from November to February. Similar to NDF, ADF concentration was comparable for standing forage, baled forage, and forage stored in windrows in September and averaged 39.1%.

Although there was no difference in ADF concentration between standing forage and forage stored in windrows, ADF concentration increased over time compared to baled forage and averaged 46.2% in February (Volesky et al., 2002). The authors concluded decreased forage quality after October was largely attributed to weathering and its associated nutrient losses due to leaching and leaf loss.

Managing Forage Waste in a Swathed Fall Grazing System

Another challenge associated with fall grazing swathed forage with stocker calves is potential for forage waste. With proper management strategies, waste can be reduced to allow efficient utilization of forage. It is important to reduce forage waste when grazing swathed forage since residual forage in windrows appears to deteriorate rapidly, especially if there is precipitation throughout the winter and into the spring months (Volesky et al., 2002). Thus, if forage is left behind following grazing, there will be little material left the following spring which results in increased forage waste and potentially large economic losses for the producer. Strip-grazing windrowed forages using temporary fencing is an effective method to manage the amount of forage available for cattle to graze at one time. Allowing cattle access to a supply of forage that will meet requirements for one to two days at a time will help minimize forage that becomes trampled and wasted (Volesky et al., 2002), but the extra management necessary for moving fences more frequently will increase labor requirements. In a study conducted in Canada, forage waste averaged 29% when grazing stocker cattle on swathed forage. Stocker calves fed hay had forage refusals averaging 12.5%; thus there may be

considerable forage waste when calves are managed in a swathed grazing system. When grazing swathed forage with stocker calves, the overall percentage of forage waste may be significantly reduced by grazing mature cows after the calves have finished grazing an area (Volesky et al., 2002).

Advantages of Grazing Stocker Cattle on Pastures during the Backgrounding Phase

Grazing stocker calves on winter pasture allows beef producers to retain ownership while reducing reliance on stored or purchased feedstuffs compared to calves that are grown and finished under conventional confinement feeding (Phillips et al., 2004). Even with increasing forage availability and forage quality with cool-season grasses in fall grazing systems, there may be a shortage in forage allowance during the fall and winter months. Providing protein or energy supplementation may extend the grazing season, improve forage utilization, and further reduce dependence on stored or purchased feedstuffs while promoting BW gains in stocker cattle (Scaglia et al., 2008). Steers grazing wheat pasture without supplementation had ADG from 0.80 to 0.97 kg during fall and winter (Horn et al., 1995). Coffey et al. (2002) compared growth performance of stocker calves backgrounded on winter annuals or supplemented with 2.7 kg per day of a grain sorghum-based supplement containing 15.3% CP and 1.3 Mcal NE_g per kg DM in addition to 0.29 kg of cottonseed meal while having *ad libitum* access to Bermudagrass hay. Calves grazing annual forage pastures had greater daily gains (1.0 kg vs. 0.64 kg) compared to calves consuming Bermudagrass hay and supplement after a 112-day backgrounding period (Coffey et al., 2002). If forage allowance is restricted

however, a grain or by-product based energy or protein supplement may be offered at 0.75% of BW to increase stocking rate or ADG (Horn et al., 1995).

Another benefit to grazing stocker calves on forages over winter is the opportunity to restrict energy consumption for the possibility of inducing compensatory gain during the finishing phase. Calves that are consuming diets low in digestible DM and CP, such as dormant native prairie or other forages, may be temporarily restricted in energy and protein intake. However, when energy restriction is lifted, such as when cattle are placed in feedlots and consume high-concentrate finishing diets, there is an opportunity for a period of rapid and efficient gain. There may be mixed performance responses when calves are switched from a low energy diet to a high concentrate diet. Tolley et al. (1988) reported that calves switched to wheat forage, which is high in digestible DM and CP, after grazing dormant native range required an adjustment phase, both metabolically and physiologically, before positive BW gains were achieved. Calves may need up to 21 days before they fully adapt to the new diet (Phillips and Von-Tungeln, 1995). Generally, compensatory gain by stocker calves occurs during the first 28 days in the feedlot (Choat et al, 2003). If a producer is trying to elicit compensatory gain with stocker calves on wheat forage, the adaptation phase may overlap and suppress any expression of compensatory gain (Phillips et al., 2004). Because wheat forage contains high concentrations of soluble nitrogen, water, and digestible DM, stocker calves may not readily consume this forage when first introduced on wheat pasture, which may increase the adaptation phase (Phillips et al., 2000). Compared to wintering calves on wheat pasture, restricting ADG by limit-feeding a mixed diet to stocker calves

during the winter months elicited increased ADG upon feedlot entry (Phillips et al., 2004). Producers have options for feedstuffs that add BW to stocker calves, so the decision to utilize forages or grains to produce early BW gains may depend largely on economics. Stocker calves fed either forages or grains may have similar early BW gains, but feeding grains to cattle are more efficient than forages at adding BW later during the finishing period (Brokken and Bywater, 1982).

Options for Conventional Backgrounding Systems

The two major systems that determine age at time of feedlot entrance are finishing cattle either as calf-feds or yearlings. According to Klopfenstein et al. (2000), approximately 30% of calves born in the United States enter feedlots as calf-feds. The goals of the producer, the type of cattle, availability of forages and feedstuffs, and market outlooks will dictate which program is used. In the calf-fed system, calves are placed directly into the feedlot and consume high-energy diets approximately 30 to 40 days after weaning. Calves in yearling programs are usually nutritionally restricted to varying degrees for different lengths of time to induce compensatory gain during the finishing phase (Klopfenstein et al., 2000). Calves, especially heifers or British breeds, placed in yearling programs are generally grazed on pastures, crop-residues, or other low-input, forage-based systems or fed low energy, forage-based rations in a dry lot to increase frame size and BW prior to feedlot entrance. Differences in total DOF, nutritional backgrounds, and feedlot entrance BW according to system may influence feedlot performance and carcass characteristics of steers and heifers (Klopfenstein et al., 2000).

Due to heavier feedlot entrance weights, yearling cattle will generally consume more feed and gain more rapidly in the feedlot compared to calf-feds. Also, calf-feds tend to convert feed to gain more efficiently than yearlings, but yearlings typically have leaner carcasses with heavier hot carcass weights (HCW) and lower percentages of carcasses grading USDA Choice (Sindt et al., 1991). The heavier final live BW of yearling steers can positively influence gross income when sold either live or on a grid, reduce chance of lightweight carcass discounts in some British breeds and heifers, and reduce break-even prices; however, the additional weight in some larger-framed, Continental breeds may actually increase discounts applied to overweight carcasses, so endpoint goals that match the type of livestock being fed should influence choice of stocker cattle program used (Shain et al., 1998).

Deposition of intramuscular fat, or marbling, is a lifetime event and begins at an early stage of growth in cattle. Glucose is well-known to be the primary substrate for intramuscular lipid deposition unlike the use of acetate in subcutaneous fat deposition (Smith and Crouse, 1984). The presence of glucose or glucose precursors, such as propionate, may increase the presence of enzymes and hormones that facilitate fatty acid synthesis and subsequent deposition to improve meat quality (Smith and Crouse, 1984). Research indicates feeding high concentrate, high energy grain diets in calf-fed systems to early-weaned steers and heifers may effectively improve feed efficiency and carcass quality by initiating the onset of marbling at an earlier age. The result is an advantage in increased overall intramuscular fat and therefore, greater percentages of carcasses grading USDA Choice or higher at the end of the feeding phase than calves that were

grazed on pasture before entering the feedlot (Loy et al., 1999; Myers et al., 1999). Cattle placed on high (75%) concentrate diets had higher proportions of ruminal propionate and lower proportions of ruminal acetate to allow for increased marbling compared to cattle fed on low (25%) concentrate rations offered *ad libitum* (Wertz et al., 2001b).

Wertz et al. (2002) studied performance and carcass characteristic differences between heifers fed in an accelerated program versus 2-year old heifers. The results suggest that early-weaning heifers and finishing them in a calf-fed program increased gain efficiency as well as marbling deposition compared to heifers backgrounded on pasture and finished as 2-year olds. The proportion of intramuscular fat relative to subcutaneous fat was increased in the calf-fed heifers which allowed heifers to reach higher USDA quality grades and obtain grid premiums before attaining less desirable USDA yield grades compared to heifers finished in long-yearling programs (Wertz et al., 2002).

Goals of the yearling program are to increase frame size and muscle accretion of stocker calves, as well as induce compensatory gain, to realize an economic advantage during the overall finishing phase by restricting feed or energy intake through utilization of available forages prior to feedlot entry. However, feed restriction must be severe enough because it is possible to restrict feed intake without realizing the benefits of compensatory gain during the finishing period. Wertz et al. (2001a) did not induce compensatory gain when restricting intake of a wet corn gluten feed (WCGF)-based diet to heifers at 83% *ad libitum* intake. The lack of feed restriction, a failure to reduce the

gastrointestinal tract volume due to the fibrous nature of the WCGF, or a combination of the two factors may have contributed to why compensatory gain in the feedlot did not occur. However, Sainz et al. (1995) induced compensatory gain during the finishing phase when cattle were limit-fed concentrate intake to 54% *ad libitum* during the backgrounding phase. Because intestinal and liver size fluctuate with intake level and may contribute to large proportions of total body energy expenditure (Wester et al., 1995), a potential explanation for the increased efficiency and therefore compensatory gain as a result of restricting intake may be attributed to having more energy partitioned to muscle accretion. More energy may be available as a result of reduced maintenance energy requirements from a smaller gastrointestinal tract or reduced energy cost of tissue synthesis (Sainz et al., 1995).

Following through to slaughter, HCW was nearly 13 kg heavier for heifers consuming the WCGF-based diets *ad libitum* during the growing phase compared to heifers that were restricted to 83% *ad libitum* intake (Wertz et al., 2001a). When fed to a common number of DOF, the limit-fed heifers had lighter HCW, reduced marbling scores and subsequent lower USDA quality grades, less 12th rib backfat, and therefore, improved USDA yield grades compared to the non-restricted heifers. During the overall feeding phase, heifers fed the WCGF-based diet *ad libitum* consumed 0.75 kg more DMI and gained more rapidly during the growing phase than the average of the limit-fed heifers even though overall feed efficiency was not different due to intake among heifers. Conclusions from this study indicate limit-feeding WCGF and corn-based diets to growing beef heifers can allow moderate rates of gain without negatively impacting feed

efficiency. Although WCGF or other alternative feedstuffs can successfully replace portions of corn grain in limit-feeding situations, total DOF may be increased during the finishing phase compared to heifers grown on *ad libitum* intake. Thus, economic advantages of reducing feed costs during the growing phase may be lost due to expenses incurred with additional DOF or reduced income due to lighter HCW and lower USDA quality grades at time of slaughter (Wertz et al., 2001a).

Methods of Estrus Prevention in Feedlot Heifers

Depending on age, breed, weight, and nutritional status, heifers may reach puberty between 8 and 16 months of age. Estrus activity during the backgrounding phase or in the feedlot increases the risk for bodily injury induced by riding activity. Additionally, one heifer exhibiting estrus in a feedlot pen can severely disrupt and reduce DMI and performance of the entire pen. Undetected pregnant heifers in the feedlot can be a significant economic problem. Therefore, methods of estrus suppression and prevention of pregnancies in heifers must be managed to improve performance in the feedlot. There are several ways this has been accomplished which include the most common method of oral supplementation of melengestrol acetate (MGA) and less common methods of non-surgical, active immunization against gonadotropin-releasing hormone (GnRH) and surgical removal of ovarian tissue through spaying or ovariectomizing feedlot heifers (Adams et al., 1990).

Estrus Prevention via Melengestrol Acetate

Supplementing MGA, an oral synthetic progestin that enhances endogenous estrogen production to increase growth, in finishing diets fed to intact, pubertal heifers helps improve gains and efficiencies by eliminating estrus occurrence, activity, and subsequent stress in the feedlot. The mode of action of MGA or other synthetic forms of progesterone inhibit the gonadotropic complex through the interaction of luteinizing hormone with follicle stimulating hormone to alter ovarian function and eliminate the estrous cycle (O'Brien et al., 1968). By eliminating estrous activity and disruption of normal heifer behavior and also maintaining uninterrupted influence of endogenous estrogens as a natural anabolic agent to increase growth and muscle accretion, feeding MGA allows heifers to gain BW and convert feed to gain similarly to steers in the feedlot (O'Brien et al., 1968).

Heifers supplemented with MGA have been observed in estrus in the feedlot; however, this incidence of estrous behavior is usually very low and more likely to occur when low (0.3 to 0.4 mg/d instead of the recommended 0.5 mg/d) doses are fed (Bloss et al., 1966; Zimelman and Smith, 1966; O'Brien et al., 1968). Compared to non-supplemented heifers, MGA-supplemented heifers gained 6% faster and required 9% less feed per unit of gain (Bloss et al., 1966; Utley et al., 1972). In a meta-analysis of 18 research trials, both implanting feedlot heifers with estrogenic implants or supplementing heifers with MGA increased DMI; however, supplementing heifers with MGA increased back fat depth, decreased longissimus muscle (LM) area, increased USDA yield grade, and increased percentage of carcasses with USDA Yield Grades 4 and 5 (Wagner et al.,

2007). Synthetic progestins may act directly on muscle cells by reducing DNA synthesis and the rate of muscle cell deposition for reduced muscle cell proliferation (Sissom et al., 2006); thus, MGA may reduce performance while increasing fat deposition when supplemented to feedlot heifers (Wagner et al., 2007).

Estrus Prevention via Active Immunization Against GnRH

Early research suggests active immunization against GnRH reduces the size and secretory activity of gonadal tissue in heifers due to suppression of the release of gonadotropin from the anterior pituitary gland (Adams and Adams, 1986). In the absence of gonadotropins, atrophy of the gonadal tissue occurs, thus inhibiting gametogenesis and preventing estrous behavior and reproductive function in beef heifers (Adams and Adams, 1990). Using the method of active immunization against GnRH has been proposed as a more humane and less invasive alternative to surgical methods of spaying heifers (Robertson et al., 1979).

Estrus Prevention via Spaying Heifers

A management tool used more extensively in western United States ranching states for estrus suppression and prevention of pregnancy in the feedlot is spaying heifers. Spaying, or ovariectomizing, heifers involves surgically removing both ovaries so heifers will not exhibit estrus (Klindt and Crouse, 1990). There are many advantages associated with spaying heifers prior to feedlot entrance. These advantages include maintaining stocker or feeder heifers in an open or neutered status (Klindt and Crouse, 1990), early

detection of pregnant heifers and prevention of pregnant heifers in the feedlot (Adams et al., 1990), elimination of feeding estrus-suppressing feed additives, elimination of checking heifers for pregnancy prior to feedlot entry (Garber et al., 1990), improved ADG and feed conversion when spayed heifers are implanted versus intact, implanted heifers (Garber et al., 1990), and ability to graze or feed heifers and steers together and within fence-line contact of herd sires.

Spaying can be accomplished either as flank spaying or vaginal spaying. Flank spaying requires more invasive surgery and has resulted in additional scarring, tissue cut-out losses, and increased costs and subsequent profit losses for packing plants, so techniques and instruments for vaginal spaying were developed. With development of the Willis, the Kimberling-Rupp, and other similar spaying instruments, speed and ease of spaying heifers increased while reducing negative effects of scarring and cut-out losses, thus allowing spaying heifers to become a more practical method of estrus suppression and pregnancy prevention in the feedlot (Rupp and Kimberling, 1982). The procedure for spaying heifers described by Garber et al. (1990) involves restraining the heifer in a standing position in a squeeze chute, washing and disinfecting the vulva and surrounding area prior to insertion of the sterilized instrument into the vagina. The instrument is then pierced through the wall of the vagina, and the ovaries are located via palpation by an experienced veterinarian performing the surgery. Once located, each ovary is placed through the open end of the instrument, severed from the ovarian ligament, and allowed to drop within the abdominal cavity. A long acting antibiotic is administered to each heifer at the time of spaying for prevention of infection from the

surgery. The procedure is quick, and heifers displayed very little discomfort besides some heifers that exhibited arched backs or raised tails for several hours following surgery. There is typically no death loss or incidence of excessive bleeding reported following vaginally spaying heifers (Garber et al., 1990).

Vaginally spaying feedlot heifers was reported to be 96% successful by Garber et al. (1990). There is potential for vaginal spaying to be incomplete, but these instances are quite rare. Because the veterinarian performing the surgery cannot directly see the ovaries and must rely on palpation to locate and sever them with the instrument, it is possible to completely miss or only partially sever an ovary. In these instances, or if the ovary reattaches to the abdominal mesentery, there is potential for the ovary to function normally to allow heifers to exhibit behavioral estrus in the feedlot (Garber et al., 1990). Success of the spaying procedure should increase as the veterinarian performing the surgery becomes more experienced.

Effects of Estrus Prevention on Feedlot Heifer Performance and Carcass

Characteristics

Active immunization against GnRH reduced feedlot performance in beef heifers. Heifers that were immunized had reduced weight gain, reduced ADG, and reduced feed efficiency compared to non-immunized heifers (Adams and Adams, 1990). During the last four weeks of the finishing phase, heifers actively immunized against GnRH gained 0.76 kg/d while non-immunized heifers gained 1.32 kg/d. Likewise, heifers actively

immunized against GnRH required 9.8 kg compared to 7.1 kg of feed per kg of gain required by intact, non-immunized feedlot heifers (Adams and Adams, 1990).

When spaying heifers, removal of both ovaries eliminates endogenous sources of gonadal steroids, mainly estrogen and progesterone, which has been related to reduced intake, ADG, and feed efficiency in the feedlot (Horstman et al., 1982). Over a four-month finishing period, suppression of endogenous steroidogenesis due to ovariectomy or immunization against GnRH tended to reduce feedlot performance variables of ADG, final live BW, and HCW, while heifers that were ovariectomized had increased marbling compared to implanted, actively immunized heifers and had reduced dressing percentage compared to implanted control and MGA-supplemented finished heifers (Adams et al., 1990). In contrast to Adams et al. (1990) and earlier reports (Dinusson et al., 1950; Kercher et al., 1960; Nygaard and Embry, 1966; Horstman et al., 1982), Hamernik et al. (1985), Crouse et al. (1987), and Klindt and Crouse (1990) reported ovariectomy did not reduce ADG or feed efficiency in feedlot heifers. Ovariectomized heifers fed for 112 d on a 70% steam-rolled barley diet had similar growth performance, feed efficiency, and carcass characteristics as intact heifers receiving 0.35 mg per head MGA daily and to hysterectomized heifers (Hamernik et al., 1985). Heifers weighed 300 kg at time of spaying, so perhaps differences in age at time of spaying, a shorter finishing phase, and the concentration of supplemented MGA in their study attributed to similar performance among all heifers (Hamernik et al., 1985). The potential negative effects associated with ovariectomizing heifers are not expressed consistently and may be dependent upon management factors that include feedlot entry weight, length of finishing phase, number

of heifers housed per pen, pen size, and composition of finishing diets (Adams et al., 1990).

An experiment conducted by Field et al. (1996) evaluated carcass maturity differences in spayed heifers, virgin heifers, and single-calf heifers that were all of similar breed (Angus/Gelbvieh cross), age, fed to have similar body condition on pasture, and were removed from pasture and fed for 100-d in the feedlot prior to slaughter in groups (with all treatments represented equally) at 31, 33, and 35 months of age. There were no differences in total weight gain during the finishing phase or in slaughter age among all heifers. Spayed heifers had higher dressing percentages at slaughter than both virgin and single-calf heifers, perhaps because spayed heifers had less reproductive tract development than other heifers (Field et al., 1996). Carcasses of spayed heifers had similar marbling and lean maturity scores as other heifers, but spayed heifers had younger maturity scores for sacral, lumbar, and thoracic vertebrae, likely due to lower influence of estrogen on carcass maturity (Field et al., 1996). Influence of endogenous estrogen may increase calcium deposition in skeletal bones, thus increasing the maturity score (Field et al., 1996). However, rib bone maturity was similar for all heifers, but overall bone maturity scored within the A, B, and C maturity groups for spayed, virgin, and single-calf heifers, respectively (Field et al., 1996). Similarly, carcasses from ovariectomized heifers had similar carcass maturity scores as steers but younger bone maturity scores compared to intact heifers (Klindt and Crouse, 1990). When bone growth was measured for heifers, metacarpal weight and length were heavier and longer for spayed heifers compared to bones from single-calf heifers (Field et al., 1996), suggesting that estrogen influence

during estrus, pregnancy, calving, and early lactation may have induced earlier growth plate closure and thus limited bone growth (Field et al., 1996).

Anabolic Steroid Strategies for Intact Feedlot Heifers

Use of growth-promoting agents is a common management practice to improve ADG, increase final live BW, and enhance efficiency of feedlot cattle. The majority of implants contain estrogenic, androgenic, or a combination of estrogenic and androgenic properties. Estrogenic implants increase thyroid gland activity and intake (Trenkle, 1997), and implants containing trenbolone acetate (TBA) decrease maintenance energy requirements to reduce metabolic heat load and increase feedlot efficiency (Hunter and Vercoe, 1987). Anabolic implants primarily increase muscle mass and subsequent BW gain by increasing the rate of protein accretion with little or no negative impacts on fat deposition rate. This allows an increase in cattle growth rates to attain similar empty body fat percentages at heavier final BW as non-implanted cattle (Hutcheson et al., 1997; Guiroy et al., 2002). Although anabolic implants are effective growth agents and improve feedlot performance in finishing cattle, research suggests certain implant strategies may reduce tenderness and consumer acceptability of beef retail products (Platter et al., 2003).

Recommended long-term implant programs for young, recently-weaned heifer calves may include an initial implant that contains low- or moderate-estrogenic activity followed by subsequent re-administration of an implant containing estrogenic or androgenic activity every 70 to 100 days thereafter (Mader, 1994). For yearling heifers,

the combination of feeding MGA and implanting either initially or approximately 60 days after feedlot entrance with implants containing androgenic activity seem to induce superior performance than management strategies that do not involve feeding MGA and initially implanting with estrogenic activity followed by re-implant with estrogenic and androgenic combinations later. An example of this management strategy would be to implant initially with Synovex[®] C or Synovex[®] H followed by a re-implant with Synovex[®] H or Finaplix[®] H (Mader and Lechtenberg, 2000).

A meta-analysis of 18 feedlot experiments suggested that implanting finishing heifers with TBA increased final BW, ADG, gain to feed (G:F), and HCW without affecting DMI (Wagner et al., 2007). Additionally, implanted heifers had larger LM area and improved USDA yield grade compared to non-implanted heifers (Wagner et al., 2007). Although the synthetic progestin, MGA, acts to block ovulation and estrus activity in beef feedlot heifers, the ovaries in MGA supplemented heifers still contain large (> 2 cm) follicles that produce estrogen (Zimbelman and Smith, 1966), to allow increased and faster weight gain compared to heifers that are not under estrogenic influence (Bloss et al., 1966). Overall performance improvements associated with supplementing heifers with MGA may not be additive or expressed in feedlot heifers that receive estrogenic, androgenic, or combination implants. A review of studies suggested there was no improvement in feedlot performance when supplementing MGA to implanted heifers regardless of implant strategy, but implanted heifers supplemented with MGA had increased backfat thickness (Hutcheson et al., 1993). Performance results are mixed, however, as some reports suggest there is an added performance response when

supplementing MGA to heifers that are implanted with androgenic implants (Duckett et al., 1997; Wagner et al., 2007).

Anabolic Steroid Strategies for Spayed Feedlot Heifers

Endogenous anabolic effects of the ovaries must be replaced in spayed heifers via appropriate implant strategies to improve feedlot performance and efficiency (Adams et al., 1990). Previous research by Garber et al. (1990) suggested spayed heifers respond better to implants containing progesterone rather than testosterone and had more rapid BW gains and more efficient feed conversion. In the study, spayed heifers implanted with Synovex[®] H had a threefold improvement in ADG (0.30 vs. 0.09 kg/d increase) compared to intact heifers implanted with Synovex[®] H. Spayed heifers implanted with progesterone tended to have heavier final BW and therefore heavier HCW, decreased backfat thickness, and improved marbling scores and USDA yield grades, suggesting that implanting spayed heifers effectively partitions consumed dietary energy away from fat accretion to increase muscle protein deposition without negatively affecting USDA quality grade (Garber et al., 1990). Removal of the ovaries and therefore, endogenous production of estrogen and progesterone, render spayed heifers very similar to steers. Thus, implanting spayed heifers with a combination of estradiol and progesterone may be more effective in eliciting a performance response than implants containing a combination of estradiol and testosterone (Garber et al., 1990).

When spayed heifers or heifers actively immunized against GnRH were implanted with Synovex[®] H, weight gains improved and were comparable to total BW gains

realized by intact heifers that also received Synovex[®] H implants (Adams et al., 1990). As estimated from carcass density, total proportion of weight gain deposited as fat was increased in heifers actively immunized against GnRH and tended to be increased in ovariectomized heifers over a four-month finishing phase (Adams et al., 1990). However, this effect was reversed with concurrent administration of Synovex[®] H implants. When implanted, heifers either actively immunized or ovariectomized had composition of gain and similar protein deposition to intact heifers (Adams et al., 1990).

Potential Effects of Anabolic Steroids on Carcass Characteristics

Number, as well as potency, of implants administered during the finishing phase not only improves muscle deposition and animal growth performance but also may influence carcass quality and beef tenderness traits (Morgan, 1997; Smith et al., 2006). Greater potency implants administered more than once during the finishing phase have the most pronounced adverse effects on marbling and beef quality (Morgan, 1997), and some implant programs may result in advanced skeletal maturity (Reiling and Johnson, 2003). When an important goal of beef production is supplying high quality retail beef products that exceed consumer acceptance, careful consideration of implant strategies is necessary to optimize animal performance without sacrificing carcass quality and meat tenderness.

Schneider et al. (2007) evaluated carcass characteristics of feedlot heifers implanted with one or two androgenic implants (200 mg TBA each), a single combination implant (8 mg estradiol (E₂) and 80 mg TBA or 20 mg E₂ and 200 mg TBA),

or two, low-dose combination implants (8 mg E₂ and 80 mg TBA). In agreement with Berger and Galyean (2000) and Brandt et al. (2000), Schneider et al. (2007) reported heifers implanted with a single combination or low-dose combination implants had greater percentage of carcasses grading USDA Choice and Prime than heifers implanted with high, cumulative, combined doses of estrogen and androgens (i.e. two implants of 14 mg E₂ and 140 mg TBA, 8 mg E₂ and 80 mg TBA followed by re-implant with 20 mg E₂ and 200 mg TBA, 14 mg E₂ and 140 mg TBA followed by re-implant with 20 mg E₂ and 200 mg TBA, or two implants of 20 mg E₂ and 200 mg TBA). Additionally, single ingredient implants containing 200 mg of TBA had no negative effects on heifer carcass quality or meat tenderness, whereas the use of implants containing the combination of 20 mg of E₂ and 200 mg TBA reduced marbling score and increased strip loin steak Warner Bratzler shear force values (Schneider et al., 2007). However, post-mortem aging of carcasses for 28 days may negate tenderness differences for both implant strategies evaluated, so it may be possible to overcome negative impacts of growth-promoting agents on meat tenderness (Schneider et al., 2007).

Ethanol and Corn Milling Co-Product Production

As the United States attempts to further free itself from dependence on foreign oil, there is continued expansion of the fuel ethanol industry, particularly throughout the cornbelt in the Midwest. A greater proportion of the total corn supply is processed for ethanol production rather than being fed directly to livestock, so tighter corn supplies may be a significant factor contributing to current increased corn grain market prices in

the United States. Thus, there is an urgent need for feedlot producers to maximize inclusion concentrations of alternative feedstuffs in finishing diets for cattle to reduce cost of gain and overall production expenses. As stated in the January 2010 report by the Renewable Fuels Association, there are 189 ethanol biorefineries online that are slated to produce approximately 45 billion liters of ethanol annually (Renewable Fuels Association, 2011). In 2009, the United States ethanol industry produced 40.1 billion liters of ethanol that reduced dependence on foreign oil by 364 million barrels. Because the United States did not have to import this quantity of oil from other countries, the United States ethanol industry saved the economy \$21.3 billion. The money saved from reduced dependence of imported oil may be used domestically within the United States to create jobs and stimulate economic growth (Renewable Fuels Association, 2011).

From one bushel of corn, approximately one-third is returned back into the livestock sector as a feedstuff. In 2009, ethanol plants in the United States produced 30.5 million metric tons of high quality co-products, mainly distillers grains and corn gluten feed and meal, from 96.5 million metric tons of corn (Renewable Fuels Association, 2011). Ethanol plants are estimated to produce 33 million metric tons of co-product feeds for livestock and 44.7 billion liters of ethanol from 106.7 million metric tons of corn in the 2009/2010 marketing year (Renewable Fuels Association, 2011). Compared to corn grains, typical co-products are concentrated three times in protein and cell wall components, and the amount of starch remaining varies depending on the efficiency of the milling process (Kertz, 1998). The current energy concern in the United States has prompted ethanol companies to improve efficiency of ethanol production through

implementation of technological developments to more effectively utilize starch in corn grain. Development of improved corn milling processes not only results in greater ethanol production, but also different types of corn milling co-products are derived that may be fed to livestock (Ponnampalam et al., 2004; Murthy et al., 2006; Widmer et al., 2007). The production of ethanol is mitigated mainly through the dry milling process, but the wet milling process can yield ethanol as well. In addition to ethanol, dry milling results in production of dry and wet distillers grains and solubles which may or may not be added back to the grains at various concentrations. These co-products are attractive feed ingredients due to their improved energy value relative to corn, price, availability, flexibility in feeding, and propensity to alleviate incidence and severity of acidosis in feedlot cattle (Stock et al., 2000).

Traditional Dry Corn Milling Process for Ethanol Production

Described by Duensing and colleagues (2003), traditional dry milling begins with grinding whole corn grain, which is processed entirely without separation of the grain components, into flour or meal. The meal is mixed with water to form a mash, heated, and enzymes are added to the mash to convert starch into dextrose. To control the pH of the mash, ammonia is added which also serves as nutrient media for the yeast cultures. The mash is then cooked at high temperatures to impede bacteria before fermentation. After cooling, the mash is transferred to fermentation tanks, and yeast is added to convert dextrose molecules into ethanol and CO₂. The mash is fermented and agitated for 40 to 50 hours at cool temperatures to sustain yeast activity. Following fermentation, the

resulting product, known as ‘beer,’ is distilled through columns which separate the ethanol from the ‘stillage.’ The stillage is centrifuged to separate the wet grains from the liquid portion known as solubles. The grains can be dried through drum dryers to produce dried distillers grains. The solubles are evaporated and concentrated to produce condensed distillers solubles, commonly known as syrup. The solubles may be added back to the wet grains and marketed as wet distillers grains plus solubles (WDGS), partially dried and marketed as modified wet distillers grains plus solubles, or dried together to become the common livestock feed, dried distillers grains with solubles (DDGS). Exposure to high temperatures during manufacturing may damage a portion of the protein in DDGS (Kleinschmit et al., 2006) and this may reduce or render the protein unavailable to the animal (Licitra et al., 1996).

Innovative Dry Corn Milling Processes for Ethanol Production

Several ethanol companies have developed alternative technology to improve ethanol yield and resulting co-product nutrient availability (Ponnampalam et al., 2004; Murthy et al., 2006; 2009). Enhanced technology increases efficiency of ethanol production by capturing more starch and using less energy during the milling process (Ponnampalam et al., 2004). Improved biorefining methods may replace heating and cooking steps prior to fermentation in the traditional dry milling process with raw starch hydrolysis (Wang et al., 2007; Williams et al., 2010). Protein contained in the resulting dried distillers grains is less likely to have heat damage with removal of these high temperature steps (Kleinschmit et al., 2007; Williams et al., 2010). Proteins can be

denatured by high temperatures; therefore, heat-damaged proteins likely have lower solubility and rates of degradation in the rumen and consequently, may be less available for ruminal digestion (Firkins et al., 1984; Russell et al., 1992). In contrast, several studies have shown that variable amounts of heat-damaged protein do provide amino acids post-rationally (Nakamura et al., 1994; Klopfenstein, 1996; Schwab et al., 2003). Generally, these non-traditional distillers grains are of higher quality and nutritive value than distillers grains derived from the traditional dry milling process (Kleinschmit et al., 2006).

Another improved biorefining ethanol technology employs dehulling and degerming procedures prior to fermentation which fractionates whole corn into three main components of endosperm, germ, and bran (Corredor et al., 2006; Widmer et al., 2008; Murthy et al., 2009). The endosperm is fermented through a similar dry milling process that replaces high temperatures associated with heating and cooking with raw starch hydrolysis prior to fermentation to yield ethanol, corn condensed distillers solubles, and high protein dried distillers grains (Williams et al., 2010), which may be fed to livestock as an excellent source of digestible amino acids. The germ is dried and marketed as dehydrated corn germ meal. The solubles resulting from the fermentation process of the endosperm are not added back to the high protein dried distillers grains (Widmer et al., 2007; Williams et al., 2010) and may instead be added back to the bran, dried, pelleted, and sold as a livestock feedstuff high in digestible fiber (Janicek et al., 2007; Widmer et al., 2008). The chemical composition of the high protein dried distillers grains is different from traditional DDGS largely because of removal of the fiber during

the dehulling process prior to fermentation. Additionally, fat and P are concentrated more in the solubles fraction of distillers grains, and because solubles are not added to the high protein dried distillers grains, conventional DDGS is expected to have greater concentrations of fat and some minerals (Widmer et al., 2007).

Chemical Composition of Traditional Dried Distillers Grains Plus Solubles

Differences exist in the chemical composition of distillers grains plus solubles. These differences can be attributed to type of DDGS, method of production, day and location of ethanol plant, and quality of corn fermented. The Nutrient Requirements of Beef Cattle (2000) lists the chemical composition of several co-products. Dried distillers grains with solubles is 29.5% CP, 88% TDN, 46% NDF, 4.2% lignin, 10.3% ether extract, 8% degradable intake protein (DIP), 0.83% P, and 0.40% S (NRC, 2000). Spiehs et al. (2002) evaluated the chemical composition of DDGS from ten different ethanol plants in Minnesota and South Dakota over a three-year study. The authors analyzed 118 samples of DDGS from the ethanol plants and observed a range of 28.7 to 31.6% for CP [coefficient of variation (CV) = 6.4%], 10.2 to 11.7% fat (CV = 7.8%), and 36.7 to 49.1% NDF (CV = 14.3%). Kleinschmit et al. (2006) determined DIP, undegradable intake protein (UIP), digestible UIP (dUIP), and total digestible protein contents of various sources of DDGS ranged from 63.0 to 80.7%, 53.6 to 71.4%, 42.4 to 59%, and 70.7 to 85.3% of the CP, respectively. All corn milling co-products except corn gluten feed have UIP fractions greater than 50% (Clark et al., 1987). In comparison, soybean meal contains 87.6, 12.4, 40.3, and 93.9% of the CP for DIP, UIP, dUIP, and total digestible

protein contents, respectively. These values vary considerably due to differences in particle size, degradation rates, and grain processing methods (Kleinschmit et al., 2006).

Chemical Composition of Non-Traditional Dried Distillers Grains

Novel corn milling co-products may differ in chemical composition and nutrient availability compared to traditional co-products. Kelzer et al. (2010) evaluated the chemical composition of different corn milling co-products. Dried distillers grains plus solubles derived from a traditional dry milling process contained 86.9% DM, 25.9% CP, 33.9% NDF, 25.2% ADF, 6.9% starch, 11.8% ether extract, 0.56% S, and 0.86% P. A DDGS derived from an alternative dry milling process that uses raw starch hydrolysis rather than heating and cooking prior to fermentation contained 86.7% DM, 26.9% CP, 30.2% NDF, 13.1% ADF, 7.7% starch, 13.3% ether extract, 0.90% S, and 0.92% P. A high protein dried distillers grains (that do not contain solubles) contained 94.7% DM, 45.4% CP, 22.5% NDF, 6.6% ADF, 9.5% starch, 4% ether extract, 0.88% S, and 0.35% P (Kelzer et al., 2010).

Recommended Inclusion Concentrations of Distillers Grains Plus Solubles in Feedlot Diets and Feeding Value Relative to Corn

Distillers grains plus solubles derived from the ethanol industry contain low concentrations of starch and are excellent sources of protein and highly digestible fiber. Because of their high concentration of CP, DDGS initially were fed as a UIP source (Klopfenstein et al., 1978), with UIP values being up to 2.6 times greater than UIP values

of soybean meal (Aines et al., 1987). Corn bran contains 69% NDF, of which has been reported to have a high rate (6.2%/h) and extent (87%) of digestion (DeHaan et al., 1983). Carbohydrate concentration of DDGS is comprised mainly of highly digestible NDF, thus making DDGS an excellent energy source when fed to ruminant livestock. The gross energy concentration of DDGS is reported as 5,434 kcal/kg of DM and is greater than the gross energy concentration of corn grain (Stein and Shurson, 2009). However, when measured as a percentage of gross energy, digestibility of gross energy in DDGS may not be as high as the digestibility of gross energy present in corn, likely due to the increased concentration of fiber relative to corn (Stein and Shurson, 2009).

Feeding value relative to corn for corn milling co-products is dependent on type of co-product and diet composition in which it is included. Relative to corn, WDGS has greater energy value compared to DDGS and has been included in finishing diets as an energy source to replace portions of corn grain. In a study conducted by Vander Pol et al. (2006), WDGS was fed in place of corn at 0, 10, 20, 30, 40, and 50% inclusion concentrations to finishing yearling steers. The authors reported quadratic responses for DMI, linear and quadratic responses for ADG, G:F, and HCW, and cubic responses in feeding value relative to the control diet not containing WDGS. At 30% WDGS inclusion, DMI, ADG, and HCW were maximized at 11.8 kg/d, 1.96 kg, and 376 kg, respectively, while G:F was maximized at 0.176 with 40% WDGS inclusion. Relative to the control diet (reference value of 100), feeding value was 178, 138, 144, 137, and 121 for 10, 20, 30, 40, and 50% inclusion concentrations of WDGS, respectively (Vander Pol et al., 2006). A meta-analysis of nine experiments encompassing 34 treatment means and

1,257 steers evaluating inclusion concentrations of WDGS (ranging from 5.2 to 50%) replacing portions of DRC, HMC, or a DRC/HMC combination suggested 30% WDGS inclusion maximized DMI and ADG and 30 to 50% WDGS inclusion maximized G:F (Klopfenstein et al., 2008). Feeding values relative to the control diet decreased with increasing WDGS inclusion however (Klopfenstein et al., 2008). Replacing portions of corn grain with WDGS in finishing diets allowed feedlot cattle to gain more rapidly; thus providing the opportunity for cattle to be heavier at equal DOF or to be finished in fewer DOF for increased profitability (Klopfenstein et al., 2008).

Because of high cost and energy usage associated with drying WDGS, it is generally not economical or logical to dry WDGS unless an ethanol plant is not located in close proximity to feedlots. Additionally, partial or complete drying of WDGS will potentially increase greenhouse gas emissions and reduce environmental benefits associated with using ethanol in place of gasoline (Bremer et al., 2011*a*). It is more economical to transport DDGS long distances, so it may be necessary to expend energy for drying WDGS to facilitate transportation. To determine optimal feeding concentrations of DDGS, Buckner et al. (2007) fed 0, 10, 20, 30, and 40% DDGS in place of DRC in finishing diets. Dry matter intake was similar across all treatment diets, but the authors observed a quadratic response for steer ADG and HCW, with the greatest gain being 1.68 kg/d and heaviest HCW being 370 kg occurring at 20% DDGS inclusion (Buckner et al., 2007). Feeding value of all inclusion concentrations of DDGS was greater than the corn control diet (reference value of 100) and was estimated to be 156,

146, 112, and 109 for 10, 20, 30, and 40% DDGS. Thus, the authors concluded optimal concentration of DDGS in finishing diets was at 20% diet DM.

Depenbusch et al. (2009) fed DDGS up to 75% dietary DM in steam-flaked corn (SFC)-based diets to finishing heifers and observed a quadratic response in DMI, ADG, and final live BW as concentration of DDGS inclusion increased. These performance variables were maximized at 15% DM inclusion in SFC-based finishing diets. When a meta-analysis was conducted with five different feeding trials evaluating increasing concentrations of DDGS in finishing diets, DMI increased linearly with increasing DDGS inclusion concentration and was maximized at 30% DDGS inclusion (Klopfenstein et al., 2008). However, there was a quadratic response for ADG in which gain was maximized between 20 and 30% DDGS inclusion and a cubic response for G:F, with maximum G:F occurring between 10 and 20% DDGS inclusion. Additionally, feeding values decreased from 153 for 10% DDGS inclusion to 100 (the same as corn control) at 40% DDGS inclusion in finishing diets (Klopfenstein et al., 2008). This response may be explained partially due to increased dietary fatty acid concentration as inclusion concentrations increase that may reduce rumen fermentation (Zinn et al., 2000) and reduce intestinal fatty acid digestion (Plascencia et al., 2003). The economic advantages of feeding corn milling co-products will vary depending on the current price paid for the co-products, dietary inclusion concentrations, DOF needed to reach the same market weight, location of the feedlot relative to the ethanol plant, and additional costs associated with feeding diets including co-products (Buckner et al., 2011).

Concentration of Fat in Distillers Grains Plus Solubles and Effects on Feedlot Cattle Performance, Carcass Characteristics, and Meat Quality

The digestibility of fat will vary in different types of corn milling co-products. Ruminant microbial populations have the ability to modify dietary fats consumed by the ruminant animal, and the fatty acid profile of resulting beef products may reflect the ruminal modification and influence beef quality (de Mello Jr. et al., 2008*b*). Increased concentrations of polyunsaturated fatty acids (PUFA) in beef products are associated with increased oxidation rates which leads to undesirable beef color, off-flavors, and overall reduced shelf-life and consumer acceptance (de Mello Jr. et al., 2008*b*). Because distillers grains contain higher concentrations of PUFA than corn grain, beef products from cattle finished with elevated concentrations of distillers grains may contain higher concentrations of these fats (Deppenbusch et al., 2009). The oxidation of myoglobin pigment in meat is directly related to oxidation of lipid, and as PUFA concentration increases in meat products, the potential for oxidative rancidity increases and produces undesirable meat color and rancid flavor, which reduces shelf-life stability, beef quality, and consumer satisfaction (de Mello Jr. et al., 2009).

Some research suggests that marbling score is reduced when feeding DDGS at concentrations reaching 50% dietary DM inclusion (Gunn et al., 2009); however, when feeding 15 or 30% WDGS (de Mello Jr. et al., 2008*a*) or 30% DDGS (Leupp et al., 2009) in finishing diets, marbling score, distribution, texture, and fat content were not influenced. Gunn et al. (2009) indicated that live steer performance, marbling score,

USDA quality grade, and color stability of ground product during retail display were negatively affected when DDGS inclusion increased from 25 to 50% of the dietary DM. This may be related to the increased dietary CP or fat concentrations, or a combination of both. However, when DDGS inclusion was increased from 25 to 50% dietary inclusion, there were no apparent differences in meat quality characteristics including tenderness and lipid oxidation of ground beef product (Gunn et al., 2009).

Roeber et al. (2005) and Gunn et al. (2009) indicated feeding either DDGS or WDGS at high concentrations (40 to 50% dietary DM) may negatively affect color stability of strip loins and ground product during retail display. However, Roeber et al. (2005) suggested feeding either DDGS or WDGS at lower inclusion concentrations (10 to 25% dietary DM) may maintain, or possibly enhance shelf life stability of cooked beef without affecting palatability. Although color was affected, feeding distillers grains up to 50% dietary DM inclusion did not impact tenderness or sensory attributes of beef (Roeber et al., 2005). In agreement, research suggests that inclusion of WDGS (de Mello Jr. et al., 2008c) or DDGS (Leupp et al., 2009) up to 30% DM in finishing diets resulted in darker (less desirable) color scores of steaks, and thus reduced shelf life of these products. In contrast, when DDGS was included in SFC-based diets fed to finishing heifers at concentrations up to 75% dietary DM, overall tenderness increased linearly and juiciness, off-flavor intensity, and redness (i.e. a^*) of steaks (after 5 d of retail display) were not affected even though total PUFA increased linearly as concentration of DDGS increased in the diet (Depenbusch et al., 2009). It appears results in both finishing performance and beef quality attributes of feedlot cattle fed varying concentrations of

DDGS or WDGS are not consistent. However, most research suggests the elevated concentrations of PUFA in the distillers grains with solubles may have the greatest influence on beef quality and sensory characteristics.

Innovative ethanol companies have developed alternative processes to enhance efficiency of ethanol production. Novel corn milling co-products are derived from these new processes and can include high protein dried distillers grains which do not contain solubles (HPDG). This novel distillers grains contains lower concentration of lipid and higher concentration of CP compared to conventional DDGS. There is limited research available evaluating the effects of finishing cattle with HPDG on feedlot performance and carcass characteristics. Depenbusch et al. (2008) fed 13.5% HPDG in place of SFC to feedlot heifers and reported similar performance and carcass characteristics to heifers consuming a traditional SFC-based finishing diet. The chemical composition of the HPDG fed in the experiment was 91% DM, 43% CP, and 4% fat. The control diet contained 81% SFC, 6% alfalfa hay, 1.2% urea, 14.8% CP, and 3.8% fat, while the 13.5% HPDG diet contained 71% SFC, 6% alfalfa hay, 13.9% CP, and 3.9% fat. Because similar feedlot performance and carcass characteristics were reported (Depenbusch et al, 2008), an opportunity may exist to develop a feeding strategy that maximizes HPDG inclusion concentrations in feedlot diets while reducing negative effects of PUFA on quality and shelf-life stability of the resultant beef retail products.

Gigax et al. (2011) fed crossbred yearling steers experimental diets containing either 35% low-fat or 35% conventional WDGS in place of a 50:50 blend of DRC and HMC and evaluated live steer performance and carcass characteristics. The low-fat

WDGS co-product contained 34.8% CP, 6.7% fat, and 0.85% S while the conventional WDGS co-product contained 34.5% CP, 12.9% fat, and 0.94% S. The control diet contained 13.6% CP, 3.6% fat, and 0.12% S, the low-fat WDGS diet contained 17.9% CP, 4.7% fat, and 0.37% S, and the conventional WDGS diet contained 17.8% CP, 6.9% fat, and 0.41% S. Carcass-adjusted final live BW, ADG, and HCW were greater for steers finished with 35% conventional WDGS despite similar DMI and G:F among all treatments. Marbling score, 12th rib back fat thickness, and LM area were not different among treatments. Steers finished with low-fat WDGS performed similarly to steers fed the control diet; therefore, finishing steers with a low-fat WDGS is comparable to finishing steers with traditional corn-based diets (Gigax et al., 2011).

Finishing cattle with WDGS has been reported to increase the oxidation potential in beef retail products. Strip loins from steers finished with diets containing 35% low-fat WDGS and 4.7% fat (Gigax et al., 2011) had greater oxidative rancidity and decreased shelf-life stability than strip loins that were collected from yearling steers fed a diet containing 35% conventional WDGS or a control diet containing 85% of a 50:50 blend of DRC and HMC (Haack et al., 2011). Compared to the traditional corn-based control diet, loin steaks from cattle finished on WDGS had greater concentration of PUFA, mostly from an increase in C18:1 fatty acids (Haack et al., 2011). Additionally, strip loins derived from steers finished with conventional WDGS had greater overall tenderness and less off-flavor detected than strip loins from either the control diet or diets containing low-fat WDGS. However, there were no treatment differences for juiciness, beef flavor intensity, or Warner Bratzler shear force values (Haack et al., 2011). Differences of

where fat was contained in the two WDGS may explain why there was greater lipid oxidation in strip loins from steers fed diets containing 35% low-fat WDGS and 4.7% fat compared to strip loins derived from steers finished with diets containing 35% conventional WDGS and 6.9% fat. Much of the fat contained in the low-fat WDGS was located in the grains fraction which may be protected from biohydrogenation in the rumen to allow for greater concentrations of PUFA in meat products. Fat contained in the solubles fraction of conventional WDGS may be more fully hydrogenated in the rumen by microbial populations to result in lower PUFA concentrations in the resulting meat products (Haack et al., 2011).

Concentration and Variability of Sulfur in Distillers Grains Plus Solubles

Sulfur is an essential nutrient required for normal growth and reproduction of bacteria in the rumen of cattle. Ruminal bacteria use dietary S to produce certain amino acids and other compounds that are required by the animal (NRC, 2000). The recommended concentration of S in beef cattle rations is 0.18 to 0.24% DM and will depend on production demands (NRC, 2005). The range of S in beef cattle diets should allow ruminal bacteria to produce sufficient amounts of S-containing compounds to meet requirements. Insufficient, as well as excessive, S intake can reduce growth and performance of livestock. Perhaps more importantly however, excessive S intake can be toxic and possibly fatal to cattle. Maximum recommended concentrations of S will differ depending on the type of diet. In feedlot rations containing 85% or more of the DM as concentrate, S concentrations should not exceed 0.30% DM. It is not usual for S

concentrations of contemporary corn-based finishing rations to exceed 0.30% DM. Whereas in rations containing 40% of the DM as forage, S concentrations can be as high as 0.50% DM without reducing performance or health of cattle (NRC, 2005).

During the dry corn milling process used to convert corn into ethanol, sulfuric acid is added to control pH during fermentation, which increases and concentrates S content of the byproduct (Vanness et al., 2009c). On a DM-basis, S concentration of distillers grains is highly variable within and among ethanol plants and can range from 0.44% to well over 1.0% S (Buckner et al., 2008). When DDGS or WDGS are included in feedlot diets, there is potential for feedlot cattle to consume dietary S concentrations greater than the maximum tolerable concentration of 0.40% (NRC, 2000). Sulfur concentration in feedstuffs and water can vary greatly depending on location, so it is important to know how much total S cattle are consuming to prevent toxicity. Therefore, S concentrations of both the feedlot diet and water source must be considered when evaluating total dietary S intake (Gould, 1998; Vanness et al., 2009c).

Potential for Sulfur Toxicity and Polioencephalomalacia in Feedlot Cattle

Acute or prolonged intake of high dietary S concentration may cause increased production of hydrogen sulfide (H_2S) gas in the rumen which can result in S toxicity and in severe cases, polioencephalomalacia (PEM), or polio, in feedlot cattle (Vanness et al., 2009a). The pKa of H_2S is 7.04, so at normal pH ranges in the rumen, sulfates are reduced by ruminal bacteria to result in production of H_2S . Mammals are not capable of assimilatory or dissimilatory reduction of sulfates to S^{2-} , which is necessary for

production of S-containing amino acids, B-vitamins, and coenzyme A. Thus, production of H₂S by ruminal bacteria is required and is normal; however, excess dietary S in the form of sulfates used as a terminal electron acceptor may undergo dissimilatory reduction to increase production of H₂S in the rumen (Kung, 2008). The bioavailability of S for ruminal microbial growth from different dietary S sources will vary and is approximately 35.8% and 50% for elemental S and sulfates, respectively (Kahlon et al., 1975). Therefore, inorganic S in the form of sulfates is more readily reduced and may combine with H ions to promote H₂S formation in the rumen (Gould et al., 2002; Kung, 2008). As temperatures increase from 20 to 40°C, solubility of H₂S in water decreases, thus allowing accumulation of H₂S in the rumen gas cap.

In contrast to H₂S concentration in ruminal fluid, H₂S concentration in the ruminal gas cap appears to change more readily and is likely a reflection of all anabolic and catabolic processes of S metabolism occurring in the fluid phase (Gould et al., 1997). Additionally, the concentration of H₂S in the ruminal gas cap is largely influenced by many factors including the volume of both the fluid and gas compartments; therefore, accurate measurement of H₂S concentration in the ruminal gas cap may be difficult and may need to encompass factors including sulfide concentration in the rumen fluid, pH of the rumen fluid, frequency of eructation, and absorption of H₂S across the ruminal mucosa (Gould et al., 1997). With increased accumulation in the gas cap of the rumen, excess H₂S can be eructated from the rumen and inhaled, allowing the respiratory system to serve as a route for excess H₂S to enter the bloodstream. The circulatory H₂S then

circulates to the brain, causes necrosis, and subsequently initiates the onset of PEM (Gould, 1998).

Sulfur toxicity is widely reported to decrease DMI and reduce ADG in finishing cattle (Weeth and Hunter, 1971; Weeth and Capps, 1972; Bolsen et al., 1973; Zinn et al., 1999; Loneragan et al., 2001; Spears and Lloyd, 2005; Cammack et al., 2010; Sarturi et al., 2011; Uwituzze et al., 2011), while PEM is a disorder of the central nervous system distinguished by necrosis of the cerebral cortex, or the gray matter of the brain (Gould, 1998). The deleterious effects of S toxicity on performance of feedlot cattle may be attributed to decreased ruminal and intestinal motility, and therefore reduced passage rate and DMI, when excessive dietary sulfates are reduced and result in high concentrations of H₂S in the rumen (Bird, 1972; Kandylis, 1984). Cattle affected with PEM, commonly referred to as ‘brainers’, may experience blindness, compromised coordination, seizures, and often death due to softening of the brain (Gould, 1998). Because acidic ruminal conditions (low pH) favor production and may increase the concentration of H₂S in the rumen gas cap, it is suggested by some researchers that high dietary S concentration in conjunction with high concentrate, low roughage finishing rations increases the incidence of PEM in feedlot cattle (Kung et al., 2000; Vanness et al., 2009*b*).

Polioencephalomalacia was induced in yearling steers fed a 50% (as-fed basis) forage diet while consuming water with a high sulfate concentration of 3,651 mg of SO₄/L, but no steers contracted polio when drinking water containing a low sulfate concentration of 566 mg of SO₄/L (Cammack et al., 2010). In a study conducted by Buckner et al. (2007), 6 of 40 feedlot steers consuming a common diet containing 50%

DDGS in place of DRC and 0.60% dietary S were either symptomatic or died of PEM. Additionally, Wilken et al. (2009) diagnosed PEM in 4 of 48 yearling crossbred steers fed a common finishing diet containing 0.59% dietary S, 43.8% WDGS, 43.8% WCGF, and 7.5% alfalfa hay. One steer consuming a high S (0.65%) diet containing 30% DDGS in place of SFC was reported to have blindness associated with PEM by Uwituzi et al. (2011). From these reported observations of PEM in feedlot cattle, it is apparent there are differences in dietary S concentration, as well as other factors associated with diet and management, that may result in the onset of PEM.

Not all cattle are affected similarly when consuming toxic concentrations of dietary S as the response is highly variable for individual animals and may be largely dependent on diet and DMI (Gould et al., 1991). Uwituzi et al. (2011) compared moderate (0.42%) or high (0.65%) dietary S concentrations in either DRC or SFC-based finishing diets containing 30% DDGS and reported similar H₂S in the rumen of feedlot steers during the first 4 h after feeding. However, steers consuming DRC-based diets had greater concentration of H₂S in the rumen 8 h post-feeding than steers consuming SFC-based diets which may be attributed to increased DMI in steers fed DRC-based diets (Uwituzi et al., 2011). Additionally, cattle may adapt after three or four weeks to consuming high dietary S concentrations to reduce the incidence of polio (Cammack et al., 2010; Uwituzi et al., 2011). Cummings et al. (1995) reported the capacity to generate H₂S from sulfate in steers increased after 10 to 12 d of feeding a high-S diet; however, Alves de Oliveira et al. (1997) reported 7 d of adaptation to a high-S diet in an *in vitro* semi-continuous fermenter system were sufficient to reach high sulfide

production capacity. In contrast, Loneragan et al. (2001) reported peak ruminal H₂S concentrations that lasted from d 15 to 30 after cattle were consuming water containing sulfates that equated to 0.40% dietary S concentration. However, ruminal sulfide concentrations were markedly reduced following peak sulfide concentrations, which is in agreement with results by Uwituze et al. (2011) that suggest cattle may adapt to chronic exposure of high dietary S intake as ruminal H₂S concentration also decreased in feedlot steers over time.

Methods Investigated to Mitigate Sulfur Toxicity in Feedlot Cattle

Acidic conditions (low pH) may favor production of H₂S in the rumen and increase H₂S concentration in the rumen gas cap; therefore, it is believed high dietary S concentration in finishing rations containing low roughage concentrations increases incidence of PEM in feedlot cattle (Vanness et al., 2009b). Vanness et al. (2009c) compiled data from 4,143 cattle finished on feedlot diets containing corn milling co-products and traditional roughage concentrations (6 to 7.5% DM) and reported a 0.14% PEM incidence in cattle consuming dietary concentrations of 0.46% S or less, 0.35% PEM incidence with dietary S concentrations ranging from 0.47 and 0.56% S, and 6.06% PEM incidence when dietary S concentrations exceeded 0.56%. Therefore, provided dietary roughage concentrations are maintained at 6.5 to 7% DM, 0.46% dietary S may be the threshold concentration where low incidence of PEM will occur in feedlot cattle consuming finishing diets containing corn milling co-products (Vanness et al., 2009c).

A common method proposed to reduce risk of PEM is to increase or maintain ruminal pH by including greater concentrations of roughage in feedlot rations containing high concentrations of distillers grains. Wilken et al. (2009) fed 29.4% roughage in a finishing diet containing 66% WDGS and 0.55% dietary S to steers and did not induce any cases of PEM. In the same experiment however, Wilken et al. (2009) fed a diet containing 7.5% roughage, 33% WDGS, and 0.48% dietary S and reported confirmed cases of PEM. Vanness et al. (2009b) fed feedlot diets containing 50% WDGS and 0.44% dietary S with 0, 7.5, or 15% grass hay to steers and evaluated ruminal H₂S concentration. Cattle consuming 15% grass hay had a 55% decrease in ruminal H₂S gas concentration at 8 h post-feeding compared to cattle consuming 7.5% grass hay. The authors concluded feeding additional roughage in diets containing high concentrations of dietary S may reduce risk for PEM.

Type of corn milling co-product may also influence ruminal concentration of H₂S in feedlot cattle. Nichols et al. (2011) fed ruminally fistulated crossbred beef steers with one of five diets consisting of (DM-basis): 1) 28.5% WDGS, 37.5% Sweet Bran[®], 25% DRC, 0% alfalfa, and 0.45% S; 2) 28.5% WDGS, 37.5% Sweet Bran[®], 17.5% DRC, 7.5% alfalfa, and 0.46% S; 3) 44% WDGS, 44% Sweet Bran[®], 0% DRC, 7.5% alfalfa, and 0.58% S; 4) 50% WDGS, 0% Sweet Bran[®], 37.5% DRC, 7.5% alfalfa, and 0.45% S; or 5) 0% WDGS, 87.5% Sweet Bran[®], 0% DRC, 7.5% alfalfa, and 0.46% S. Steers consuming diet 3 had lower DMI than steers consuming diets 2 and 5 but had similar DMI to steers consuming diets 1 and 4. Hydrogen sulfide concentration was also higher in the rumen of steers consuming diet 3 as was expected since diet 3 had the highest

dietary S concentration (0.58% S); however, steers consuming diet 5 had lower ruminal H₂S concentration compared to other diets, even though S concentration for diet 5 was the same as dietary S concentrations of diets 1, 2, and 4. Furthermore, although only statistically different from diet 1, total minutes per day ruminal pH was less than 5.6 was lowest for diet 5 which may partially explain lower ruminal H₂S concentrations (656.7, 145.1, 150.9, 461.1, and 116.9 ± 133.5 min/d for diets 1, 2, 3, 4, and 5, respectively). Therefore, higher fiber concentrations contained in the Sweet Bran[®] co-product may promote a ruminal environment that is less conducive to H₂S formation to result in reduction of toxic concentrations of ruminal H₂S in feedlot cattle.

Supplementing high-S feedlot diets containing traditional roughage concentrations with minerals or compounds in excess of dietary requirements has been evaluated as a method to reduce H₂S concentration in the rumen. Feeding elevated concentrations of copper (Cu), zinc, and iron (Fe) is suggested to form insoluble salt compounds with sulfide and may reduce sulfur toxicity (Gould, 1998; Vanness et al., 2009a). Vanness et al. (2009a) supplemented high concentrations of Fe and Cu in a finishing diet containing 50% WDGS, 19.5% DRC, 19.5% HMC, 6% cornstalks, 5% supplement, and 0.53% dietary S to evaluate effectiveness of these minerals to reduce S metabolism of sulfides to H₂S gas in the rumen. Treatments included: 1) no mineral added (Control), 2) 1500 ppm Fe + 100 ppm Cu (1500/100 Fe:Cu), 3) 3000 ppm Fe + 200 ppm Cu (3000/200 Fe:Cu), and 4) 4500 ppm Fe + 300 ppm Cu (4500/300 Fe:Cu). Steers fed the control treatment had greater DMI than steers supplemented with 1500/100 Fe:Cu and 3000/200 Fe:Cu but had similar DMI as steers supplemented with 4500/300

Fe:Cu. Ruminant pH was not measured in this experiment, and there were no effects on H_2S concentration in the rumen at 0, 4, 8, or 12-h post-feeding due to Fe or Cu supplementation. Therefore, the authors conclude Fe and Cu supplementation in excess of dietary requirements did not effectively bind S and may not reduce or affect ruminal H_2S concentration in feedlot cattle.

Manganese oxide (MnO) is commonly supplemented to feedlot cattle as a source of manganese (Mn) and is also a powerful oxidizing agent. Manganese oxides may effectively oxidize H_2S into sulfate, sulfur, and small amounts of thiosulfate (Herszage and Afonso, 2003). The entropy of reaction for MnO_2 reduction with H_2S suggests the reaction is associative and occurs through inner-sphere redox reactions (Herszage and Afonso, 2003). It appears the distribution of oxidation products may be pH dependent. As pH decreases, the thermodynamic driving force of the reaction increases to result in sulfates being the main product at low pH and elemental sulfur being the main product with pH at or above neutral (Herszage and Afonso, 2003). With excess MnO_2 , it has been demonstrated that elemental S will not form or is rapidly oxidized into sulfates from Na_2S at a pH of 6.5 (Luther et al., 2001).

At pH of 5, aqueous MnO oxidized H_2S to sulfate and elemental S at a rate of 1.49 g of MnO to 1.0 g of H_2S (Herszage and Afonso, 2003). Ruminant pH of feedlot cattle consuming finishing rations generally ranges from 5.25 to 6.0. Therefore, supplementing MnO to feedlot cattle consuming rations high in dietary S concentration may result in lower ruminal concentrations of H_2S due to increased oxidation of H_2S into sulfates in the rumen. The sulfates are then likely eliminated in the small intestine of the

animal; thus reducing potential negative effects of S toxicity and PEM on health and performance of feedlot cattle exposed to high-S diets. Nevertheless, distillers grains often contain high concentrations of P which may reduce the rate and effectiveness at which MnO can oxidize H₂S in the rumen and minimize any benefits MnO may have in mitigating the effects of S toxicity in feedlot cattle. Although known to be rapid, the rate of sulfide oxidation by MnO₂ may be reduced by approximately 50% in the presence of 10 μM phosphate (Yao and Millero, 1993). A decrease in the surface-controlled reduction of H₂S may be attributed to adsorption of the phosphate onto the surface sites of the MnO₂ molecule, thus occupying the surface sites necessary for the reaction with sulfide to occur (Yao and Millero, 1993).

Summary

Volatility of commodity and cattle markets creates challenges for beef cattle producers to remain profitable each year. Beef cattle producers must adjust their management practices to fit changing dynamics in the beef industry to remain competitive. With increasing costs of production in the beef industry, alternative strategies of raising cattle are explored to improve profitability. Some of these strategies may include retaining ownership of beef stocker cattle and employing backgrounding systems that utilize available, cost-effective forages. If fall grazing is an available system for backgrounding, stockpile or swath grazing annual, cool-season forages allows stocker cattle to gain muscle mass and frame size while potentially extending the grazing season later into the fall and winter. Although forage and pasture management may be tedious

and increase labor requirements, fall grazing systems may provide opportunities to reduce costs of production compared to more traditional backgrounding systems that utilize harvested, stored, or purchased feedstuffs often fed to stocker cattle in a feedlot.

Backgrounded stocker cattle can then either be marketed in the spring months for added value or enter the feedlot at heavier placement weights for a shorter, high-energy diet finishing phase to improve overall profitability.

Traditionally, finishing heifers in the feedlot has been less profitable than finishing steers. However with appropriate management strategies, finishing beef heifers in the feedlot can be successful for producers. Most importantly with feedlot heifers, estrus prevention must be managed continually either through supplementation of the oral progestin, MGA, or through removal of both ovaries via spaying. Additionally, appropriate anabolic implant strategies must be chosen to maximize performance of feedlot heifers, particularly spayed heifers, since removal of the ovaries also eliminates endogenous excretion of anabolic steroids. Implant strategies for all feedlot cattle must be carefully considered as more aggressive or long-term implant programs may negatively affect carcass quality and consumer acceptance of resulting meat products. Regardless of strategy, the improvement in performance resulting from administration of anabolic implants allows increased profitability in feeding cattle.

Another strategy for reducing costs of production when feeding cattle is to replace portions of expensive energy and protein dietary ingredients with cost-effective feedstuffs, such as corn milling co-products. Corn milling co-products, particularly distillers grains plus solubles, are excellent sources of highly digestible fiber, protein, and

energy and are attractive feed ingredients to producers, especially in the Midwest, because they are readily available and have higher feeding value relative to corn. However, there are concerns with feeding distillers grains plus solubles in feedlot diets, especially at high inclusion concentrations. Traditional distillers grains plus solubles contain 12-15% fat, so when fed at high inclusion concentrations, resulting dietary fat concentration may reduce feedlot performance and subsequent meat quality. Additionally, distillers grains plus solubles contain variable and inconsistent concentrations of S. When dietary S intake exceeds maximum recommended concentrations for feedlot cattle, S toxicity or polioencephalomalacia may be induced to result in reduced feedlot performance and potential death in feedlot cattle consuming diets high in corn milling co-products. Because feeding high inclusion concentrations of corn milling co-products to finishing cattle is likely to continue into the future, practical methods for mitigating negative effects on feedlot performance and carcass characteristics associated with high dietary fat and S intake are warranted to optimize economic benefits.

Research Objectives

The overall goal of this research was to explore alternative strategies of growing and finishing beef cattle to provide options for reducing input costs to result in improved profitability of beef production. To attain this goal, the following research objectives were proposed:

1. Evaluate the effectiveness of fall grazing stockpiled and swathed annual ryegrass as backgrounding systems on forage quality and beef stocker cattle performance.
2. Evaluate the effects of reproductive status (spayed vs. intact heifers supplemented with melengestrol acetate) and terminal implant strategy (moderate vs. aggressive) on beef feedlot heifer performance during backgrounding and finishing phases and on carcass characteristics.
3. Evaluate the effects of partially replacing dry-rolled corn in traditional corn-based finishing diets with either 35% conventional dried distillers grains plus solubles or 35% high protein dried distillers grains on beef steer feedlot performance and carcass characteristics.
4. Evaluate the effects of supplemental manganese in high-sulfur feedlot diets containing dried distillers grains plus solubles on *in vitro* and *in vivo* ruminal fermentation and hydrogen sulfide gas production.

Chapter 2

Evaluation of Annual Ryegrass (*Lolium multiflorum*) in Two Fall Grazing Systems on Forage Quality and Stocker Cattle Performance in Northern Minnesota

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Summary

Two experiments were conducted to evaluate the effects of fall grazing stockpiled and swathed annual ryegrass on forage quality and beef stocker cattle performance. In experiment 1, one renovated, 2.02-ha pasture was seeded with annual ryegrass (*Lolium multiflorum*) in late June and treated with herbicide in August for weed control. In late September, stockpiled forage from one-half of the pasture was swathed into single windrows while the other half was left standing. Angus beef heifers (n = 48; 186 ± 7 kg initial BW) were assigned randomly to one of two grazing treatments (three replications per treatment; eight heifers per replication): 1) stockpiled annual ryegrass (STO), and 2) swathed annual ryegrass (SWA). Forage samples were collected to determine change in forage quality over time and weekly DM loss following grazing. Heifers were weighed at trial initiation, weekly, and at trial completion to measure animal performance. Final concentration of CP was greater ($P < 0.01$) for STO compared to SWA (13.6 vs. 11.4 ± 0.5%). Final concentrations of NDF (56.0 vs. 66.5 ± 0.5%) and ADF (36.5 vs. 42.3 ± 0.5%) were lower ($P < 0.01$), while TDN (60.4 vs. 55.9 ± 0.5%) remained greater ($P < 0.01$) for STO compared to SWA over time. Forage DM loss was estimated at 6.3 ± 4.0% and 2.5 ± 1.0% for STO and SWA. Heifers on STO grazed 5 d longer ($P < 0.01$) than SWA (45 vs. 40 d). Although final BW (206 vs. 201 ± 8 kg) and ADG (0.43 vs. 0.37 ± 0.04 kg) were similar for STO and SWA, overall BW gain was greater ($P < 0.05$) for STO (19.2 vs. 14.9 ± 1.5 kg).

Experiment 2 evaluated effects of fall grazing stockpiled and swathed annual ryegrass on forage quality and beef steer performance. Four renovated, 2.43-ha pastures

were seeded on May 6, 2010 with annual ryegrass (*Lolium multiflorum*) at a planting rate of 28 kg seed/ha. All pastures were managed similarly, and two crops of ryegrass baleage were made during the summer prior to grazing. Urea was applied at a rate of 112 kg/ha following first cutting, and herbicide was not applied during the growing season. In anticipation of grazing in mid-October, forage was either left intact to represent the stockpiled annual ryegrass grazing treatment (STO) or swathed and two windrows were raked together the following day to represent the swathed annual ryegrass grazing treatment (SWA). Angus beef steers (n = 48; 207 ± 5 kg initial BW), managed for a forage-based finishing system from birth, were assigned randomly to either grazing STO or SWA annual ryegrass (three replications per treatment). Calves were rotated within replication when available forage was consumed. Data collected were forage quality (over time), total grazing days, and steer BW gains.

Responses in forage quality over time in STO and SWA annual ryegrass for the current experiment were similar to responses observed in experiment 1. Although CP concentrations decreased from 13.2 to 9.3% over time in STO annual ryegrass, NDF and ADF concentrations were maintained over time and averaged 48.9 and 32.1%, respectively. Energy concentration was also maintained over time and averaged 63.9% TDN for STO annual ryegrass. In contrast, CP concentration remained similar over time and averaged 13.1% for SWA annual ryegrass. However, over time, NDF (48.6 to 59.9%) and ADF (32.6 to 39.5%) concentrations increased, thus resulting in reduced energy concentration (63.5 to 58.1% TDN) over time for SWA annual ryegrass. Experiment 2 was limited to 42 d of grazing due to cold, winter weather conditions.

Final BW tended ($P = 0.06$) to be heavier for steers grazing STO (231 vs. 217 ± 5 kg) compared to steers grazing SWA. Overall BW gain (24 vs. 10 ± 2 kg) and ADG (0.58 vs. 0.24 ± 0.04 kg) were greater ($P < 0.001$) for steers grazing STO compared to steers grazing SWA. Results of both experiments suggest grazing stockpiled and swathed annual ryegrass may be viable systems to extend fall grazing; however because of their higher nutrient and energy requirements for BW gain, forage maturity and winter weather conditions may reduce forage quality and accessibility to levels that can limit stocker cattle performance.

Introduction

The relatively short forage growing season (approximately 120 days) in northern Minnesota limits available forage growth and therefore number of fall grazing days. The short grazing season increases the requirement for harvested forages or supplemental feed which comprises approximately 60% of all production expenses for beef cow/calf producers (Koch et al., 1997). Utilizing cool-season annuals in grazing systems can increase the amount and quality of available forage for grazing later in the season (Haferkamp et al., 2005). To reduce winter feeding expenses, systems that employ animals to harvest forages longer into the grazing season are explored (D'Souza et al., 1990). Stockpile grazing is a fall grazing strategy used throughout the United States and is one of the most cost-efficient fall grazing systems used in the South (Kallenbach et al., 2003). Grazing stockpiled forages can be economically and environmentally beneficial if managed correctly in north central regions (Cuomo et al., 2005). Swath (windrow)

grazing has been successfully utilized in northern Minnesota (Walker et al., 2007; 2009) and in Canada to effectively lengthen the grazing season. While these strategies can reduce the cost of processing and feeding hay by as much as 60 to 75% (Surber et al., 2001), weather impacts, such as rain or snow accumulation, are unpredictable in the upper Midwest and may have significant impacts on forage quality, forage utilization, and subsequent animal performance.

Research for understanding forage varieties and fall grazing methods suitable to tolerate harsh winter precipitation without compromising forage quality and feed intake is limited in northern Minnesota. However, cool-season grasses, such as annual ryegrass, are often chosen as ideal forages for fall grazing systems, and research has suggested annual ryegrass is effective in systems that extend the fall grazing season in northern Minnesota (Walker et al., 2009). Additionally, annual ryegrass is a high-quality, highly-palatable, cool-season forage that may allow improved performance and greater daily gains of stocker cattle (Volesky et al., 2002; Vendramini et al., 2008a) compared to grazing other cool-season or warm-season forages during the fall months. Two experiments were conducted over two consecutive fall grazing seasons to evaluate the effectiveness of annual ryegrass (*Lolium multiflorum*) in two fall grazing systems on forage quality and stocker cattle performance in northern Minnesota.

Materials and Methods

Pasture and Forage Management and Data Collection – Experiment 1

One renovated, 2.02-ha pasture was seeded in late June, 2009 with annual ryegrass (*Lolium multiflorum* var. Maximus; Barenbrug USA, Tangent, OR) using a Great Plains no-till drill at a planting rate of 28 kg seed/ha. Pasture dimensions were 97 m (north to south) x 209 m (east to west). Due to the delayed planting date, the pasture was not grazed during the summer; therefore, it was considered stockpiled over the entire summer season. Beef cows were previously wintered on the pasture; thus, fertilizer was not applied, but herbicide was applied in August to suppress weed growth. The pasture was divided into two treatment groups of equal size with each treatment having three replications (Figure 1). With anticipation of grazing in early October, forage from one-half of the 2.02-ha pasture was swathed with a 2.79 m John Deere Moco discbine on September 24, 2009 (swathed treatment; SWA), while forage from the other half of the pasture was left standing (stockpiled treatment; STO).

Because of excessive windrow mass from greater than expected forage yields, windrows were not raked together and remained as single swaths in the SWA treatment. Five forage samples from each treatment were randomly collected across all treatment replications for estimation of initial forage yield at time of swathing. Forage yield was used to estimate the number of grazing days that would supply heifers with approximately 2% of BW in DMI to gain 0.54 to 0.68 kg daily per heifer as recommended by NRC (2000). Five forage samples per treatment were collected prior to and at the end of the grazing study for forage quality analysis over time. Forage samples were dried in brown paper bags (Kraft, 9.07 kg heavyweight) that had holes drilled in them for air flow for 96 h at 55°C in a horizontal air flow drying oven (VWR 1655D;

VWR Scientific, Inc., Batavia, IL) to determine sample DM. All forage sample weights were measured using a benchtop balance (model HC-6KA; A&D Weighing; San Jose, CA). Following DM determination, forage samples collected at trial initiation and completion were uniformly cut up with a scissors, thoroughly mixed, and composited by treatment and time collected, and four subsamples of each composite were sent to Dairyland Laboratories, Inc. (St. Cloud, MN) for NIR analyses of forage quality. Analyses included CP by combustion analyzer (AOAC, 2000 method 990.03), ADF (AOAC, 1996 method 973.18), NDF (analyzed using sodium sulfite and amylase, Van Soest et al., 1991), minerals (Ca, P, Mg, K, and S; AOAC, 2000 method 985.01), TDN and NE_g (using OARDC equations).

For SWA, percent forage loss was estimated weekly throughout the experiment from approximately every third rotation within replication by collecting and weighing (platform scale, model FE-31KA2, with attached indicator, model 100KA1; A&D Weighing; San Jose, CA) remaining forage on the ground following grazing in three, randomly chosen windrows. For STO, percent forage loss was estimated weekly throughout the experiment from approximately every third rotation within replication by collecting and weighing (platform scale, model FE-31KA2, with attached indicator, model 100KA1; A&D Weighing; San Jose, CA) the remaining forage from three randomly selected, 6.096 m sections cut by a 0.91 m Carter flail harvester (Carter Manufacturing Company, Inc.; Brookston, IN) following grazing. Following determination of sample DM (as previously described), forage waste samples from the first (one week following trial initiation) and final collections were composited (as

previously described) by treatment and time collected, and four subsamples of each composite were sent to Dairyland Laboratories, Inc. for NIR analysis of forage quality (as previously described).

Pasture and Forage Management and Data Collection – Experiment 2

Four renovated, 2.43-ha pastures were seeded on May 6, 2010 with annual ryegrass (*Lolium multiflorum* var. Maximus; Barenbrug USA, Tangent, OR) using a Great Plains no-till drill at a planting rate of 28 kg seed/ha. Pasture dimensions were 247 m long (west to east) x 97.5 m wide (north to south). All pastures were managed similarly, and two crops of ryegrass baleage were made during the summer prior to grazing. First and second cuttings of ryegrass were taken on July 15 and August 21, 2010, respectively. Urea was applied at a rate of 112 kg/ha following first cutting, and forage was allowed to accumulate for fall grazing following second cutting. Herbicide was not applied during the growing season. In anticipation of grazing in mid-October, forage DM yield was estimated by collecting and weighing three, 0.093-m square samples from each treatment replication in each pasture on October 12, 2010.

Forage DM yield was used to estimate the number of grazing days that would supply steers with 2.8% of BW in DMI to ensure daily gains were not restricted by limited intake. Dry matter (determined as in experiment 1) of the annual ryegrass was 16%, and pasture layout with each respective forage DM yield is illustrated in Figure 2. Due to differences in estimated forage DM yield, pastures 1 and 2 were divided lengthwise into two paddocks of equal size, with one paddock in each pasture designated to each

treatment. Pastures 3 and 4 were considered as one replication per treatment, for three replications per treatment total (Figure 2). Forage in one paddock within each of the divided pastures (pastures 1 and 2) and in pasture 3 was swathed with a 2.79 m John Deere Moco discbine on October 13, 2010, and two windrows were raked (H & S 8-wheel ground-driven rake) together the following day to represent the swathed annual ryegrass grazing treatment (SWA). Forage from the other half of pastures 1 and 2 and pasture 4 was left intact to represent the stockpiled annual ryegrass grazing treatment (STO).

Three forage samples per treatment replication were collected (as previously described) prior to and at the end of the grazing study for forage quality analysis over time. Forage samples collected at trial initiation and completion were composited by treatment and time collected (as described in experiment 1), and one subsample of each composite was sent to Dairyland Laboratories, Inc. (St. Cloud, MN) for NIR analyses of forage quality. Analyses included CP by combustion analyzer (AOAC, 2000 method 990.03), ADF (AOAC, 1996 method 973.18), NDF (analyzed using sodium sulfite and amylase, Van Soest et al., 1991), minerals (Ca, P, Mg, K, and S; AOAC, 2000 method 985.01), TDN and NE_g (using OARDC equations).

Following grazing, forage loss was estimated approximately once weekly (weather-permitting) throughout the experiment for the SWA treatment by collecting and weighing (platform scale, model FE-31KA2, with attached indicator, model 100KA1; A&D Weighing; San Jose, CA) remaining forage from three randomly selected windrows within one rotation in each treatment replication in pastures 1 and 2 and from six

randomly selected windrows within one rotation from pasture 3. For the STO treatment, forage loss was estimated approximately once weekly in each treatment replication by collecting and weighing (platform scale, model FE-31KA2, with attached indicator, model 100KA1; A&D Weighing; San Jose, CA) remaining forage from three randomly selected 12.2 m sections cut by a 0.91 m Carter harvester following grazing in one rotation in pastures 1 and 2 and from six randomly selected 12.2 m sections within one rotation in pasture 4. Forage waste was collected three times before further collection was postponed by snow accumulation until Spring, 2011.

*Animals, Location, Experimental Design and Treatments, and Data Collection –
Experiment 1*

Care and handling of all animals used in this experiment were conducted under the approval of the University of Minnesota Institutional Animal Care and Use Committee (IACUC Protocol # 0909A72334). Spring-born Angus heifer calves (n = 48; 186 ± 7 kg initial BW) originating from the North Central Research and Outreach Center Angus cow herd in Grand Rapids, MN were used in the experiment. Prior to trial initiation, heifers received initial and subsequent booster vaccinations (Bovishield[®] Gold-V and Ultrabac[®]-7:Somubac[®]; Pfizer Animal Health, New York, NY). All heifer BW measurements during the experiment were collected using a For-Most portable squeeze chute (For-Most Livestock Equipment; Hawarden, IA) equipped with a Tru-Test scale (Tru-Test, Inc.; Mineral Wells, TX). At trial initiation, heifers were weighed on two consecutive days after withholding feed and water for 16 h each day to determine shrunk

initial BW. All heifers received a metaphylaxis antibiotic (Draxxin[®]; Pfizer Animal Health, New York, NY) prior to being assigned randomly to treatments (SWA vs. STO; three replications per treatment; eight heifers per treatment replication).

Within each treatment replication, heifers grazed on a rotational basis through multiple sections (of equal size) using temporary electric fencing. Based on forage yield and estimation of length of grazing period, size and number of rotations were targeted to supply sufficient forage to sustain intake of all heifers for three days. However, actual rotation was determined visually by one individual when available forage was no longer sufficient to supply adequate intake. Heifers were allowed access to previously grazed sections and had continuous free-choice access to water and mineral supplement to ensure daily dietary requirements were sufficient. Weekly interim 16-h shrunk BW was measured to monitor daily gains of heifers throughout the experiment. Following weighing, heifers were immediately returned to their respective treatment replications for grazing. Grazing was terminated in both treatment groups when heifers consumed all available forage within their respective treatment replication. Upon trial completion, final BW of heifers was the average of two consecutive day BW measurements after withholding feed and water for 16 h to determine overall BW gain and ADG.

*Animals, Location, Experimental Design and Treatments, and Data Collection –
Experiment 2*

Care and handling of all animals used in this experiment were conducted under the approval of the University of Minnesota Institutional Animal Care and Use

Committee (IACUC Protocol # 1007A86800). Spring-born Angus steer calves ($n = 48$; 207 ± 5 kg initial BW) originating from the North Central Research and Outreach Center Angus cow herd in Grand Rapids, MN were used in the experiment. The calves were recently weaned, castrated, and received vaccinations (Bovishield[®] Gold FP5 VL5 and Ultrabac[®] 8; Pfizer Animal Health, New York, NY) prior to trial initiation. All steer BW measurements during the experiment were collected using a For-Most squeeze chute (For-Most Livestock Equipment; Hawarden, IA) equipped with a Tru-Test scale (Tru-Test, Inc.; Mineral Wells, TX). At trial initiation, steers were weighed on two consecutive days after withholding feed and water for 16 h each day to determine initial BW. All steers were assigned randomly to one of six groups, and each group was randomly assigned to a treatment replication (eight steers per treatment replication). Due to wide variation in initial BW among steers, average BW of each group was estimated following random assignment, and steers were re-assigned as needed across group to obtain similar average BW among all treatment replications.

Within each treatment replication, steers grazed on a rotational basis through multiple sections of equal size using temporary electric fencing. Time of rotation was visually determined by one individual when available forage was no longer sufficient to supply maximum intake. Throughout the grazing period, steers were allowed continuous access to previously grazed sections and had free-choice access to water and mineral supplement. Interim 16-h shrunk BW of steers was measured every 14 d to monitor ADG throughout the experiment. Steers were immediately returned to their respective treatment replications for continued grazing following BW measurement. Grazing was

terminated in both treatment groups following 42 d of grazing due to winter weather conditions that resulted in negative interim steer ADG. Upon trial completion, final BW measurement of steers was the average of two consecutive day BW measurements after withholding feed and water for 16 h. Final BW was used to determine overall BW gain and ADG of the 42-d grazing period.

Statistical Analyses – Experiment 1

Forage data were analyzed as repeated measures using an autoregressive repeated covariance (AR 1h) structure in SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Model fixed effects included time, treatment, and treatment by time interaction. The linear model for this analysis is written as follows:

$$y_{ij} = \mu + \tau_i + \alpha_j + (\tau_i \times \alpha_j) + \varepsilon_{ij}$$

where,

y_{ij} represents observation $_{ij}$; μ represents the overall mean; τ_i represents the fixed effect of treatment $_i$; α_j represents the fixed effect of time $_j$; and $(\tau_i \times \alpha_j)$ represents the interaction of treatment $_i$ and time $_j$. The residual term ε_{ij} is assumed to be normally, independently, and identically distributed with variance σ^2_e .

Heifer performance data were analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Fixed model effects included replication and treatment. The linear model for this analysis is written as follows:

$$y_{ij} = \mu + \rho_i + \alpha_j + \varepsilon_{ij}$$

where,

y_{ij} represents observation $_{ij}$; μ represents the overall mean; ρ_i represents the fixed effect of replicate $_i$; and α_j represents the fixed effect of treatment $_j$. The residual term ε_{ij} is assumed to be normally, independently, and identically distributed with variance σ_e^2 . Statistical significance was declared with P -values ≤ 0.05 , and trends were discussed with $0.05 < P$ -values ≤ 0.10 . The PDIFF option was used to separate least squares means when a significant F -test statistic was present. Treatment means are presented as least squares means, and the largest standard error of the mean is reported.

Statistical Analysis – Experiment 2

Steer performance data were analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Fixed model effects included replication and treatment. The linear model for this analysis is written as follows:

$$y_{ij} = \mu + \rho_i + \alpha_j + \varepsilon_{ij}$$

where,

y_{ij} represents observation $_{ij}$; μ represents the overall mean; ρ_i represents the fixed effect of replicate $_i$; and α_j represents the fixed effect of treatment $_j$. The residual term ε_{ij} is assumed to be normally, independently, and identically distributed with variance σ_e^2 . Statistical significance was declared with P -values ≤ 0.05 , and trends were discussed with $0.05 < P$ -values ≤ 0.10 . The PDIFF option was used to separate least squares means when a significant F -test statistic was present. Treatment means are presented as least squares means, and the largest standard error of the mean is reported.

Results and Discussion

Forage Quality and Waste – Experiment 1

Forage quality chemical composition over time from experiment initiation to completion is reported in Table 1. Initial forage DM yield for all treatments and replications combined was estimated at 9,012 kg/ha. Percent forage DM at the end of the experiment was 41.8 ± 2.8 and $38.4 \pm 7.5\%$ for STO and SWA, respectively. Forage CP concentration did not change ($P = 0.97$) over time for either forage system, but overall CP was greater ($P < 0.01$) for STO compared to SWA (13.2 vs. $11.0 \pm 0.5\%$). Hafley (1996) reported with continuous grazing, CP concentration of Marshall ryegrass ranged from 11 to 26%, with lower concentrations likely due to inadequate N fertilization or time of harvest relative to N fertilization. Thus, advanced forage maturity, as well as a possible lack of N, may have resulted in low forage CP in the annual ryegrass. Even with apparent low CP concentrations observed in this experiment, the ryegrass contained CP concentrations that were sufficient to meet requirements of growing beef cattle (NRC, 2000).

Concentrations of NDF and ADF increased ($P < 0.01$) over time in SWA but not in STO ($P > 0.12$) forage, which suggests the increased fiber concentrations in SWA decreased forage quality more quickly than when left intact. Initial and final NDF concentrations were 57.0 and 56.0%, and initial and final ADF concentrations were 37.6 and 36.5% for STO. For SWA, NDF increased from 54.3 to 66.5%, and ADF increased from 36.0 to 42.3% over time. Similar to the current experiment, Volesky et al. (2002) observed increasing fiber concentrations in swathed forage over time; however, fiber

concentrations also increased in stockpiled forage over time in the same experiment, which contradicts the results of the current experiment. Volesky et al. (2002) concluded decreased forage quality after October was largely attributed to weathering and its associated nutrient losses due to leaching and leaf loss. Likewise, the deterioration in quality for SWA was likely attributed to wet, cold weather conditions that occurred during most of the experiment. With increased concentrations of fiber in SWA, TDN was greatly reduced ($P < 0.01$) over time. While TDN ($P = 0.12$) and NE_g ($P = 0.29$) did not change for STO and averaged 60% and 0.65 Mcal/kg, respectively, TDN decreased from 60.8 to 55.9% and NE_g decreased from 0.64 to 0.52 Mcal/kg for SWA over time. Growing beef cattle require 55% TDN to meet nutritional needs (NRC, 2000); thus, the decline in forage quality in SWA to marginal concentrations may have detrimental effects on stocker cattle performance, particularly during cold and wet weather conditions when maintenance requirements are increased.

Quality of forage waste over time is reported in Table 2. There was a significant treatment by time interaction for forage CP concentration. Concentration of CP for STO was lower ($P < 0.01$) at the beginning (7.7%) of the experiment and increased to 10.2% by the end of the experiment. However, CP concentration for forage waste in SWA was similar ($P = 0.89$) over time and averaged 8.6%. Concentration of NDF was greater ($P < 0.01$) for forage waste in SWA compared to STO (69.2 vs. $64.8 \pm 0.3\%$). Similarly, ADF concentration was greater ($P < 0.01$) for forage waste in SWA compared to STO (47.0 vs. $45.7 \pm 0.3\%$). The greater fiber concentrations in forage waste for SWA resulted in lower ($P < 0.01$) TDN for SWA compared to STO (52.3 vs. $53.3 \pm 0.2\%$) and consequently

lower ($P < 0.01$) NE_g for SWA compared to STO (0.47 vs. 0.52 ± 0.5 Mcal/kg). The observed increase in CP in forage waste over time for STO annual ryegrass is likely attributed to the increased waste by stocker cattle as the experiment progressed (data not shown). As percent of forage waste increased over time for STO, cattle were not likely consuming the high quality, leafy material to the extent they were earlier in the experiment, thus resulting in forage waste containing higher CP at the end of the experiment.

Heifers grazing SWA consumed available forage more effectively throughout the experiment as was evidenced by lower overall estimated percent forage waste ($6.3 \pm 4.0\%$ and $2.5 \pm 1.0\%$ for STO and SWA, respectively; Figure 3). Because heifers were consuming a greater proportion of the total forage available while grazing SWA, the remaining forage as waste is expected to be of lower quality than waste in the STO system. Volesky et al. (2002) suggested when utilizing a rotational grazing system with windrow grazing, forage loss can be estimated at 10% or less if rotations are grazed for less than seven days and 5% or less if grazed for one day in wintering calves. Calves in this experiment were rotated every 2 to 3 d and forage waste estimates were less than 10% for both fall grazing systems. It is important to reduce forage waste when grazing swathed forage since residual forage left in windrows appears to deteriorate rapidly, especially if there is precipitation throughout the winter and into the spring months (Volesky et al., 2002). Thus, if forage is left behind following grazing, there will be little material left the following spring which results in forage waste and potentially large economic loss to the producer. Forage waste estimates reported in this experiment may

suggest during wet or snowy weather conditions, forage presented to cattle in windrows was more readily consumed as was also observed in previous fall grazing systems research in northern Minnesota (Walker et al., 2009).

Forage Quality – Experiment 2

Forage quality over time from experiment initiation (October 15, 2010) to completion (November 25, 2010) is reported in Table 3. Changes in forage quality over time for the current experiment were reflective of changes observed for STO and SWA annual ryegrass in experiment 1. Initial average forage CP concentration for both grazing treatments was 13.6%, but final forage CP concentration was 9.3% for STO and 12.2% for SWA. Similar to the current experiment, Volesky et al. (2002) observed similar CP concentration over time in windrowed forage, but CP concentration in standing forage decreased from 10.6 to 5.7%. Others have reported decreased CP concentration in forages as grazing season or forage maturity progresses (Branine and Galylean, 1990; Coffey et al., 2002). Initial and final NDF concentrations were 49.3 and 48.4% for STO annual ryegrass; however, initial and final NDF concentrations were 48.6 and 59.9% for SWA. Similarly, initial and final forage ADF concentrations were 32.5 and 31.7% for STO, but initial and final ADF was 32.6 and 39.5% for SWA. In contrast to this experiment, maximum NDF and ADF concentrations reported by Kallenbach et al. (2003) for annual ryegrass were 45.5% and 25.2%, respectively, which is likely acceptable quality for most classes of beef cattle (NRC, 2000). When growth of winter annual forages is reduced due to cold weather, forage CP concentration may decrease

while fiber concentrations may increase as leaves senesce (Beck et al., 2007). Initial and final TDN concentrations were 63.6 and 64.2% for STO; however, with increased final fiber concentrations in SWA, initial and final TDN concentrations were 63.5 and 58.1%. Similarly, initial and final NE_g concentrations were 0.71 and 0.67 Mcal/kg for STO but were 0.72 and 0.59 Mcal/kg for SWA.

Approximately one week following trial initiation, weather conditions in Grand Rapids, MN, became relatively more cold and wet. Wet weather conditions shortly after swathing may have attributed to rapid deterioration and decreased forage quality in SWA. When forage is in contact with wet ground conditions, there is concern for rapid loss of forage quality due to leaching of highly soluble cell constituents. Leaching of these nutrients sharply increases NDF and ADF concentrations and reduces digestibility without markedly altering CP concentration (Volesky et al., 2002). Additionally, development of mold growth on the underside of the windrows prior to snowfall may have altered nutrient composition and reduced nutrient utilization in SWA annual ryegrass.

Animal Performance – Experiment 1

Performance of heifers grazing STO or SWA annual ryegrass is reported in Table 4. Total number of grazing days was greater ($P < 0.01$) for heifers grazing STO compared to SWA (45 vs. 40 d). Because forage in windrows is more concentrated than standing forage, heifers grazing SWA may consume available forage faster than heifers grazing STO and require more frequent rotation to result in fewer total days of grazing

with equal forage availability (Walker et al., 2009). Initial heifer BW was similar ($P = 0.92$) between treatments and averaged 187 ± 7 kg. Although overall BW gain for SWA heifers was lower ($P = 0.05$) compared to STO (15 vs. 19 ± 2 kg), final BW was not different ($P = 0.63$) and averaged 204 ± 8 kg across treatments. Average daily gain was similar ($P = 0.23$) between treatments and was 0.43 and 0.37 kg for STO and SWA.

Gadberry et al. (2004) reported beef stocker heifers grazing winter annual pastures and supplemented (1% of BW) with either corn, corn plus de-oiled rice bran, or de-oiled rice bran had similar overall ADG that ranged from 0.73 to 0.95 kg. The low ADG observed in heifers in the current study may be due to heifers not receiving protein or energy supplementation. Performance of heifers grazing ryegrass may be improved with energy supplementation to result in more efficient nitrogen utilization (Lake et al., 1974). Without factoring weather conditions, minimum nutrient requirements for 250 kg growing heifers that allow 0.54 kg daily gain include 10% CP, 55% TDN, and 0.62 Mcal NE_g per kg DM (NRC, 2000). In a study conducted by Volesky et al. (2002), forage quality remained relatively constant and high enough throughout the fall and early winter to allow beef calves to gain BW while grazing mixed forage (predominately cool-season species) in windrows. It appears forage quality was sufficient in the STO treatment to allow heifers to gain the targeted 0.54 kg per day when not considering winter weather conditions; however, due to increased concentrations of NDF and ADF, marginal TDN, and reduced NE_g in SWA, heifers grazing SWA likely could not consume enough forage and energy to sustain targeted gains during weather conditions incurred during this experiment.

Additionally, the annual ryegrass in this experiment had matured to reproductive stages prior to trial initiation which likely reduced forage quality and limited heifer performance. During periods of rapid growth of cool-season annuals, a shorter forage regrowth interval is important to maintain nutritive value that will support BW gains by stocker calves (Vendramini et al., 2008b). Due to a smaller body size and rumen capacity compared to mature cattle, stocker calves grazing stockpiled annual forages will have improved performance on forage that is less mature. With a longer regrowth interval and thus greater maturity in forage available for grazing, the proportion of total herbage as leaves will decrease while the stem to leaf ratio will increase (Vendramini et al., 2008b). Due to the increased structural carbohydrate concentration of forage stems, there is a linear decrease in *in vitro* digestibility of organic matter, which reduces DMI by grazing stocker calves. Therefore, grazing swards with less mature forage and higher digestibility than in the current experiment will likely support improved intake and ADG of beef stocker calves (Vendramini et al., 2008b).

Animal Performance – Experiment 2

Performance of steers grazing STO or SWA annual ryegrass is reported in Table 5. By design, initial BW of steers was similar ($P = 0.91$) between treatments and averaged 207 ± 5 kg. Because overall steer ADG was no longer positive after 42 d of grazing, the experiment was terminated and resulted in a total of 42 d of grazing for each treatment. Final BW tended to be greater ($P = 0.06$) for steers grazing STO than SWA (231 vs. 217 ± 5 kg). Overall BW gain was greater ($P < 0.01$) for steers grazing STO

compared to steers grazing SWA (24 vs. 10 ± 2 kg). Thus, ADG was greater ($P < 0.01$) for steers grazing STO than steers grazing SWA (0.58 vs. 0.24 ± 0.04 kg). In the STO grazing system, the forage may be more digestible due to its potentially lower fiber concentrations than SWA annual ryegrass. This may enable stocker calves to gain from 0.5 to 1.5 kg of BW daily as was reported by Sladden and Bransby (1992).

Coffey et al. (2002) reported stocker calves gaining 1.02 kg daily during a 56-d period while grazing bermudagrass pastures interseeded with Marshall annual ryegrass; however, stocker calves were fed daily with 0.9 kg of a grain sorghum-based supplement containing 11.4% CP, 1.22 Mcal NE_g per kg DM, and 200 mg monensin, which likely improved ADG (Gadberry et al., 2004). Steers in the current experiment were not supplemented with additional protein or energy which likely explains lower observed ADG. Additionally, age and body size of the steer calves in this experiment likely limited total ruminal capacity and forage consumption (Vendramini et al., 2008a). With increased fiber concentration, forage digestibility is decreased to result in reduced ruminal passage rates and subsequently, increased rumen fill. For these reasons, steers likely were not able to consume adequate forage nutrients and energy to support desired BW gains during this experiment.

Conclusions

Stockpile and swath grazing annual ryegrass may be effective systems for extending the fall grazing season in northern Minnesota. However, caution is warranted in these systems when grazing classes of cattle, such as stocker calves, that require higher

nutrient and energy concentrations for gain than mature beef cattle. Changes in forage nutrient concentrations for STO annual ryegrass did not appear to limit nutrient requirements for targeted gains of stocker calves in normal weather conditions. However, advanced maturity and subsequent marginal protein and energy concentrations of annual ryegrass coupled with inclement weather conditions may reduce forage quality to result in limited intake and reduced capacity to gain in non-supplemented stocker calves. It appears both fall grazing systems have associated advantages and can provide options for alternative backgrounding systems that not only extend the fall grazing season but also may reduce winter feeding expenses for beef producers. However, weather conditions, access to shelter, and forage quality management should be considered by producers when grazing stocker cattle on stockpiled or swathed annual ryegrass to minimize forage DM loss and optimize cattle performance.

Table 1. Chemical composition¹ of initial and final forage quality of stockpiled and swathed annual ryegrass (Experiment 1).

	Grazing Treatment ²				SEM ⁴	P-Value ³		
	STO		SWA			TRT	TIME	TRT x TIME
	Initial	Final	Initial	Final				
CP, %	12.8	13.6	10.6	11.4	0.5	< 0.01	0.06	0.97
NDF, %	57.0	56.0	54.3 ^a	66.5 ^b	0.5	< 0.01	< 0.01	< 0.01
ADF, %	37.6	36.5	36.0 ^a	42.3 ^b	0.5	< 0.01	< 0.01	< 0.01
TDN, %	59.6	60.4	60.8 ^a	55.9 ^b	0.5	< 0.01	< 0.01	< 0.01
NE _g , Mcal/kg ⁵	0.64	0.65	0.64 ^a	0.52 ^b	0.01	< 0.01	< 0.01	< 0.01

¹Chemical composition reported on a DM-basis.

²Treatments included stockpiled (STO) and swathed (SWA) annual ryegrass.

³P-values for treatment (TRT; average of STO vs. average of SWA), TIME (Initial vs. Final), and the interaction of treatment over time (TRT x TIME).

⁴Standard error of the mean.

⁵Net energy required for gain.

^{ab}Means within treatment with uncommon superscripts differ ($P \leq 0.05$).

Table 2. Chemical composition¹ of initial and final collections of forage waste of stockpiled and swathed annual ryegrass (Experiment 1).

	Grazing Treatment ²				SEM ⁴	<i>P</i> -Value ³		
	STO		SWA			TRT	TIME	TRT x TIME
	Initial	Final	Initial	Final				
CP, %	7.7 ^a	10.2 ^b	8.5	8.6	0.5	0.42	0.02	0.03
NDF, %	60.8	68.8	66.0	72.4	0.5	< 0.01	< 0.01	0.13
ADF, %	45.1	46.3	46.0	48.0	0.4	< 0.01	< 0.01	0.36
TDN, %	53.8	52.8	53.0	51.5	0.3	< 0.01	< 0.01	0.36
NE _g , Mcal/kg ⁵	0.54	0.50	0.50	0.44	0.01	< 0.01	< 0.01	0.59

¹Chemical composition reported on a DM-basis.

²Treatments included stockpiled (STO) and swathed (SWA) annual ryegrass.

³*P*-values for treatment (TRT; average of STO vs. average of SWA), TIME (Initial vs. Final), and the interaction of treatment over time (TRT x TIME).

⁴Standard error of the mean.

⁵Net energy required for gain.

^{ab}Means within treatment with uncommon superscripts differ ($P \leq 0.05$).

Table 3. Chemical composition¹ of initial and final forage quality of stockpiled and swathed annual ryegrass (Experiment 2).

	Grazing Treatment ²			
	STO		SWA	
	Initial	Final	Initial	Final
CP, %	13.2	9.3	13.9	12.2
NDF, %	49.3	48.4	48.6	59.9
ADF, %	32.5	31.7	32.6	39.5
TDN, %	63.6	64.2	63.5	58.1
NE _g ³ , Mcal/kg	0.71	0.67	0.72	0.59

¹Chemical composition reported on a DM-basis.

²Grazing treatments included stockpiled (STO) and swathed (SWA) annual ryegrass.

³Net energy required for gain.

Table 4. Performance of stocker cattle grazing stockpiled or swathed annual ryegrass (Experiment 1).

	Grazing Treatment ¹		SEM ²	<i>P</i> -Value
	STO	SWA		
Grazing Days, d	45	40	0.35	< 0.01
Initial BW, kg	187	186	7	0.92
Final BW, kg	206	201	8	0.63
Overall BW Gain, kg	19	15	2	0.05
ADG, kg	0.43	0.37	0.04	0.23

¹Treatments included stockpiled (STO) and swathed (SWA) annual ryegrass.

²Standard error of the mean.

Table 5. Performance of stocker cattle grazing stockpiled or swathed annual ryegrass (Experiment 2).

	Grazing Treatment ¹		SEM ²	P-Value
	STO	SWA		
Grazing Days, d	42	42	---	---
Initial BW, kg	207	207	5	0.91
Final BW, kg	231	217	5	0.06
Overall BW Gain, kg	24	10	1.7	<0.01
ADG, kg	0.58	0.24	0.04	<0.01

¹Grazing treatments included stockpiled (STO) and swathed (SWA) annual ryegrass.

²Standard error of the mean.

NORTH

SWA 3	STO 3
SWA 2	STO 2
SWA 1	STO 1

SOUTH

Figure 1. Illustration of grazing treatment (stockpiled, STO, vs. swathed, SWA) and replication layout of the annual ryegrass pasture (Experiment 1).

NORTH

Pasture #1 – 2,024 kg Forage DM/ha	SWA 1
	STO 1
Pasture #2 – 2,024 kg Forage DM/ha	SWA 2
	STO 2
Pasture #3 – 1,019 kg Forage DM/ha	SWA 3
Pasture #4 – 1,019 kg Forage DM/ha	STO 3

SOUTH

Figure 2. Illustration of grazing treatment (stockpiled, STO, vs. swathed, SWA) and replication layout of annual ryegrass pastures and their respective estimated forage dry matter yields (Experiment 2).

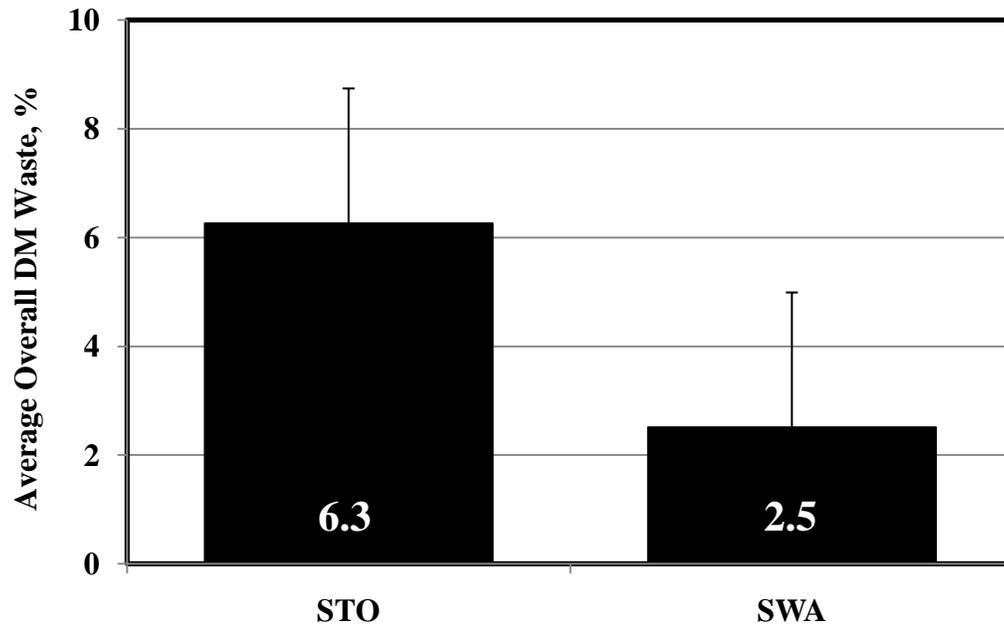


Figure 3. Average overall percent of forage waste for stockpiled (STO) and swathed (SWA) annual ryegrass (Experiment 1).

Chapter 3

Effects of Spaying and Terminal Implant Strategy on Performance and Carcass Characteristics of Beef Feedlot Heifers

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Summary

Crossbred beef heifers (n = 139) averaging 273 ± 22 kg initial BW were blocked by weight (heavy; HY, and light; LT) and assigned to 1 of 16 pens. Pen was assigned randomly to treatments within block to evaluate effects of reproductive status (spayed vs. intact) and terminal implant strategy (moderate, Synovex[®] H; 200 mg testosterone propionate plus 20 mg estradiol benzoate vs. aggressive, Synovex[®] Plus; 200 mg trenbolone acetate plus 28 mg estradiol benzoate) on feedlot heifer performance and carcass characteristics. On d -14, 8 pens of heifers (n = 70) were spayed via the ovarian-drop technique. On d 1, all heifers were implanted (Synovex[®] C; 100 mg progesterone plus 10 mg estradiol benzoate) and fed backgrounding diets (1.10 Mcal/kg NE_g, 14.2% CP) at 2.0% BW for 65 or 85 d (HY and LT blocks, respectively). On d 66 and 86 respectively, HY and LT heifers received terminal implants to begin the finishing phase. Heifers were fed diets (1.32 Mcal/kg NE_g, 11.4% CP, 360 mg/d monensin, 90 mg/d tylosin) *ad libitum*. Intact heifers were supplemented with melengestrol acetate (0.5 mg/d) for estrus suppression throughout the entire feeding period. On d 146 and 174 respectively, HY and LT heifers were harvested at a commercial abattoir. During backgrounding, intact heifers had greater DMI ($P = 0.02$; 6.6 vs. 6.4 ± 0.1 kg/d), greater ADG ($P = 0.02$; 1.60 vs. 1.46 ± 0.05 kg), improved G:F ($P = 0.05$; 0.244 vs. 0.228 ± 0.006), and heavier final BW ($P = 0.04$; 391 vs. 382 ± 4 kg). During finishing, no status x implant interactions occurred ($P > 0.88$) for performance. Heifers with moderate terminal implants had greater DMI ($P = 0.05$; 8.91 vs. 8.54 ± 0.21 kg/d) than heifers with aggressive terminal implants, but ADG was similar among all heifers. Intact heifers and

heifers with aggressive terminal implants tended ($P = 0.06$) to have improved G:F. Final BW, HCW, LM area, marbling score, and 12th rib fat thickness were not influenced by spaying or implanting. Intact heifers receiving melengestrol acetate had greater performance than spayed heifers during backgrounding; however, aggressive implanting may allow similar performance during finishing.

Introduction

The state of Minnesota was downgraded from bovine tuberculosis (TB)-free status in January, 2006, following the discovery of five TB-infected beef herds in northwestern Minnesota. Effective on October 1, 2010, the Minnesota Board of Animal Health upgraded the state of Minnesota to split-state status, with the majority of the state in TB accredited-free status and a small zone in upper northwestern Minnesota in modified accredited advanced status. With the downgrade in TB status in 2006, the state of Minnesota enforced diligent TB testing and placed restrictions on livestock movement within and out of the state. Unlike breeding stock, feeder cattle including spayed heifers could be exported across most state borders to feedlots without any restrictions if they originated from the modified accredited advanced zone. Because of the added expenses of TB testing feeder cattle in Minnesota, a management strategy investigated to eliminate TB-testing feeder heifers is heifer spaying or castration.

Spaying, or ovariectomizing, female cattle involves surgically removing both ovaries so heifers will not exhibit estrus (Klindt and Crouse, 1990). Although not common in Minnesota, spaying heifers is more prevalent in large western ranching states

as a management strategy to increase feedlot performance and prevent pregnancies in the feedlot. Advantages associated with spaying heifers prior to feedlot placement include: maintenance of stocker or feeder heifers in an open or neutered status (Klindt and Crouse, 1990), elimination of estrous activity and associated reduced performance and efficiency in the feedlot, elimination of checking intact heifers for pregnancy (Garber et al., 1990) and detection of pregnant heifers prior to feedlot entry (Adams et al., 1990), elimination of feeding estrus suppressing feed additives, elimination of testing stocker heifers for TB prior to export, improved ADG and feed conversions (with proper implanting; Garber et al., 1990), ability to graze or feed heifers and steers together, and ability to graze spayed heifers near cow-calf herds with herd sires present.

With removal of the ovaries, spaying heifers eliminates endogenous sources of gonadal steroids, mainly estrogen and progesterone. The absence of these hormones has attributed to reduced dry matter intake (DMI), average daily gain (ADG), and feed efficiency (G:F) in the feedlot (Horstman et al., 1982). Over a four-month finishing period, suppression of endogenous steroidogenesis through ovariectomy tended to reduce ADG, final BW, and HCW, and heifers that were ovariectomized had reduced dressing percentage compared to implanted control and heifers supplemented with melengestrol acetate (MGA; Adams et al., 1990). In contrast to Adams et al. (1990) and earlier reports (Dinusson et al., 1950; Kercher et al., 1960; Nygaard and Embry, 1966; Horstman et al., 1982), Hamernik et al. (1985), Crouse et al. (1987), and Klindt and Crouse (1990) reported ovariectomy did not significantly reduce ADG or G:F in feedlot heifers. Spayed heifers finished for 112-d on a 70% steam-rolled barley diet had similar growth

performance, G:F, and carcass characteristics as intact heifers receiving 0.35 mg per head daily MGA (Hamernik et al., 1985). Heifers weighed 300 kg at time of spaying, so perhaps differences in age at spaying, a shorter finishing phase, and the concentration of supplemented MGA in this study attributed to similar performance among all heifers (Hamernik et al., 1985).

Garber et al. (1990) reported spayed heifers implanted with Synovex[®] S (200 mg progesterone plus 20 mg estradiol benzoate) had greater ADG and improved G:F during finishing compared to spayed heifers implanted with Synovex[®] H (200 mg testosterone propionate plus 20 mg estradiol benzoate). Moreover, spayed heifers implanted with Synovex[®] H had a threefold improvement in ADG (0.30 vs. 0.09 kg) compared to intact heifers implanted with Synovex[®] H. Spayed heifers implanted with progesterone (Synovex[®] S) tended to have heavier final BW and therefore heavier HCW, decreased backfat thickness, and improved marbling scores and USDA yield grades compared to spayed heifers implanted with Synovex[®] H (Garber et al., 1990). This observation suggests implanting spayed heifers effectively partitions consumed dietary energy away from fat accretion to increase muscle protein deposition without negatively affecting USDA quality grades (Garber et al., 1990). With removal of the ovaries and sources of endogenous estrogen and progesterone, spayed heifers are nearly the endocrine equivalent of a steer. Thus, implanting spayed heifers with combinations of estradiol and progesterone may be more effective in eliciting a performance response than implants containing combinations of estradiol and testosterone (Garber et al., 1990).

The specific objectives of this experiment were to evaluate differences in performance during a backgrounding phase due to reproductive status (spayed vs. intact) of feedlot heifers and differences in performance and carcass characteristics during the finishing phase due to reproductive status (spayed vs. intact) and terminal implant strategy (moderate vs. aggressive terminal implant). The hypothesis tested was performance of spayed, implanted heifers would be similar to performance of implanted, intact heifers supplemented with MGA, and the aggressive terminal implant strategy would enhance finishing performance of heifers.

Materials and Methods

Animals, Location, and Arrival Procedures

Care and handling of all animals used in this experiment were conducted under the approval of the University of Minnesota Institutional Animal Care and Use Committee (IACUC Protocol # 0809A47041 and Protocol # 0809A48721). Crossbred beef heifers ($n = 139$; 273 ± 22 kg initial BW) used in this experiment were enrolled by producers into the University of Minnesota Carcass Merit Program. Upon arrival to the feedlot at the University of Minnesota Northwest Research and Outreach Center (Crookston, MN), heifers were weighed and blocked by BW (heavy and light), tagged with an electronic ID, assigned to pen, and allowed access to water and a recorded amount of dry hay. Heifer owner, BW, sex, color and markings, and tag number were recorded. Initial processing of all cattle included a 5-way viral vaccination (Bovi-Shield[®] Gold-5; Pfizer Animal Health; New York, NY), vaccination against *Mannheimia*

haemolytica (One-Shot[®]; Pfizer Animal Health; New York, NY), and a 7-way clostridial vaccine that included *Histophilus somnus* (Ultrabac[®]-7/Somubac[®]; Pfizer Animal Health; New York, NY). Heifers were dewormed with Dectomax[®] pour-on solution (Pfizer Animal Health; New York, NY) and dosed with a metaphylaxis antibiotic (Draxxin[®]; Pfizer Animal Health; New York, NY). When cattle were processed and all data were recorded, heifers were assigned to a home pen and treated as a group.

At 21 d, cattle were boosted with 5-way viral and 7-way clostridial vaccines (including *Histophilus somnus*) and treated with Valbazen[®] (Pfizer Animal Health; New York, NY) for deer fluke (*Fasciola magna*) control. Rectal temperatures were measured on d 21, and any heifer exhibiting a temperature higher than 39.7°C was treated with Excede[®] (Pfizer Animal Health; New York, NY). Cattle were observed daily and if respiratory disease was suspected, Micotil[®] (tilmicosin injection; Elanco Animal Health; Greenfield, IN) or Nuflor[®] (florfenicol; Intervet Schering-Plough Animal Health; Summit, NJ) was administered according to label directions. Heifers were assigned randomly within BW block to a 2 x 2 factorial arrangement of treatments (spayed vs. intact and moderate vs. aggressive terminal implant) and assigned to one of 16 pens (four replications per treatment).

At d -14, an experienced veterinarian spayed one-half of heifers within each BW block using the ovarian-drop vaginal spaying technique. With this procedure, the heifer was restrained in a standing position in a hydraulic squeeze chute (Silencer[®]; Moly Manufacturing, Inc.; Lorraine, KS) while the area around her vulva was cleansed and sterilized. The veterinarian rectally palpated with one hand for the ovaries while

inserting a sterile spaying instrument into the vagina of the heifer with the other hand. The instrument was a stainless steel rod, small in diameter, and with a hollowed oval shaped head at the end of the rod. With a quick movement, the vagina was traversed and the instrument was then in the pelvic cavity. Via rectal palpation, one ovary was placed in the instrument and excised. The same was done with the second ovary and the instrument was removed from the heifer. Heifers received long-acting antibiotic (Liquamycin[®] LA-200[®]; Pfizer Animal Health; New York, NY) to prevent post-surgery infection and were observed closely for two weeks after spaying to ensure their return to normal health.

Experimental Design, Experimental Treatments, and Data Collection

The backgrounding experiment comparing only reproductive status (spayed vs. intact heifers) began on d 42 after arrival and continued until the average BW of the heavy block was approximately 386 kg (after 66 d on feed, DOF) and the light block was 318 kg (after 86 DOF). Heifers were implanted with 100 mg progesterone plus 10 mg estradiol benzoate (Synovex[®] C; Pfizer Animal Health; New York, NY) using a standard implanting gun subcutaneously in the middle third of the backside of the ear on d 1 of the backgrounding phase. Heifers were adapted to a diet (Table 1) containing 1.1 Mcal/kg NE_g and 14% CP and consisting of corn silage (32.4% DM, 7.9% CP, 41.0% NDF, 23.9% ADF, and 1.0 Mcal/kg NE_g), beet pulp (15.4% DM, 8.8% CP, 48.4% NDF, 29.5% ADF, and 0.73 Mcal/kg NE_g), ground corn (86.5% DM, 9.4% CP, 9.5% NDF, 4.1% ADF, and 1.48 Mcal/kg NE_g), alfalfa haylage (46.9% DM, 20.6% CP, 46.9% NDF,

38.9% ADF, and 0.66 Mcal/kg NE_g), and supplement (89.6% DM and 66.5% CP; Table 2). Heifers were limit-fed diets at approximately 2% of BW, and intact heifers were supplemented with melengestrol acetate (MGA[®]; Pfizer Animal Health; New York, NY) at a targeted daily intake of 0.5 mg per head for estrus suppression. Amount of feed delivered and refused was recorded daily, and DM of the diet was measured to determine DMI of pen. Average daily gain and gain to feed (G:F) were calculated from direct or adjusted final weight and DMI at completion of the backgrounding phase. Initial and final BW measurements of the backgrounding phase were the average of two consecutive day BW measurements after removing feed for 16 h. Heifers had *ad libitum* access to automatic water fountains. Interim BW was measured every 28 d prior to feeding throughout the experiment.

Heifers were randomly assigned to one of two terminal implant strategies (moderate; 200 mg testosterone propionate plus 20 mg estradiol benzoate; Synovex[®] H, or aggressive; 200 mg trenbolone acetate plus 28 mg estradiol benzoate; Synovex[®] Plus; Pfizer Animal Health; New York, NY) during the finishing phase. Terminal implant date for each weight class represented d 1 of the finishing period. Pens were adapted to the finishing ration over a 28-d adaptation period. The finishing ration contained 1.32 Mcal/kg NE_g and 11.4% CP (Table 2) and consisted of (Table 1) high moisture corn (70.5% DM, 8.9% CP, 10.2% NDF, 3.4% ADF, and 1.52 Mcal/kg NE_g), corn silage (32.4% DM, 7.9% CP, 41.0% NDF, 23.9% ADF, and 1.0 Mcal/kg NE_g), and supplement (89.6% DM and 66.5% CP) containing monensin sodium (360 mg/hd daily; Rumensin[®]; Elanco Animal Health; Greenfield, IN) and tylosin phosphate (90 mg/hd daily; Tylan[®],

Elanco Animal Health; Greenfield, IN). Intact heifers continued to receive MGA[®] (0.5 mg/head daily). Heifers were fed for *ad libitum* intake, and amount of feed delivered and refused were recorded daily to determine DMI of pen. Average daily gain and G:F were calculated from direct or adjusted final weight and DMI at completion of the finishing phase.

Proper degree of finish (visual assessment of 60% USDA Choice) and endpoint BW determined when heifers were marketed by BW block. Heavy heifers were marketed after 80 DOF in the finishing phase and light heifers were marketed after 88 DOF in the finishing phase to JBS Swift and Company in Grand Island, NE, for humane slaughter according to approved procedures of the abattoir. Final BW was calculated from individual hot carcass weight (HCW) and common dressing percentage for experimental cattle harvested on that date. Following a 24-h chill, carcass data, including dressing percent, HCW, longissimus muscle (LM) area, 12th rib fat depth, USDA quality grade, and USDA yield grade were collected and summarized by experienced personnel at the abattoir. Carcass tags were cross-referenced to individual animal ID tags for identification.

Samples of ground corn, haylage, beet pulp, corn silage, high moisture corn, supplements, and diets were collected weekly, immediately frozen (-20°C), and composited by month prior to overnight shipment of sub-samples to Dairy One Forage Analysis Laboratory (Ithaca, NY) for chemical analysis. The analyses reported each month included DM (AOAC, 2000 method 930.15), CP (AOAC, 2000 method 990.06), soluble protein (Roe and Sniffen, 1990), NDF and ADF (Van Soest et al., 1991; without

sodium sulfite using an Ankom Fiber Analyzer; ANKOM Technology, Fairport, NY and with 100 μ L per 0.50 g of sample heat stable alpha-amylase, number A3306; Sigma Chemical Co, St. Louis, MO), lignin (AOAC, 2000 method 973.18 D), starch (Smith, 1969), ash (AOAC, 2000 method 942.05), ether extract (AOAC, 2000 method 2003.05), and minerals (Ca, P, S, Mg, K, Na, Fe, Zn, Cu, Mn, and Mo; Sirois et al., 1994). Chemical composition values for each monthly analysis were averaged to obtain an overall mean value and standard deviation for chemical composition of each individual ingredient and treatment diet.

Statistical Analyses

Live heifer performance and carcass characteristics were analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Data were analyzed as a randomized complete block design with a 2 x 2 factorial arrangement of treatments with pen as the experimental unit. Model fixed effects included reproductive status (spayed vs. intact), terminal implant strategy when appropriate (moderate vs. aggressive), and their interaction when appropriate, and random effect was block. Initial BW was used as a covariate but was removed from the model when the effect was not significant. The linear model for these analyses is written as follows:

$$y_{ijk} = \mu + \beta_i + \rho_j + \alpha_k + (\rho_j \times \alpha_k) + \varepsilon_{ijk}$$

where,

y_{ijk} represents observation _{ijk} ; μ represents the overall mean; β_i represents the random effect of block; ρ_j represents the fixed effect of reproductive status; α_k represents the

fixed effect of terminal implant strategy y_k , and $(\rho_j \times \alpha_k)$ represents the interaction of reproductive status y_j and terminal implant strategy y_k . The residual term ε_{ijk} is assumed to be normally, independently, and identically distributed with variance σ^2_e .

Carcass USDA quality grade and USDA yield grade categorical data were analyzed using the GENMOD procedure of SAS with fixed model effects of reproductive status (spayed vs. intact), terminal implant strategy (moderate vs. aggressive), and their interaction, and random effect was block. The linear model for these analyses is written as follows:

$$y_{ijk} = \mu + \beta_i + \rho_j + \alpha_k + (\rho_j \times \alpha_k) + \varepsilon_{ijk}$$

where,

y_{ijk} represents observation $_{ijk}$; μ represents the overall mean; β_i represents the random effect of block; ρ_j represents the fixed effect of reproductive status $_j$; α_k represents the fixed effect of terminal implant strategy $_k$, and $(\rho_j \times \alpha_k)$ represents the interaction of reproductive status $_j$ and terminal implant strategy $_k$. The residual term ε_{ijk} is assumed to be normally, independently, and identically distributed with variance σ^2_e .

Statistical significance was declared with P -values ≤ 0.05 , and trends were discussed with $0.05 < P$ -values ≤ 0.10 . The PDIF option was used to separate least squares means when a significant F -test statistic was present. Treatment means are presented as least squares means, and the largest standard error of the mean is reported.

Results and Discussion

Feedlot Heifer Live Performance

Performance of heifers due to effects of reproductive status during the backgrounding phase is reported in Table 3. Initial BW was similar ($P = 0.25$) between intact and spayed heifers and averaged 273 ± 22 kg. Intact heifers had greater ($P = 0.02$) DMI (6.6 vs. 6.4 ± 0.1 kg/d) and greater ($P = 0.02$) ADG (1.60 vs. 1.46 ± 0.05 kg) than spayed heifers during backgrounding. Therefore, at the end of the backgrounding phase, intact heifers had heavier ($P = 0.04$) final BW (391 vs. 382 ± 4 kg) than spayed heifers. Additionally, intact heifers had improved ($P = 0.05$) G:F (0.244 vs. 0.228 ± 0.006) than spayed heifers during the backgrounding phase. Previous research reports similar DMI, ADG, or G:F between spayed and intact heifers (Hamernik et al., 1985; Grotelueschen et al., 1988; Klindt and Crouse, 1990; Field et al., 1996), but these observations contradict earlier reports that suggest spaying has a negative effect on rate and efficiency of gain (Dinusson et al., 1950; Kercher et al., 1960; Nygaard and Embry, 1966; Horstman et al., 1982) as was also observed in the current experiment.

The choice of low potency implant (Synovex[®] C) combined with supplementing intact heifers with MGA, an estrus suppressing feed additive that is known to enhance feedlot performance in intact, pubertal heifers (Bloss et al., 1966; Utley et al., 1972) but is not approved for use in spayed heifers, likely contributed to these performance differences during backgrounding. Other research suggested heifers supplemented with MGA gained 6% faster and required 9% less feed per unit of gain compared to non-supplemented heifers; thus, advantages associated with feeding MGA to intact feedlot

heifers are apparent (Bloss et al., 1966; Utley et al., 1972). O'Brien et al. (1968) suggested feeding MGA allowed heifers to gain BW and convert feed to gain similarly to steers in the feedlot. The performance advantages associated with MGA supplementation are largely due to elimination of estrous activity and disruption of normal heifer behavior while maintaining uninterrupted influence of endogenous estrogens as natural anabolic agents that increase growth and muscle accretion (O'Brien et al., 1968).

Table 4 lists the effects of reproductive status and terminal implant strategy on heifer performance during the finishing phase. There were no significant interactions ($P \geq 0.39$) between reproductive status and terminal implant strategy for feedlot performance during finishing; therefore, main effects of reproductive status and terminal implant strategy are discussed. Because initial BW for the finishing phase was the same as final BW from the backgrounding phase, the intact heifers began the finishing phase at heavier ($P = 0.04$) BW (391 vs. 382 ± 4 kg) than spayed heifers. It appears spayed heifers were able to compensate for BW gain likely as a result of terminal implant strategy during the finishing phase however, as there were no differences ($P = 0.15$) between intact and spayed heifers for final live BW (516 vs. 511 ± 6 kg). Terminal implant strategy also did not affect ($P = 0.94$) final live BW as BW were equal (614 kg) for heifers receiving either moderate or aggressive terminal implants. Similar to the current experiment, Adams et al. (1990) reported spayed heifers implanted with Synovex[®] H had comparable total BW gains over the finishing period as control heifers implanted with Synovex[®] H, and implants did not affect total BW gain in MGA-supplemented heifers. A review of studies suggested there was no improvement in

feedlot performance when supplementing MGA to implanted heifers regardless of implant strategy (estrogenic, androgenic, or combination implants; Hutcheson et al., 1993). Performance results are mixed, however, as some reports suggest there is an added performance response when supplementing MGA to heifers that are implanted with androgenic implants (Duckett et al., 1997; Wagner et al., 2007).

Intact and spayed heifers had similar ($P = 0.91$) DMI during finishing (8.7 kg), but heifers receiving moderate terminal implants had greater ($P = 0.05$) DMI than heifers with aggressive implants (8.9 vs. 8.5 ± 0.2 kg/d). Overall DMI during combined backgrounding and finishing phases was similar ($P = 0.42$) between intact and spayed heifers (7.7 vs. 7.7 ± 0.1 kg/d) as well as similar ($P = 0.15$) between heifers with moderate or aggressive terminal implants (7.7 vs. 7.6 ± 0.1 kg/d). During the finishing phase, ADG was similar ($P = 0.17$) between intact and spayed heifers (1.52 vs. 1.47 ± 0.04 kg) and also was not affected ($P = 0.85$) by terminal implant strategy. However, when combining the backgrounding and finishing phases, overall ADG tended to be greater ($P = 0.08$) for intact heifers than spayed heifers (1.53 vs. 1.49 ± 0.02 kg), but was not different ($P = 0.83$) between terminal implant strategies and averaged 1.51 kg. In contrast, Garber et al. (1990) reported spayed heifers implanted with Synovex[®] H had a threefold improvement in ADG (0.30 vs. 0.09 kg increase) compared to intact heifers also implanted with Synovex[®] H.

In the current experiment, G:F tended to be improved ($P = 0.06$) for intact compared to spayed heifers (0.176 vs. 0.169 ± 0.003) during finishing. Because heifers receiving moderate terminal implants (200 mg testosterone propionate plus 20 mg

estradiol benzoate) had greater DMI but similar gains, these heifers tended to have poorer ($P = 0.06$) G:F than heifers receiving more aggressive (200 mg trenbolone acetate plus 28 mg estradiol benzoate) terminal implants (0.169 vs. 0.176 ± 0.003) during finishing. Macken et al. (2003) reported similar DMI but improved G:F in feedlot heifers implanted with 200 mg trenbolone acetate plus 28 mg estradiol benzoate compared to heifers implanted with only 200 mg trenbolone acetate, suggesting there may be an additive performance improvement with implants containing a combination of trenbolone acetate with estradiol, even with concurrent MGA supplementation. When combining both backgrounding and finishing phases, intact heifers had improved ($P = 0.02$) overall G:F over spayed heifers (0.200 vs. 0.193 ± 0.003), but terminal implant strategy did not affect ($P = 0.39$) overall G:F. A meta-analysis of 18 feedlot experiments suggested that implanting finishing heifers with trenbolone acetate improved G:F without affecting DMI (Wagner et al., 2007). Additionally, Follmer et al. (2009) reported greater ADG and improved G:F with no differences in DMI in heifers receiving initial implants containing 8 mg estradiol plus 80 mg trenbolone acetate compared to heifers initially receiving Synovex[®] H. Although it was unexpected for heifers receiving moderate terminal implants to have greater DMI in this experiment, it is well-documented heifers receiving implants containing a combination of trenbolone acetate and estradiol may have improved G:F during finishing.

In another experiment, spayed heifers finished for 112-d on a 70% steam-rolled barley diet had similar growth performance, G:F, and carcass characteristics as intact heifers receiving 0.35 mg per head daily MGA (Hamernik et al., 1985). Heifers weighed

300 kg at time of spaying, so perhaps differences in age at time of spaying, a shorter finishing phase, and the concentration of supplemented MGA in this study attributed to similar performance among all heifers (Hamernik et al., 1985). The potential effects on feedlot performance associated with spaying heifers have not been expressed consistently and may be dependent upon management factors that include age at time of spaying, residual ovarian tissue inadvertently left within the heifer after spaying, feedlot entry BW, length of finishing phase, number of heifers housed per pen, pen size, composition of finishing diets, and implant strategy (Adams et al., 1990).

Feedlot Heifer Carcass Characteristics

Table 5 lists the effects of reproductive status and terminal implant strategy on heifer carcass characteristics. There were no significant interactions ($P \geq 0.15$) between reproductive status and terminal implant strategy for carcass characteristics during finishing, so main effects of reproductive status and terminal implant strategy are discussed. Hot carcass weight was similar ($P = 0.16$) between intact and spayed heifers, as well as between heifers receiving moderate or aggressive terminal implants, and averaged 319 ± 3 kg for all heifers. Subcutaneous fat depth over the 12th rib was similar ($P = 0.28$) for intact and spayed heifers (1.211 vs. 1.127 ± 0.097 cm) and was also similar ($P = 0.28$) between heifers with moderate or aggressive terminal implants (1.197 vs. 1.141 ± 0.097 cm). Longissimus muscle area was not affected by reproductive status ($P = 0.98$) or terminal implant strategy ($P = 0.88$) and averaged 78.1 ± 2.5 sq. cm for all heifers. Average USDA marbling score (where 500 = Small⁰⁰, 600 = Modest⁰⁰) was not

affected by reproductive status ($P = 0.29$) or terminal implant ($P = 0.66$) and averaged 592 ± 13 for all heifers.

Percentage of heifer carcasses grading USDA Prime was similar ($P = 0.18$) between intact and spayed heifers (3.6 vs. $7.5 \pm 2.0\%$) but tended to be higher ($P = 0.08$) for heifers receiving moderate compared to aggressive terminal implants (8.2 vs. $3.0 \pm 2.0\%$). Percentage of heifer carcasses grading USDA Choice tended to be greater ($P = 0.06$) for intact heifers than spayed heifers (81.0 vs. $70.5 \pm 3.8\%$) but was not affected ($P = 1.00$) by implant strategy and averaged $75.8 \pm 3.8\%$ for heifers receiving either moderate or aggressive terminal implants. Percentage of heifer carcasses grading upper 2/3 USDA Choice was not different ($P = 0.16$) between intact or spayed heifers (31.3 vs. $39.9 \pm 4.3\%$) and was also similar ($P = 0.18$) for heifers receiving moderate or aggressive terminal implants (31.5 vs. $39.7 \pm 4.3\%$). Percentage of heifer carcasses grading USDA Choice and Prime was similar ($P = 0.14$) for intact and spayed heifers (84.7 vs. $77.9 \pm 3.1\%$) and was also similar ($P = 0.25$) between heifers receiving moderate or aggressive terminal implants (83.9 vs. $78.7 \pm 3.1\%$). Percentage of heifer carcasses grading USDA Select tended to be lower ($P = 0.09$) for intact compared to spayed heifers (13.5 vs. $20.5 \pm 2.7\%$) but was similar ($P = 0.63$) between heifers with moderate or aggressive terminal implants (16.1 vs. $17.9 \pm 2.7\%$). Percentage of heifer carcasses graded as USDA Standard or below was similar ($P = 0.88$) between intact and spayed heifers (1.8 vs. $1.6 \pm 1.0\%$) but was higher ($P = 0.03$) for heifers that received aggressive compared to moderate terminal implants (3.3 vs. $0.0 \pm 1.0\%$). Explanations for why carcasses were graded as USDA Standard or lower were not provided when carcass characteristics were

collected. Although not conclusive from this study, there have been concerns of aggressive or long-term implant strategies negatively affecting carcass quality and meat tenderness (Morgan, 1997).

Average USDA yield grade was not affected by reproductive status ($P = 0.52$) or terminal implant strategy ($P = 0.78$) and averaged 2.90 ± 0.16 for all heifers. Percentage of heifer carcasses that were USDA Yield Grade 2 tended to be higher ($P = 0.06$) for spayed compared to intact heifers (50.8 vs. $38.3 \pm 4.4\%$) but was similar ($P = 0.11$) between heifers receiving moderate or aggressive terminal implants (49.7 vs. $39.4 \pm 4.4\%$). Therefore, percentage of carcasses that were USDA Yield Grade 3 was higher ($P < 0.01$) for intact compared to spayed heifers (48.7 vs. $28.3 \pm 2.8\%$) but was similar ($P = 0.48$) for heifers receiving either moderate or aggressive terminal implants (37.1 vs. $39.9 \pm 2.8\%$). The increased percentage of USDA Yield Grade 3 carcasses was likely related to the tendency for increased percentage of USDA Choice carcasses with intact heifers.

In contrast to the current experiment, Garber et al. (1990) suggested carcass characteristics of spayed heifers were not affected, and some were even improved when implanting spayed heifers. Garber et al. (1990) reported spayed heifers implanted with progesterone tended to have heavier final BW and therefore heavier HCW, decreased backfat thickness, and improved marbling scores and USDA yield grades. Field et al. (1996) also observed no differences in carcass characteristics between spayed or intact heifers. In contrast, Adams et al. (1990) reported surgical removal of ovaries increased marbling and reduced dressing percentage but did not impact backfat thickness or proportion of fat deposition in weight gained. Spaying heifers did not improve carcass

characteristics in this experiment other than reducing the percentage of USDA Yield Grade 3 carcasses and thus tending to increase the percentage of USDA Yield Grade 2 carcasses. Additionally, choice of implant should be carefully considered as it does appear to influence some performance variables in both spayed and intact heifers.

Conclusions

Compared to intact heifers supplemented with MGA, spayed heifers consumed less feed and gained less BW to result in reduced G:F during the backgrounding phase. Likely, the choice of low potency implant (Synovex[®] C) to all heifers and inclusion of MGA to intact heifers contributed to performance differences between spayed and intact heifers during backgrounding. During finishing, spaying heifers had no effect on DMI, ADG, or final BW but tended to reduce G:F. Suppression of weight gain during backgrounding induced from spaying may have been reversed by concurrent administration of Synovex[®] H (200 mg testosterone propionate plus 20 mg estradiol benzoate) or Synovex[®] Plus (200 mg trenbolone acetate plus 28 mg estradiol benzoate) terminal implants. However, heifers given a moderate terminal implant (Synovex[®] H) consumed more DMI, but had similar ADG, to result in poorer G:F during finishing compared to heifers given a more aggressive terminal implant (Synovex[®] Plus).

Major carcass characteristics were not affected by either reproductive status or terminal implant strategy. Spaying heifers did not improve carcass characteristics in this experiment other than reducing the percentage of USDA Yield Grade 3 carcasses and subsequently tending to increase the percentage of USDA Yield Grade 2 carcasses.

However, percentage of USDA Choice carcasses tended to decrease while percentage of USDA Select carcasses tended to increase in spayed heifers. Additionally, choice of implant should be carefully considered as it does appear to influence some performance and carcass quality variables in both spayed and intact heifers. Results of this experiment have provided a more complete understanding of how an alternative management strategy (spaying heifers vs. the traditional practice of supplementing MGA to intact heifers) affects performance and carcass characteristics of beef feedlot heifers. Additionally, valuable information emphasizing appropriate implant strategies for spayed heifers was obtained.

Table 1. Formulated ingredient composition¹ of diets fed to beef heifers during backgrounding and finishing phases.

Ingredient, %	Backgrounding	Finishing
Ground Corn	37.0	---
High Moisture Corn	---	83.5
Wet Beet Pulp	30.0	---
Corn Silage	20.0	11.0
Alfalfa Haylage	7.0	---
Pelleted Supplement ²	6.0	5.5

¹Ingredient composition reported on a DM-basis.

²Two supplements formulated to differ only in melengestrol acetate inclusion (0.5 mg per head daily; MGA[®]; Pfizer Animal Health; New York, NY) fed only to intact heifers. Supplements contained 9.8% Ca, 1.1% P, 0.9% Mg, 1.1% K, 1.8% Na, 1.1% S, 754 ppm Zn, 207 ppm Cu, 803 ppm Fe, and 12 ppm Co. Supplements were formulated to contain monensin sodium (360 mg per head daily; Rumensin[®]; Elanco Animal Health; Greenfield, IN) and tylosin phosphate (90 mg per head daily; Tylan[®]; Elanco Animal Health; Greenfield, IN).

Table 2. Analyzed chemical and energy composition¹ of diets fed to beef feedlot heifers during backgrounding and finishing phases.

Item	Backgrounding	SD ²	Finishing	SD ²
DM, %	34.1	0.7	65.0	2.5
CP, %	14.2	0.4	11.4	0.5
NDF, %	29.1	2.2	12.4	1.7
ADF, %	18.1	2.3	5.46	1.86
Fat, %	2.98	0.13	4.43	0.34
TDN, %	72.5	2.4	80.0	3.7
Ca, %	0.975	0.026	0.441	0.144
P, %	0.248	0.010	0.315	0.030
S, %	0.223	0.017	0.153	0.010
NE _g ³ , Mcal/kg	1.10	0.08	1.32	0.10

¹Composition reported on a DM-basis.

²Standard deviation of the mean.

³Net energy required for gain.

Table 3. Effect of reproductive status on beef feedlot heifer performance during the backgrounding phase.

Item	Status		SEM ¹	<i>P</i> -Value
	Intact	Spayed		
Initial BW, kg	272	274	22	0.25
End BW, kg	391	382	4	0.04
DMI, kg/d	6.56	6.43	0.06	0.02
ADG, kg	1.60	1.46	0.05	0.02
Gain:Feed	0.244	0.228	0.006	0.05

¹Standard error of the mean.

Table 4. Effect of reproductive status and terminal implant strategy on beef feedlot heifer performance during the finishing phase.

Item	Status		Implant ¹		SEM ³	<i>P</i> -Value ²		
	Intact	Spayed	Moderate	Aggressive		S	I	S x I
Initial BW, kg	391	382	---	---	4	0.04	---	---
Final Live BW, kg	516	511	514	514	6	0.15	0.94	0.90
DMI, kg/d	8.72	8.74	8.91	8.54	0.21	0.91	0.05	0.89
Overall DMI ⁴ , kg/d	7.66	7.72	7.75	7.63	0.05	0.42	0.15	0.87
ADG, kg	1.52	1.47	1.49	1.50	0.04	0.17	0.85	0.90
Overall ADG ⁴ , kg	1.53	1.49	1.51	1.51	0.02	0.08	0.83	0.95
Gain:Feed	0.176	0.169	0.169	0.176	0.003	0.06	0.06	1.00
Overall Gain:Feed ⁴	0.200	0.193	0.195	0.198	0.003	0.02	0.39	0.39

¹Moderate implant contained 200 mg testosterone propionate and 20 mg estradiol benzoate per dose (Synovex[®] H; Pfizer Animal Health; New York, NY). Aggressive implant contained 200 mg trenbolone acetate and 28 mg estradiol benzoate per dose (Synovex[®] Plus; Pfizer Animal Health; New York, NY).

²Main effects of status (S) and implant (I) are reported with non-significant status by implant (S x I) interaction.

³Standard error of the mean.

⁴Overall feeding period including backgrounding and finishing phases.

Table 5. Effect of reproductive status and terminal implant strategy on beef feedlot heifer carcass characteristics.

Item	Status		Implant ¹		SEM ³	P-Value ²		
	Intact	Spayed	Mod.	Aggr.		S	I	S x I
HCW, kg	320	317	319	319	3	0.16	0.99	0.89
12 th Rib BF, cm	1.211	1.127	1.197	1.141	0.097	0.28	0.47	0.59
LM Area ⁴ , sq. cm	78.0	78.1	78.3	77.8	2.5	0.98	0.88	0.32
Marbling Score ⁵	582	601	588	595	12.5	0.29	0.66	0.16
USDA Prime Carcasses, %	3.65	7.47	8.16	2.95	1.97	0.18	0.08	0.15
USDA Choice Carcasses, %	81.0	70.5	75.8	75.8	3.8	0.06	1.00	0.80
USDA Select Carcasses, %	13.5	20.5	16.1	17.9	2.7	0.09	0.63	0.44
USDA Std ⁶ or lower Carcasses, %	1.79	1.56	0.00	3.35	1.03	0.88	0.03	0.88
Upper 2/3 USDA Choice Carcasses, %	31.3	39.9	31.5	39.7	4.3	0.16	0.18	0.26
USDA Choice or Higher Carcasses, %	84.7	77.9	83.9	78.7	3.1	0.14	0.25	0.53
USDA Yield Grade ⁷	2.97	2.83	2.93	2.87	0.16	0.52	0.78	0.33
USDA Yield Grade 2, %	38.3	50.8	49.7	39.4	4.4	0.06	0.11	0.42
USDA Yield Grade 3, %	48.7	28.3	37.1	39.9	2.8	<0.01	0.48	0.66

¹Moderate (Mod.) implant contained 200 mg testosterone propionate and 20 mg estradiol benzoate per dose (Synovex[®] H; Pfizer Animal Health; New York, NY). Aggressive (Aggr.) implant contained 200 mg trenbolone acetate and 28 mg estradiol benzoate per dose (Synovex[®] Plus; Pfizer Animal Health; New York, NY).

²Main effects of status (S) and implant (I) are reported with status by implant (S x I) interaction.

³Standard error of the mean.

⁴Cold camera estimate of LM area.

⁵Marbling score based on 500 = Small⁰⁰; 600 = Modest⁰⁰.

⁶USDA Standard Quality Grade.

⁷Cold camera estimate of USDA yield grade.

Chapter 4

Effects of Including High Protein Dried Distillers Grains in Finishing Diets on Feedlot Performance and Carcass Characteristics of Beef Steers

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Summary

When compared to conventional dried distillers grains plus solubles (DDGS), the lower concentration of polyunsaturated fatty acids present in high protein dried distillers grains (HPDG) may reduce energy content of cattle diets and alter feedlot performance and carcass characteristics. The objective of this experiment was to evaluate effects of partially replacing dry-rolled corn (DRC) in traditional corn-based finishing diets with conventional DDGS or HPDG on feedlot cattle performance and carcass characteristics. Angus steers ($n = 48$) averaging 317 ± 8 kg initial BW were assigned randomly to one of three finishing diets (DM-basis): 1) 82.5% DRC, 12.1% CP, 55% starch, 3.55% fat, 0.15% S, and 1.29 Mcal/kg NE_g, (CON); 2) 35% DDGS, 51% DRC, 17.1% CP, 34% starch, 5.96% fat, 0.42% S, and 1.29 Mcal/kg NE_g, (DDGS); and 3) 35% HPDG, 51% DRC, 22.0% CP, 36% starch, 3.53% fat, 0.37% S, and 1.26 Mcal/kg NE_g, (HPDG). All diets contained 12% haylage and were formulated to supply 300 mg monensin sodium/steer daily. Steers were fed for *ad libitum* intake once daily at 0700 using individual Calan gates. Amount of feed offered was recorded daily, and feed refusals were collected weekly. Following 118 days on feed, steers were harvested at a commercial abattoir where carcass characteristics were collected by University of Minnesota and USDA personnel. Hot carcass weight was divided by a common dressing percentage (60.9%) to calculate adjusted final BW, which was reported as the final BW for steer performance measures. Final BW was similar ($P = 0.54$) among treatments and averaged 553, 552, and 540 ± 9 kg for CON, DDGS, and HPDG, respectively. Overall DMI tended to be greater ($P = 0.08$) for CON compared to HPDG (10.3 vs. 9.7 ± 0.2

kg/d) but was similar ($P = 0.58$) to DDGS (10.2 kg/d). However, DMI from d 28 through finishing was greater ($P < 0.01$) for CON than HPDG (10.8 vs. 9.9 ± 0.2 kg/d) but was similar ($P = 0.16$) to DDGS (10.5 kg/d). Average daily gain was similar ($P = 0.49$) among treatments and averaged 1.98, 1.99, and 1.91 ± 0.05 kg for CON, DDGS, and HPDG. Gain to feed was not different ($P = 0.69$) among treatments and averaged 0.192, 0.196, and 0.197 ± 0.004 for CON, DDGS, and HPDG. Hot carcass weights were similar ($P = 0.54$) and were 337, 336, and 329 ± 6 kg for CON, DDGS, and HPDG. Carcass USDA yield grade, 12th rib backfat depth, and percent KPH fat were similar ($P \geq 0.18$) among treatments. Longissimus muscle area was similar ($P = 0.57$) and averaged 80.0 sq. cm across treatments. Marbling score (where 500 = Small⁰⁰, 600 = Modest⁰⁰) was not different ($P = 0.26$) among treatments and averaged 561, 594, and 609 ± 22 for CON, DDGS, and HPDG. Finishing beef cattle with HPDG tended to reduce overall DMI; however, it may successfully replace conventional DDGS or up to 35% DRC in feedlot diets without having deleterious effects on other live performance variables or carcass characteristics.

Introduction

Corn co-products, particularly wet distillers grains plus solubles (WDGS) or dried distillers grains plus solubles (DDGS), have become common ingredients in feedlot diets. Co-products of the ethanol industry are attractive feed ingredients due to their improved energy value relative to corn, price, availability, flexibility in feeding, and propensity to alleviate incidence and severity of acidosis (Stock et al., 2000). According to Buckner et

al. (2007), DDGS can be included in dry-rolled corn (DRC)-based finishing diets to improve steer ADG and gain to feed (G:F), with optimum inclusion concentration being 20% of the diet DM. Feeding value of all inclusion concentrations of DDGS was greater than the DRC control diet (reference value of 100) and was estimated to be 156, 146, 112, and 109 for 10, 20, 30, and 40% DDGS inclusion, respectively (Buckner et al., 2007). A recent study by Depenbusch et al. (2009) fed DDGS up to 75% dietary DM in steam-flaked corn (SFC)-based diets to finishing heifers and observed maximum performance responses for DMI, ADG, and final live BW at 15% dietary DM inclusion.

When a meta-analysis was conducted with five different feeding trials evaluating increasing concentrations of DDGS in finishing diets, DMI increased linearly with increasing DDGS inclusion concentration and was maximized at 30% DDGS (Klopfenstein et al., 2008). However, there was a quadratic response for ADG in which ADG was maximized between 20 and 30% DDGS inclusion and a cubic response for G:F, with maximum G:F occurring between 10 and 20% DDGS inclusion. Additionally, feeding values decreased from 153 for 10% DDGS inclusion to 100 (the same as DRC control) at 40% DDGS inclusion in finishing diets (Klopfenstein et al., 2008). The apparent inverse relationship of decreasing feeding value of DDGS with increasing inclusion concentrations may be explained partially by increased dietary fatty acid concentration which may reduce rumen fermentation (Zinn et al., 2000) and reduce intestinal fatty acid digestion (Plascencia et al., 2003).

Increased concentrations of polyunsaturated fatty acids (PUFA) in beef products are associated with increased oxidation rates that lead to undesirable beef color, off-

flavors, and overall reduced shelf-life and consumer acceptance of beef retail products (de Mello Jr. et al., 2008b). Because DDGS contain higher concentrations of PUFA than corn grain, beef products from cattle finished with elevated concentrations of DDGS will likely contain higher concentrations of these fats (Depenbusch et al., 2009). Therefore, beef product degradation is accelerated due to more rapid oxidation of the less stable PUFA which also reduces color stability and consumer satisfaction of whole muscle (Roeber et al., 2005) and ground (Gunn et al., 2009) beef products. However, Roeber et al. (2005) reported feeding either WDGS or DDGS at lower inclusion concentrations (10 to 25% dietary DM) may maintain, or possibly enhance, shelf life stability of cooked beef without affecting palatability. Although color was affected, feeding WDGS or DDGS up to 50% dietary DM inclusion did not impact tenderness or sensory attributes of beef (Roeber et al., 2005). It appears results in both finishing performance and beef quality attributes of feedlot cattle fed varying concentrations of WDGS or DDGS are not consistent. However, most research suggests the elevated concentrations of PUFA in the distillers grains plus solubles may have the greatest influence on beef quality and sensory characteristics.

Innovative ethanol companies have developed alternative processes to enhance efficiency of ethanol production. Novel corn-milling co-products are derived from these new processes and can include high protein dried distillers grains (HPDG). The HPDG contain lower concentration of lipid and higher concentration of CP compared to conventional DDGS. There is limited research available evaluating the effects of HPDG inclusion in finishing diets on beef cattle feedlot performance and carcass characteristics.

Depenbusch et al. (2008) fed 13.5% HPDG in place of SFC to feedlot heifers and reported similar performance and carcass characteristics to heifers consuming a traditional SFC-based finishing diet. The chemical composition of the HPDG fed in the experiment was 91% DM, 43% CP, and 4% fat. The control diet contained 81% SFC, 6% alfalfa hay, 1.2% urea, 14.8% CP, and 3.8% fat while the 13.5% HPDG diet contained 71% SFC, 6% alfalfa hay, 13.9% CP, and 3.9% fat (Depenbusch et al., 2008).

Gigax et al. (2011) fed crossbred yearling steers diets containing either 35% low-fat or 35% conventional WDGS in place of a 50:50 blend of DRC and high moisture corn (HMC) and evaluated live steer performance, carcass, and meat quality characteristics. The low-fat WDGS co-product contained 34.8% CP, 6.7% fat, and 0.85% S while the conventional WDGS co-product contained 34.5% CP, 12.9% fat, and 0.94% S. The control diet contained 13.6% CP, 3.6% fat, and 0.12% S, the low-fat WDGS diet contained 17.9% CP, 4.7% fat, and 0.37% S, and the conventional WDGS diet contained 17.8% CP, 6.9% fat, and 0.41% S. Carcass-adjusted final live BW, ADG, and HCW were greater for steers finished with 35% normal-fat WDGS despite similar DMI and G:F among all treatments. Marbling score, 12th rib back fat thickness, and LM area were not different among treatments. Steers finished with low-fat WDGS performed similarly to steers fed the control diet; therefore, finishing steers with a low-fat WDGS is comparable to finishing steers with traditional corn-based diets (Gigax et al., 2011). An opportunity may exist to develop a feeding strategy that maximizes HPDG inclusion concentrations in feedlot diets while reducing negative effects of PUFA on rumen fermentation and quality of resultant beef retail products. The objective of the experiment was to evaluate the

effects of partially replacing DRC in traditional DRC-based finishing diets with 35% conventional DDGS or 35% HPDG on feedlot performance and carcass characteristics of beef steers.

Materials and Methods

Animals, Location, and Backgrounding Phase

Care and handling of all animals used in this experiment was conducted under the approval of the University of Minnesota Institutional Animal Care and Use Committee (IACUC Protocol # 0908A71701). Purebred Angus steers (n = 48) initially weighing 230 ± 28 kg and originating from the beef cow herd at the University of Minnesota North Central Research and Outreach Center (Grand Rapids, MN) were used to evaluate the effects of partially replacing DRC in traditional DRC-based finishing diets with 35% conventional DDGS or 35% HPDG on feedlot performance and carcass characteristics. All steers received vaccinations against infectious bovine rhinotracheitis virus, bovine viral diarrhea Types 1 and 2, parainfluenza₃, and bovine respiratory syncytial virus (Bovi-Shield[®] Gold FP5 VL5; Pfizer Animal Health; New York, NY) and against *Clostridium chauvoei*, *Cl. septicum*, *Cl. novyi*, *Cl. sordellii*, *Cl. perfringens* types B, C, and D, and *Cl. haemolyticum* (Ultrabac[®] 8; Pfizer Animal Health; New York, NY) prior to trial initiation. Seventy-five days prior to initiation of the experiment, steers were allocated into one of two pens in a facility with a Calan gate individual feeding system (American Calan, Inc.; Northwood, NH) at the North Central Research and Outreach Center. Each Calan gate had a 36.6 cm base and a 91.4 cm depth of bunk. One concrete floor pen

contained 18 steers (pen 1 dimensions were 5.18 m wide by 10.7 m long; 71.1 cm per steer of bunk space) and the other concrete floor pen contained 30 steers (pen 2 dimensions were 5.18 m wide by 9.75 m long; 63.5 cm per steer of bunk space). Average BW of steers in both pens was equal, and each pen had continuous access to an outdoor dry lot (pen 1 dry lot was 1,769 sq. m and pen 2 dry lot was 1,415 sq. m) and an automatic water fountain (pen 1 - Mirafount E3465, 100 head capacity and pen 2 - Ritchie 300, 125 head capacity). Steers were fed a common backgrounding diet at 0700 as they began the training process to the Calan gates. The backgrounding diet contained increasing proportions of DRC and decreasing proportions of alfalfa haylage as energy concentration was increased from 1.0 to 1.2 Mcal NE_g per kg DM over a four-wk growing phase.

Experimental Design, Experimental Diets, and Data Collection

On d -42, steers within pen were assigned to finishing diets so that average BW was equal among all three treatment diets within and across pen and assigned randomly to individual Calan gates within pen. All steers continued to receive a common backgrounding diet until d -28 as they were trained to their assigned Calan gate. Finishing diets included (Table 1): 1) 82.5% DRC (86.9% DM, 9.5% CP, 11.6% NDF, 4.9% ADF, 64.2% starch, 3.4% fat, 85.7% TDN, and 1.41 Mcal/kg NE_g), 12.1% CP, 55% starch, 3.55% fat, 0.15% S, and 1.29 Mcal/kg NE_g, (CON); 2) 35% conventional DDGS, 51% DRC, 17.1% CP, 34% starch, 5.96% fat, 0.42% S, and 1.29 Mcal/kg NE_g, (DDGS); and 3) 35% HPDG, 51% DRC, 22.0% CP, 36% starch, 3.53% fat, 0.37% S, and 1.26

Mcal/kg NE_g, (HPDG). All diets contained 12% haylage (36.7% DM, 14.2% CP, 55.4% NDF, 36.2% ADF, 10.6% ash, 53.5% TDN, and 0.53 Mcal/kg NE_g) and were formulated to supply 300 mg monensin sodium/steer daily. Conventional DDGS (Lake Crystal, MN) and HPDG (Glenville, MN) were sourced from POET Nutrition (Sioux Falls, SD). A single delivery of each co-product was sufficient for the entire duration of the finishing phase. All diets were mixed as needed in large batches using a mixer truck and unloaded into individual bays located within the Calan gate facility. Batch sizes were estimated to last approximately three days to maintain diet integrity and freshness. If more than one diet was mixed on the same day, CON was mixed first followed by the HPDG diet prior to the DDGS diet in attempt to minimize carryover of ingredients and fat between diets.

On d -28, adaptation to finishing diets began while training to the Calan gates continued, and all steers received an initial implant (Synovex[®] Choice; Pfizer Animal Health; New York, NY) on d -11. On d 1 of the experiment, steers were consuming the finishing diets *ad libitum*. Initial BW was a 1-d BW measurement following a 16-h period where steers were withheld from feed. Average initial BW of steers on d 1 of the experiment was 317 ± 8 kg. Steers were fed for *ad libitum* intake once daily at 0700. Prior to feeding, all steers were temporarily locked out of the Calan gate facility (approximately 90 min) and were allowed access to the facility after feed delivery was complete. Daily feed deliveries were weighed individually using a platform scale (model FE-31KA2; A&D Weighing; San Jose, CA) with attached indicator (model 100KA1; A&D Weighing; San Jose, CA), recorded, and delivered to the respective bunk. Bunks were read daily and managed as in a typical commercial feedlot employing the slick bunk

approach. Daily addition or reduction in individual feed delivery did not exceed 0.22 kg. Feed refusals were measured and recorded once weekly, and a sub-sample of each refusal was collected and immediately frozen (-20°C) for subsequent DM analysis.

Samples of ration ingredients and diets were collected weekly, immediately frozen (-20°C), and composited by month prior to overnight shipment to Dairyland Laboratories (St. Cloud, MN) for chemical analyses by NIR. Chemical composition values for each monthly analysis were averaged to obtain an overall mean value and standard deviation for chemical composition of each individual ingredient and treatment diet. Dry-rolled corn, alfalfa haylage, and each co-product were analyzed for laboratory DM at 105°C (Shreve et al. 2006; NFTA method 2.1.4), CP by combustion analyzer (AOAC, 2000 method 990.03), ADF (AOAC, 1996 method 973.18), NDF (analyzed using sodium sulfite and amylase, Van Soest et al., 1991), acid detergent insoluble CP (AOAC, 1996 method 973.18), soluble CP (AOAC, 2000 method 990.03), crude fat (AOAC, 2000 method 920.39), ash (AOAC, 1996 method 942.05), minerals (Ca, P, Mg, K, and S; AOAC, 2000 method 985.01), and TDN and NE_g (using OARDC equations). Treatment diets were analyzed for laboratory DM at 105°C (Shreve et al. 2006; NFTA method 2.1.4), CP by combustion analyzer (AOAC, 2000 method 990.03), ADF (AOAC, 1996 method 973.18), NDF (analyzed using sodium sulfite and amylase, Van Soest et al., 1991), lignin (AOAC, 1996 method 973.18), acid detergent insoluble CP (AOAC, 1996 method 973.18), soluble CP (AOAC, 2000 method 990.03), starch (Bach Knudsen, 1997), crude fat (AOAC, 2000 method 920.39), ash (AOAC, 1996 method 942.05), minerals (Ca, P, Mg, K, S, Na, and Cl; AOAC, 2000 method 985.01), and TDN and NE_g

(using OARDC equations). Diet ingredient proportions were adjusted accordingly if percent DM changed for alfalfa haylage or DRC to maintain formulated diet composition on a DM-basis. Weekly diet refusal samples were dried for 48 h in a 60°C forced-air oven (model DC-246-E; Blue M Electric, Watertown, WI) at the ruminant nutrition lab (University of Minnesota, St. Paul, MN) to determine DM to correct for actual steer daily DMI.

Steers were weighed every 28-d prior to the morning feeding using a For-Most portable squeeze chute (For-Most Livestock Equipment; Hawarden, IA) equipped with a Tru-Test scale (Tru-Test, Inc.; Mineral Wells, TX). On d 56, all steers received a terminal implant (Synovex[®] Choice; Pfizer Animal Health; New York, NY). On d 118 of the finishing phase, steers were transported 485 km to a commercial abattoir (PM Beef Holding, LLC; Windom, MN) where carcass characteristics were collected by University of Minnesota (St. Paul, MN) and USDA personnel following a 48-h carcass chill. Carcass characteristics collected included HCW, cold carcass weight, subcutaneous fat thickness over the 12th rib, LM area, percentage of KPH fat, and marbling score. Carcass USDA quality grades and USDA yield grades assigned by USDA personnel were also recorded. Hot carcass weight was divided by the overall group dressing percentage (60.9%) to calculate adjusted final live BW. To offset differences in gut fill among steers, carcass-adjusted final live BW was used for calculation of overall BW gain, ADG, and G:F.

Statistical Analyses

Live steer performance and carcass characteristics were analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Experimental unit was steer. Fixed model effect was treatment and random effect was pen. The linear model for these analyses is written as follows:

$$y_{ij} = \mu + \beta_i + \alpha_j + \varepsilon_{ij}$$

where,

y_{ij} represents observation $_{ij}$; μ represents the overall mean; β_i represents the random effect of pen $_i$; and α_j represents the fixed effect of treatment $_j$. The residual term ε_{ij} is assumed to be normally, independently, and identically distributed with variance σ_e^2 .

Carcass USDA quality grade and USDA yield grade categorical data were analyzed using the GENMOD procedure of SAS with fixed model effects of treatment and pen. The linear model for these analyses is written as follows:

$$y_{ij} = \mu + \rho_i + \alpha_j + \varepsilon_{ij}$$

where,

y_{ij} represents observation $_{ij}$; μ represents the overall mean; ρ_i represents the fixed effect of pen $_i$; and α_j represents the fixed effect of treatment $_j$. The residual term ε_{ij} is assumed to be normally, independently, and identically distributed with variance σ_e^2 . Statistical significance was declared with P -values ≤ 0.05 , and trends were discussed with $0.05 < P$ -values ≤ 0.10 . The PDIFF option was used to separate least squares means when a significant F -test statistic was present. Treatment means are presented as least squares means, and the largest standard error of the mean is reported.

Results and Discussion

Chemical and Energy Composition of Corn Milling Co-Products and Experimental Diets

Chemical and energy composition (DM-basis) of traditional DDGS and HPDG co-products analyzed by Dairyland Laboratories are reported in Table 1. The reported chemical and energy values are the average of four monthly analyses derived from composites of four weekly samples. The standard deviation of the averages is also reported. The objective of the experiment was to replace portions of DRC in finishing diets with either co-product; therefore, diets were not formulated to be isonitrogenous or isocaloric. As expected, the CP concentration of HPDG was much higher (39.1%) than conventional DDGS (27.6%), and fat concentration of HPDG was lower (5.1%) than conventional DDGS (10.9%). The CP and fat concentrations for HPDG used in this experiment were lower and higher, respectively, than CP and fat concentrations reported by others (Depenbusch et al., 2008; Kelzer et al., 2009; 2010) for a similar high protein corn milling co-product. Sulfur concentration was lower (0.69%) for HPDG compared to conventional DDGS (0.84%). As dietary inclusion concentration of HPDG increases in finishing cattle diets, there will be lower total dietary intake of fat and S, which may promote performance advantages in feedlot cattle when feeding similar inclusion concentrations of HPDG and conventional DDGS.

Concentrations of TDN and NE_g in HPDG were lower (76.7% and 1.32 Mcal/kg) than concentrations in conventional DDGS (82.2% and 1.40 Mcal/kg) likely due to its lower fat concentration. Lower fat concentration may reduce feeding value of HPDG compared to DDGS (Bremer et al., 2011b) as well as reduce energy concentrations of

diets containing similar inclusion concentrations of these corn milling co-products (Gigax et al., 2011). Chemical and energy composition (DM-basis) of experimental diets are reported in Table 2. The reported chemical and energy values are the average of four monthly analyses derived from composites of four weekly diet samples. Compared to CON not containing distillers grains co-products (12.1% CP), the DDGS diet contained 17.1% CP while the HPDG diet contained 22.0% CP due to differences in co-product CP composition. As expected, the HPDG diet contained lower concentration of fat (3.53%) compared to DDGS (5.96%) but was comparable to the fat concentration of CON (3.55%). Compared to a similar feedlot experiment conducted by Gigax et al. (2011), dietary fat concentrations of diets containing 35% conventional WDGS (6.91% dietary fat) or low fat WDGS (4.72% dietary fat) were greater than fat concentrations of diets fed in the current experiment due to greater fat concentrations of each WDGS. Lower TDN and NE_g concentrations of the HPDG diet (75.7% and 1.26 Mcal/kg) compared to CON (79.9% and 1.29 Mcal/kg) and DDGS (77.2% and 1.29 Mcal/kg) diets were likely a result of the lower fat concentration in the HPDG diet (Bremer et al., 2011b). When NE_g concentrations of experimental diets were calculated using NRC (1996) equations based on actual steer intake and BW gain during finishing, dietary NE_g concentrations were higher than NE_g concentrations calculated using OARDC equations (based on diet ADF and digestibility estimates) and averaged 1.45, 1.47, and 1.48 Mcal/kg for CON, DDGS, and HPDG, respectively. Due to differences in S concentration of each co-product fed in the current experiment, dietary S concentrations averaged 0.15, 0.42, and 0.37% S for CON, DDGS, and HPDG. Dietary S concentrations of all diets met minimum dietary S

requirements (0.15% S), but S concentrations of the DDGS and HPDG diets were greater than the maximum tolerable S concentration (0.30% S) for high-concentrate diets (NRC, 2005). However, the S concentrations of the DDGS and HPDG diets did not exceed the 0.46% threshold concentration reported by Vanness et al. (2009c) for risk of polioencephalomalacia in feedlot cattle consuming finishing diets containing high concentrations of corn milling co-products.

Feedlot Steer Live Performance

Results for live steer feedlot performance are listed in Table 3. Initial BW was similar ($P = 0.90$) across all treatments and averaged 317 ± 8 kg. Final live BW was not different ($P = 0.54$) and averaged 553, 552, and 540 ± 9 kg for CON, DDGS, and HPDG. Overall BW gain for the finishing period was similar ($P = 0.49$) and averaged 234, 235, and 226 ± 6 kg for CON, DDGS, and HPDG. In contrast, Gigax et al. (2011) reported crossbred yearling steers had heavier final live BW when finished with a diet containing 35% conventional WDGS (12.9% fat) compared to steers finished with a traditional corn-based diet or a diet containing 35% low-fat WDGS (6.7% fat). Similar to the current experiment, Depenbusch et al. (2008) reported similar final live BW for heifers consuming a finishing diet containing 13.5% HPDG (4% fat) compared to heifers consuming a traditional SFC-based diet or a diet containing 12.9% conventional DDGS (12% fat).

Overall DMI tended ($P = 0.08$) to be greater for CON compared to HPDG (10.3 vs. 9.7 kg/d) but DMI for CON was similar ($P = 0.58$) to DDGS (10.2 kg/d). This

observation is in contrast to Depenbusch et al. (2008), who reported similar DMI in heifers consuming the control (traditional SFC-based diet) and either diet containing 12.9% conventional DDGS or 13.5% HPDG. Gigax et al. (2011) also reported similar DMI between yearling steers consuming corn-based control and low-fat WDGS finishing diets. In the current experiment, DMI from d 28 through finishing was greater ($P < 0.01$) for CON than HPDG (10.8 vs. 9.9 kg/d), but DMI for CON was similar ($P = 0.16$) to DDGS (10.5 kg/d). However, DMI from d 28 through finishing tended to be greater ($P = 0.07$) for DDGS than HPDG. In the current study, it is unclear why differences in DMI were observed. Depenbusch et al. (2008) reported greater DMI in feedlot heifers consuming 12.9% conventional DDGS compared to heifers consuming 13.5% HPDG in traditional SFC-based finishing diets. However, 0.7% urea was added to the conventional DDGS diet but was not added to the diet containing HPDG. Thus, Depenbusch et al. (2008) speculated the diet containing HPDG may have been deficient in DIP and thus limited intake due to reduced microbial fermentation. Urea was not included in any of the treatment diets in the current experiment; therefore, it is difficult to speculate whether differences in DMI could be attributed to a deficiency in DIP. Likely, the tendency for increased DMI from d 28 through finishing in steers consuming DDGS compared to HPDG is related to possible improved diet palatability with inclusion of 35% conventional DDGS.

Overall ADG was similar ($P = 0.49$) among treatments and averaged 1.98, 1.99, and 1.91 ± 0.05 kg for CON, DDGS, and HPDG. Average daily gain from d 28 through end of finishing was also similar ($P = 0.44$) across treatments and averaged 2.20, 2.13,

and 2.09 ± 0.06 kg for CON, DDGS, and HPDG. Depenbusch et al. (2008) also reported similar ADG among all heifers, but these observations are in contrast to Gigax et al. (2011). Gigax et al. (2011) reported yearling steers consuming a diet containing 35% conventional WDGS gained 0.3 kg BW more per day than yearling steers consuming a control diet or a diet containing 35% low-fat WDGS, even though DMI was similar across all treatments. However, steers consuming the low-fat WDGS had similar ADG to steers consuming the control diet (Gigax et al., 2011). In agreement with Depenbusch et al. (2008), overall G:F was not different ($P = 0.68$) among treatments in the current study and averaged 0.192, 0.196, and 0.197 ± 0.004 for CON, DDGS, and HPDG. Gigax et al. (2011) also reported similar G:F among steers consuming traditional corn-based and low-fat WDGS finishing diets. Additionally, G:F from d 28 through the end of finishing was similar ($P = 0.62$) across all treatments and averaged 0.203, 0.205, and 0.210 ± 0.005 for CON, DDGS, and HPDG, even though DMI differed across treatments during this phase.

Feedlot Steer Carcass Characteristics

Carcass characteristics were not affected by finishing diet and are reported in Table 4. Calculated dressing percent $[(\text{HCW} / \text{final live BW}) * 100]$ was not different ($P = 0.22$) and was 59.6, 60.3, and $59.5 \pm 0.4\%$ for CON, DDGS, and HPDG. Hot carcass weight was similar ($P = 0.54$) and averaged 337, 336, and 329 ± 6 kg for CON, DDGS, and HPDG. These results are to be expected as final BW and dressing percentages were similar among all steers. Depenbusch et al. (2008) reported similar HCW among heifers consuming a traditional SFC-based finishing diet or a finishing diet containing either

13.5% HPDG or 12.9% conventional DDGS. In contrast, Gigax et al. (2011) reported heavier HCW for yearling steers consuming a finishing diet containing 35% conventional WDGS compared to steers consuming a traditional DRC/HMC finishing diet or a diet containing 35% low-fat WDGS. The heavier HCW reported by Gigax et al. (2011) was expected as steers finished with 35% conventional WDGS had greater ADG and therefore were heavier at harvest. However, steers consuming the corn control and 35% low-fat WDGS diets had identical HCW (Gigax et al., 2011).

Subcutaneous backfat over the 12th rib was similar ($P = 0.18$) and measured 1.429, 1.572, and 1.651 ± 0.084 cm for CON, DDGS, and HPDG. Longissimus muscle area was also similar ($P = 0.57$) and averaged 78.6, 78.4, and 76.9 ± 1.3 sq. cm for CON, DDGS, and HPDG. Percentage of KPH fat was not different ($P = 0.34$) and averaged 2.35, 2.70, and $2.60 \pm 0.18\%$ for CON, DDGS, and HPDG. Average USDA yield grades were similar ($P = 0.54$) and were 2.56, 2.75, and 2.69 ± 0.12 for CON, DDGS, and HPDG. Percent carcasses grading USDA Yield Grades 2 and 3 were similar ($P = 0.51$) across treatments (42.6, 23.9, and $30.1 \pm 11.7\%$ USDA Yield Grade 2 carcasses and 57.4, 76.1, and $69.9 \pm 11.7\%$ USDA Yield Grade 3 carcasses for CON, DDGS, and HPDG, respectively).

Average marbling score (where 500 = Small⁰⁰, 600 = Modest⁰⁰) was not affected ($P = 0.26$) by treatment and was 561, 594, and 609 ± 22 for CON, DDGS, and HPDG. Percent carcasses grading USDA Prime and Choice were similar ($P = 0.86$) and were 81.3, 87.5, and $81.3 \pm 9.4\%$ for CON, DDGS, and HPDG. Those carcasses grading in the upper 2/3 USDA Choice category or higher were similar ($P = 0.40$) and averaged 41.6,

58.5, and $65.6 \pm 13.2\%$ for CON, DDGS, and HPDG. Percent carcasses grading USDA Select were similar ($P = 0.86$) and were 18.7, 12.5, and $18.7 \pm 9.4\%$ for CON, DDGS, and HPDG. Some research suggests marbling score is reduced when feeding DDGS at concentrations reaching 50% dietary DM inclusion (Gunn et al., 2009); however, when feeding 15 or 30% DDGS (de Mello Jr. et al., 2008a) or 30% DDGS (Leupp et al., 2009) in finishing diets, marbling score, distribution, texture, and fat content were not affected. No treatment differences for carcass characteristics were reported by Depenbusch et al. (2008), and no treatment differences in carcass characteristics other than HCW were reported by Gigax et al. (2011).

Conclusions

Finishing beef cattle with diets containing HPDG tended to reduce overall DMI; however, this co-product may successfully replace up to 35% of DRC or conventional DDGS in feedlot diets as there were no deleterious effects on other live performance variables or carcass characteristics. Although the analyzed energy concentration of the HPDG co-product was lower than conventional DDGS due to its reduced fat concentration, it appears this co-product was able to provide energy and nutrients necessary to maintain similar performance and carcass characteristics as steers finished with traditional DRC-based diets or with diets containing similar concentrations of conventional DDGS. With current high corn prices and increasing production costs in the feedlot industry, incorporating co-products into finishing diets at higher inclusion concentrations in place of more expensive ingredients may be attractive to provide

economic advantages to feedlot producers. Additionally, if there are positive effects on either rumen digestibility or resulting meat quality from feeding lower dietary concentration of PUFA, HPDG may be a viable alternative to conventional DDGS in finishing beef cattle diets.

Table 1. Analyzed chemical and energy composition¹ of conventional dried distillers grains plus solubles and high protein dried distillers grains.

Item	Corn Milling Co-Product ²			
	Conventional DDGS	SD	HPDG	SD
DM, %	91.0	0.9	91.3	0.7
CP, %	27.6	1.0	39.0	0.0
ADF, %	9.7	0.6	13.6	0.4
aNDF ³ , %	23.9	0.8	23.6	0.1
Fat, %	10.9	0.1	5.1	0.8
Ca, %	0.07	0.01	0.04	0.01
P, %	0.96	0.01	0.54	0.03
S, %	0.84	0.02	0.69	0.03
TDN, %	82.2	0.4	76.7	1.0
NE _g ⁴ , Mcal/kg	1.40	0.01	1.32	0.03

¹Analyzed by Dairyland Laboratories, Inc. (St. Cloud, MN). Values in the table are the average of four samples analyzed monthly throughout the experiment. Monthly samples are composites of four samples, each collected at weekly intervals. Standard deviation (SD) of nutrient analyses are presented following their respective mean values. All values are reported on a DM-basis.

²Both corn milling co-products were sourced from POET Nutrition. Conventional DGS = conventional dried distillers grains plus solubles sourced from Lake Crystal, MN; HPDG = high protein dried distillers grains containing no solubles sourced from Glenville, MN.

³NDF was analyzed using sodium sulfite.

⁴Analyzed by Dairyland Laboratories using OARDC equations based on ADF and digestibility estimates.

Table 2. Formulated ingredient and analyzed chemical and energy composition¹ of experimental diets.

Ingredient	Experimental Diet ²					
	CON	DDGS		HPDG		
Dry-Rolled Corn, %	82.5	51.0		51.0		
Alfalfa Haylage, %	12.0	12.0		12.0		
Conventional DGS ³ , %	0.0	35.0		0.0		
HPDG ⁴ , %	0.0	0.0		35.0		
Supplement, %	5.5 ⁵	2.0 ⁶		2.0 ⁶		
Chemical	Mean	SD	Mean	SD	Mean	SD
DM, %	75.2	0.8	75.7	2.2	75.7	1.9
CP, %	12.1	0.4	17.1	0.5	22.0	0.1
Fat, %	3.55	0.26	5.96	0.29	3.53	0.09
ADF, %	9.0	1.5	10.6	0.7	9.7	1.0
aNDF ⁷ , %	15.6	2.5	22.4	0.7	20.7	1.7
Starch, %	55.0	4.3	33.9	0.7	36.0	2.3
Ca, %	0.70	0.1	0.97	0.1	1.03	0.06
P, %	0.31	0.01	0.53	0.01	0.34	0.01
S, %	0.15	0.02	0.42	0.01	0.37	0.01
Energy	Mean	SD	Mean	SD	Mean	SD
TDN, %	79.9	1.8	77.2	1.3	75.7	1.0
NE _g ⁸ , Mcal/kg (OARDC)	1.29	0.05	1.29	0.04	1.26	0.02
NE _g ⁹ , Mcal/kg (NRC)	1.45	---	1.47	---	1.48	---

¹Analyzed by Dairyland Laboratories, Inc. (St. Cloud, MN). Mean values in the table are the average of four diet samples analyzed monthly throughout the experiment. Monthly samples are composites of four diet samples, each collected at weekly intervals. Standard deviation (SD) of nutrient analyses are presented following their respective mean values. All values are reported on a DM-basis.

²Experimental diets included: CON, containing 0% corn-milling co-products; DDGS, containing 35% conventional dried distillers grains plus solubles; and HPDG, containing 35% high protein dried distillers grains.

³Conventional dried distillers grains plus solubles sourced from POET Nutrition, Lake Crystal, MN.

⁴High protein dried distillers grains sourced from POET Nutrition, Glenville, MN.

⁵Supplement contained 60% CP and 0.55 g monensin sodium per kg DM (DM-basis).

⁶Supplement contained 1.65 g monensin sodium per kg DM (DM-basis).

⁷NDF was analyzed using sodium sulfite.

⁸Analyzed by Dairyland Laboratories using OARDC equations based on ADF and digestibility estimates.

⁹Calculated using NRC (1996) equations based on observed steer intake and weight gain.

Table 3. Effect of feeding 35% high protein dried distillers grains in place of dry-rolled corn or conventional dried distillers grains plus solubles on beef feedlot steer performance.

Item	Experimental Diet ¹			SEM ²	P-Value
	CON	DDGS	HPDG		
Initial BW, kg	319	317	314	8	0.90
Final Live BW ³ , kg	553	552	540	9	0.54
Overall BW Gain ³ , kg	234	235	226	6	0.49
Overall DMI, kg/d	10.3	10.2	9.7	0.2	0.08
DMI, d 28-End of Finishing, kg/d	10.8 ^a	10.5 ^{ab}	9.9 ^b	0.2	< 0.01
Overall ADG ³ , kg	1.98	1.99	1.91	0.05	0.49
ADG, d 28-End of Finishing, kg	2.20	2.13	2.09	0.06	0.44
Overall Gain:Feed ³	0.192	0.196	0.197	0.004	0.68
Gain:Feed, d 28-End of Finishing	0.203	0.205	0.210	0.005	0.62

¹Experimental diets included: CON, containing 0% corn-milling co-products; DDGS, containing 35% conventional dried distillers grains plus solubles; and HPDG, containing 35% high protein dried distillers grains.

²Standard error of the mean.

³Carcass-adjusted to group dressing percentage of 60.9%.

^{ab}Means within row with uncommon superscript letters differ ($P < 0.05$).

Table 4. Effect of feeding 35% high protein dried distillers grains in place of dry-rolled corn or conventional dried distillers grains plus solubles on beef feedlot steer carcass characteristics.

Item	Experimental Diet ¹			SEM ²	P-Value
	CON	DDGS	HPDG		
HCW, kg	337	336	329	6	0.54
Calculated Dress ³ , %	59.6	60.3	59.5	0.4	0.22
12 th Rib BF, cm	1.429	1.572	1.651	0.084	0.18
LM Area, sq. cm	78.6	78.4	76.9	1.3	0.57
KPH Fat, %	2.35	2.70	2.60	0.18	0.34
USDA Yield Grade	2.56	2.75	2.69	0.12	0.54
USDA Yield Grade 2 Carcasses, %	42.6	23.9	30.1	11.7	0.51
USDA Yield Grade 3 Carcasses, %	57.4	76.1	69.9	11.7	0.51
Marbling Score ⁴	561	594	609	22	0.26
USDA Prime and Choice Carcasses, %	81.3	87.5	81.3	9.4	0.86
Upper 2/3 USDA Choice Carcasses, %	41.6	58.5	65.6	13.2	0.40
USDA Select Carcasses, %	18.7	12.5	18.7	9.4	0.86

¹Experimental diets included: CON, containing 0% corn-milling co-products; DDGS, containing 35% conventional dried distillers grains plus solubles; and HPDG, containing 35% high protein dried distillers grains.

²Standard error of the mean.

³Dressing percent determined by: $[(\text{HCW}/\text{Final Live BW}) * 100]$.

⁴Marbling score (where 500 = Small⁰⁰, 600 = Modest⁰⁰).

Chapter 5

Effects of Supplemental Manganese in High-Sulfur Feedlot Diets on *In Vitro* and *In Vivo* Ruminal Fermentation and Hydrogen Sulfide Gas Production

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Summary

Two experiments were conducted to evaluate the effects of supplemental manganese (Mn) in high-sulfur (S) feedlot diets on *in vitro* and *in vivo* ruminal fermentation and hydrogen sulfide (H₂S) gas production. In experiment 1, effects of six concentrations (DM-basis; 0 (control), 500, 1,000, 1,500, 2,000, 2,500 ppm) of Mn (supplied as manganese oxide) on *in vitro* gas and hydrogen sulfide (H₂S) production were evaluated. Ruminal fluid collected from a ruminally-fistulated dairy cow fed a 60:40 forage:concentrate ration was used to inoculate the culture. Manganese oxide was hand-mixed into substrate (81% dried distillers grains plus solubles, 19% ground corn, 0.65% S) to obtain treatment concentrations of Mn. Approximately 0.7 g DM of substrate and 50 mL of 1:1 ruminal fluid to McDougall's saliva solution were incubated in crimp-sealed, 125 mL serum bottles (n = 24; 4 reps/concentration) for 24 h at 39°C. At 2, 5, 10, and 24-h post-inoculation, bottles were briefly removed for gas measurement, and 5 mL of gas were extracted for H₂S analysis. There was a significant ($P = 0.02$) Mn concentration by hour interaction. At 2-h post-inoculation, gas production was similar ($P \geq 0.09$) across all Mn treatment concentrations and averaged 83.2 mL. At 5-h post-inoculation, gas production was similar ($P \geq 0.25$) across all Mn concentrations and averaged 127.5 mL. However, by 10-h post-inoculation, gas production for 2,000 ppm Mn was greater ($P = 0.04$) than 500 ppm Mn (174.4 vs. 170.2 mL) but was similar ($P \geq 0.14$) to 0, 1,000, 1,500, and 2,500 ppm Mn (171.8, 171.4, 172.2, and 172.9 mL, respectively). At 24-h post-inoculation, gas production for 2,000 ppm Mn was greater ($P = 0.03$) than 0 and 500 ppm Mn (216.8 vs. 212.2 and 212.3 mL) but was similar ($P \geq$

0.15) to 1,000, 1,500, and 2,500 ppm Mn (214.2, 215.3, and 213.9 mL). There was not a significant ($P = 0.19$) Mn concentration by hour interaction for H₂S release.

Concentration of 1,000 ppm Mn released less ($P = 0.03$) total H₂S than 0, 500, and 2,500 ppm Mn (2.64 vs. 3.37, 3.21, and 3.33 ± 0.17 μmol); however, 1,000 ppm Mn released similar ($P \geq 0.19$) H₂S as 1,500 (2.96 μmol) and 2,000 ppm Mn (2.69 μmol). The rate of H₂S released per mL of gas produced for 2,000 ppm Mn tended to be lower ($P = 0.09$) than the rate for 0, 500, and 2,500 ppm Mn (0.027 vs. 0.033, 0.035, and 0.034 ± 0.002 μmol/mL) but was similar ($P \geq 0.15$) to 1,000 ppm (0.028 μmol/mL) and 1,500 ppm (0.031 μmol/mL). Initial pH of the 1:1 solution of McDougall's saliva and ruminal fluid was 6.69 across all treatments. Following 24-h incubation, final pH tended to be lower ($P = 0.06$) for 0 ppm Mn compared to 500, 1,000, and 1,500 ppm Mn (5.70 vs. 5.74, 5.73, and 5.74 ± 0.01) but was similar ($P \geq 0.13$) to 2,000 (5.72) and 2,500 (5.71) ppm Mn. Concentrations between 1,000 and 2,000 ppm Mn supplied as MnO demonstrated potential to decrease 24-h H₂S release from high-S substrate without reducing microbial fermentation in an *in vitro* ruminal fluid culture system.

Experiment 2 evaluated effects of including 1,000 ppm Mn (supplied as manganous oxide) in high dietary S feedlot diets containing dried distillers grains plus solubles on ruminal pH and H₂S concentration. Seven ruminally cannulated beef steers (437 ± 61 kg initial BW) were assigned randomly to treatments in a switchback design (two, 14-d periods). Treatments included a base finishing diet (65% rolled corn, 20% dried distillers grains plus solubles, 8.2% bahia hay, 15% CP, 1.31 Mcal NE_g/kg DM, 0.46% S) containing either 0 ppm Mn (CON) or 1,000 ppm Mn (MNO). Wireless rumen

sensors programmed to record ruminal pH every 5 min were inserted into the rumen on d 10. Steers were allowed access to treatment diets from 0730 to 1630 daily. Ruminal gas samples were collected at 1 h prior to and at 1, 2, 3, 4, and 6 h post-feeding on d 11-12 for analysis of H₂S concentration. Ruminal fluid samples were collected at 1 h prior to and at 1, 2, 3, 4, and 6 h post-feeding on d 13-14 for analysis of ruminal ammonia-N concentration. Daily DMI was similar ($P = 0.22$) across treatments (8.63 vs. 8.91 ± 0.46 kg/d for steers consuming MNO and CON, respectively). Ruminal pH was higher ($P = 0.02$) at 1 h prior to feeding in steers consuming MNO (6.29) compared to CON (6.01). However, no pH differences were observed ($P \geq 0.18$) between treatments at other time points (5.89 vs. 5.78, 5.81 vs. 5.66, 5.74 vs. 5.62, 5.69 vs. 5.63, and 5.62 vs. 5.62 ± 0.07 for MNO vs. CON at 1, 2, 3, 4, and 6 h post-feeding, respectively). Average ruminal H₂S concentration tended to be lower ($P = 0.09$) in steers consuming diets containing MNO compared to CON (0.190 vs. 0.227 ± 0.016 $\mu\text{mol/mL}$). Ruminal ammonia-N concentration was not different ($P = 0.32$) between treatments and averaged 10.4 and 8.9 mg/dL for MNO and CON. Beef steers consuming high-S finishing diets containing dried distillers grains plus solubles and supplemented with 1,000 ppm Mn may have a less acidic ruminal environment prior to feeding to result in a tendency for reduced average daily ruminal H₂S concentration without affecting DMI or ruminal ammonia-N concentration.

Introduction

Corn co-products, particularly distillers grains plus solubles (DGS), have become popular ingredients to replace portions of corn grain in feedlot rations. These co-products are excellent sources of energy, protein, and digestible fiber. However, during the dry corn milling process used to convert corn into ethanol, sulfuric acid is added to control pH during fermentation, which increases and concentrates the sulfur (S) content of the co-product (Vanness et al., 2009c). Sulfur concentration of DGS is highly variable within and among ethanol plants and can range from 0.44% to well over 1.0% S (Buckner et al., 2008). The recommended concentration of S in beef cattle rations is 0.18 to 0.24% and should not exceed 0.3% in feedlot rations containing 85% or more concentrate (NRC, 2005). When DGS are incorporated into finishing diets at high inclusion concentrations, there is potential for feedlot cattle to consume dietary S concentrations greater than 0.3%, which is the maximum tolerable S concentration (NRC, 2005). Sulfur concentrations of both the feedlot diet and the water source must be considered when evaluating total daily dietary S intake (Gould, 1998; Vanness et al., 2009c).

Bacterial populations in the rumen reduce dietary sulfates through a dissimilatory process that results in the production of sulfide compounds that facilitate production of hydrogen sulfide (H₂S). Because the normal pH range of the rumen is between 5.5 and 7.2 and the pK_a of the first proton of H₂S is 7.0, these reduced sulfide compounds are easily protonated to form H₂S (Beauchamp et al., 1984). High concentration of dietary S may cause increased production and accumulation of H₂S in the rumen and result in S

toxicity and potential initiation of polioencephalomalacia (PEM) in feedlot cattle (Vanness et al., 2009a). Sulfur toxicity resulting from consuming excessive dietary S can lead to decreased intake and reduced ADG of feedlot cattle (Zinn et al., 1997; Loneragan et al., 2001; Uwituze et al., 2011). Polioencephalomalacia is a disorder of the central nervous system distinguished by necrosis of the cerebral cortex that often results in death (Gould, 1998). Animals infected with PEM often experience blindness, compromised coordination, and seizures due to softening of gray matter in the brain (Gould, 1998). Production of H₂S by rumen microflora is normal (Bray and Till, 1975; Kandylis, 1984); however, S toxicity issues arise when excess H₂S gas not used to form microbial protein accumulates in the rumen, is eructated and subsequently inhaled by the animal, allowing the respiratory system to serve as a route for H₂S to circulate throughout the bloodstream and cause necrosis of the brain (Gould, 1998).

Manganese oxide (MnO) is commonly supplemented to feedlot cattle as a source of manganese (Mn) and is also a powerful oxidizing agent. Manganese oxides may effectively oxidize H₂S into sulfate, S, and small amounts of thiosulfate (Herszage and Afonso, 2003). The entropy of reaction for MnO₂ reduction with H₂S suggests the reaction is associative and occurs through inner-sphere redox reactions (Herszage and Afonso, 2003). It appears the distribution of oxidation products may be pH dependent. As pH decreases, the thermodynamic driving force of the reaction increases to result in sulfates being the main products at low pH values and elemental S being the main product with pH values at or above neutral (Herszage and Afonso, 2003). At pH of 5,

aqueous MnO oxidized H₂S to sulfate and elemental S at a rate of 1.49 g of MnO to 1 g of H₂S (Herszage and Afonso, 2003).

Although known to be rapid (Herszage and Afonso, 2003), the rate of sulfide oxidation by MnO₂ may be reduced by approximately 50% in the presence of 10 μM phosphate (Yao and Millero, 1993). The surface-controlled reduction of the reaction rate may be attributed to adsorption of the phosphate onto the surface sites of the MnO₂ molecule, thus occupying the sites necessary for the reaction with sulfide to occur (Yao and Millero, 1993). Ruminant pH of feedlot cattle consuming finishing rations commonly ranges from 5.25 to 6.0. Therefore, supplementing MnO to feedlot cattle consuming rations high in dietary S may result in lower ruminal concentrations of H₂S due to increased oxidation of H₂S into sulfates in the rumen. The sulfates should then be eliminated in the small intestine of the animal; thus reducing the potential negative effects of S toxicity and PEM on health and performance of feedlot cattle exposed to high-S diets. Distillers grains plus solubles often contain high concentrations of P which may reduce the rate at which MnO can oxidize H₂S in the rumen. Thus, effectiveness of MnO in mitigating negative effects on feedlot performance commonly associated with S toxicity may be minimized if diets contain DGS.

Two experiments were conducted to evaluate the effectiveness of supplemental Mn (supplied as MnO) to attenuate the negative effects of S toxicity in feedlot cattle consuming high-S diets containing dried DGS (DDGS). The specific objective of experiment 1 was to determine the optimal concentration of supplemental Mn in high-S, DDGS-based substrate to effectively reduce H₂S release without affecting microbial

fermentation in an *in vitro* batch culture system. The specific objective of experiment 2 was to evaluate the effects of the concentration of supplemental Mn determined in experiment 1 on DMI, *in vivo* ruminal H₂S concentration, and ruminal fermentation of beef steers fed high-S feedlot diets containing DDGS.

Materials and Methods

Ruminal Fluid Collection – Experiment 1

An *in vitro* batch culture experiment (experiment 1) was conducted in the ruminant nutrition laboratories at University of Minnesota-St. Paul to determine the production of H₂S under various concentrations of Mn supplied from MnO. All procedures involving animals were reviewed and approved by the University of Minnesota Institutional Care and Use Committee. Approximately 1-h prior to batch culture inoculation, ruminal fluid was collected prior to AM feeding from a Holstein-Montbéliarde crossbred lactating dairy cow fitted with a flexible, 10.2 cm ruminal cannulae. The dairy cow was housed at the dairy facility on the University of Minnesota-St. Paul campus and was fed a typical 60:40 forage:concentrate lactation ration containing monensin sodium (Rumensin[®]; Elanco Animal Health; Greenfield, IN). Ruminal grab samples were collected from cranial, caudal, left lateral, and right lateral areas of the rumen to obtain a representative sample and strained through four layers of cheesecloth into a pre-warmed (with hot water) insulated container to obtain ruminal fluid. The insulated container was completely filled prior to sealing to minimize oxygen exposure to the ruminal fluid. The sealed insulated container was immediately

transported to the ruminant nutrition laboratory for processing of the ruminal fluid for inoculation of the batch culture.

Substrate and Treatments – Experiment 1

A diet (DM-basis) of 81% DDGS (0.77% S) and 19% ground corn (0.15% S) was formulated to contain 0.65% dietary S. The DDGS was left intact, but the corn grain was ground to pass through a 1-mm screen (Wiley mill; Swedesboro, NJ) prior to mixing. Feed grade MnO was thoroughly mixed with the ground corn prior to addition of the DDGS to attain appropriate concentration of Mn in the total diet for each treatment substrate. Concentrations of Mn evaluated were 0, 500, 1,000, 1,500, 2,000, and 2,500 ppm. Subsamples of each treatment substrate were dried at 100°C for 24 h in a laboratory oven (Thelco Laboratory Oven, model 130DM; Precision Scientific Inc.; Chicago, IL) to determine laboratory DM (AOAC, 1996) prior to measuring treatment amounts into serum bottles.

Gas Production and Hydrogen Sulfide Measurement – Experiment 1

To obtain approximately 0.7 g DM of substrate, 0.71 g (as-is) of each substrate was measured into one of four, 125 mL glass serum bottles (Wheaton Science Products; Millville, NJ) per concentration of Mn, for a total of 24 bottles in the incubation. Fifty mL of a 1:1 solution of 25 mL McDougall's saliva (McDougall, 1948; pre-warmed to 39°C with pH of 7.0 and containing sodium bicarbonate, sodium phosphate, potassium chloride, sodium chloride, magnesium sulfate, urea, and calcium chloride) and 25 mL

rumen fluid were measured into each 125 mL serum bottle in random order. Each bottle was purged with CO₂ for 10 s and crimp-sealed with a butyl-rubber stopper and metal retainer (Wheaton Science Products; Millville, NJ). All bottles were randomly placed and incubated at 39°C for 24 h in a reciprocal shaking water bath (Precision Scientific Model 50; Thermo Scientific Inc., Waltham, MA) set for constant agitation at 30 rpm. Initial pH (6.69) of the 1:1 solution of McDougall's saliva and ruminal fluid was measured using a hand-held pH probe (Thermo Orion model 710A pH meter; Cole-Parmer Instruments; Vernon Hills, IL).

At 2, 5, 10, and 24-h post-inoculation, bottles were briefly removed from the shaking water bath for gas measurement. Volume of gas produced at each time interval was measured in each serum bottle via water displacement in an inverted 250-mL glass buret by puncturing the butyl-rubber stopper with an 18 gauge x 25.4 mm hypodermic needle connected to a 5-mL syringe (Monoject; Covidien, Mansfield, MA) fitted with a 3-way valve that was connected on one end to rubber tubing that allowed gas to escape into the inverted buret. Following each gas measurement, an additional 5 mL of gas were extracted from the head space of each bottle using a 5 mL tuberculin syringe and 18 gauge x 25.4 mm needle (Monoject; Covidien, Mansfield, MA) for analysis of H₂S concentration. Following gas measurement and collection at 24 h, pH of the contents in each serum bottle was measured using a hand-held pH probe (Thermo Orion model 710A pH meter; Cole-Parmer Instruments; Vernon Hills, IL). Total gas volume of each bottle was corrected for 24-h incubation time (1440 min), and rates of total gas produced per min of incubation and per mg of substrate DM incubated were calculated.

The method for analyzing H₂S concentration is similar to the procedure originally described by Siegel (1965) and also reported by Kung et al. (1998), Leibovich et al. (2009) and Quinn et al. (2009). Five mL of alkaline water (prepared with 0.1 N NaOH; pH 8) were injected into a 10 mL evacuated blood collection tube (Kendall Monoject Red Stopper sterile blood collection tube, 16 x 100 mm, 10 mL draw; Covidien, Mansfield, MA) using a disposable 5 mL tuberculin syringe and 18 gauge x 25.4 mm hypodermic needle (Monoject; Covidien, Mansfield, MA). The gas was slowly bubbled through the alkaline water in the evacuated blood collection tube to capture the H₂S, and immediately following, 0.5 mL DPD (N, N dimethyl-p-phenylenediamine sulfate solution) and 0.5 mL of ferric chloride reagents were injected into each evacuated blood collection tube using separate 1 mL tuberculin syringes and 22 gauge x 25.4 mm hypodermic needles (Monoject; Covidien, Mansfield, MA).

Concentrations of H₂S released into the gas produced during *in vitro* incubation were estimated using the methylene blue method (Siegel, 1965). Calibration solutions were prepared using RAD171 (Radiello Methylene Blue Calibration Standard for H₂S; Supelco Product No. RAD171, Bellefonte, PA) to calculate a standard calibration curve (Leibovich et al., 2009). The first calibration solution was prepared by adding 0.5 mL of RAD171 to 24.5 mL of distilled water. This first solution has a concentration of 1.145 µg/mL of S⁻². The second calibration solution was prepared with 3.75 mL of the first solution and 1.25 mL of distilled water to make a solution with a concentration of 0.85875 µg/mL of S⁻². The third calibration solution included 2.5 mL of the first solution and 2.5 mL of distilled water and had a concentration of 0.5725 µg/mL of S⁻². The fourth

calibration solution was prepared with 1.25 mL of the first solution and 3.75 mL of distilled water to make a solution containing 0.28625 $\mu\text{g/mL}$ of S^{-2} . A blank solution was prepared by adding 0.5 mL of DPD reagent followed by 0.5 mL of ferric chloride reagent to 5 mL of alkaline water. After 30 min of reaction time in dim lighting, absorbance of each sample was read at a wavelength of 665 nm on a spectrophotometer equipped with a vacuum receiver and sipper cell (Gilford Response™; Gilford Systems, Oberlin, OH).

The known S^{-2} concentrations of the calibration solutions were divided by 0.9409 (H_2S has 94.09% S) to obtain H_2S concentration ($\mu\text{g/mL}$). The absorbance values and H_2S concentrations of the calibration solutions were regressed to obtain a standard curve and regression equation. Absorbance of the blank solution was subtracted from all sample absorbance values to determine true absorbance of gas samples. The regression equation of the standard curve and true absorbance values were used to calculate H_2S concentration in each gas sample. Total corrected gas volume of each bottle was multiplied by H_2S concentration to determine total μg H_2S released which was then converted to total μmol H_2S released for each Mn concentration by dividing by the molecular weight of H_2S (34.08 g/mol). Rates of H_2S released per mL gas produced, per min of incubation, and per mg of substrate DM incubated were calculated.

Location, Experimental Design, and Experimental Treatments – Experiment 2

All surgical and research procedures were reviewed and approved by the University of Florida Institutional Animal Care and Use Committee. A metabolism experiment was conducted at the feed efficiency facility located at North Florida

Research and Education Center, Marianna, FL, to determine if 1,000 ppm Mn in high-S, finishing diets containing DDGS affects DMI, ruminal pH, and concentrations of ruminal H₂S gas and ammonia-N (NH₃-N) in feedlot cattle. Seven Angus-crossbred beef steers (437 ± 61 kg initial BW) fitted with flexible ruminal and proximal duodenal cannula were assigned randomly to one of two pens (n = 3 and 4 per pen) in a switchback experimental design. Treatment diets were assigned to pen and contained (as-is basis; Table 3) 65% cracked corn, 20% DDGS (First United Ethanol, LLC.; Camilla, GA), 8.2% Bahia grass hay, 0.46% dietary S, and either 0 or 1,000 ppm Mn. Dietary S concentration was increased with feed grade CaSO₄ (Calcium sulfate dihydrate; Maximo Sulca - DH, Yesera Monterrey, S.A., Mexico), and Mn concentration was increased with feed grade MnO (600,000 ppm; Manganous Oxide 60 Feed Grade; Erachem, Baltimore, MD).

The feed efficiency facility was equipped with GrowSafe[®] 4000 technology (GrowSafe[®] Systems Ltd.; Airdrie, Alberta, Canada) to monitor daily feed intake of all steers. To mimic once daily feeding typically practiced in conventional feedlots, steers were allowed *ad libitum* access to feed bunks from 0730 to 1630 throughout the experimental period. The experimental period consisted of 14 d, with 10 d of diet adaptation and 4 d of sample collection. Individual wireless rumen sensors (KB1102 bolus; Kahne Limited, Auckland, NZ) were placed in the rumen of each steer more than 18 h prior (on d 10) to the first gas collection time and were programmed to measure ruminal pH every 5 min throughout the duration of the 4-d sample collection period. Following completion of experimental period 1, wireless rumen sensors were removed

from individual steers, pH data were downloaded to a computer, steers were rotated to opposite pens and placed on new treatments, and the experimental period was repeated.

Ruminal Gas Collection and Hydrogen Sulfide Measurement – Experiment 2

On d 11 and 12 of each experimental period, ruminal gas samples were collected for analysis of H₂S concentration. Ruminal gas was collected from each steer using a 60 mL syringe with a 15.2 cm, 18 gauge needle (Popper[®] Deflected Noncoring Septum Penetration Needle, Thermo Fisher Scientific, Inc.; Pittsburgh, PA) that was inserted directly through the ruminal fistula plug into the head space of the rumen at 1 h prior to and 1, 2, 3, 4, and 6 h post-feed access (0730). For each steer at each time point, 30 mL of ruminal gas were extracted and depressed back into the ruminal head space two times prior to final extraction of 30 mL, of which 5 mL gas were then slowly bubbled into 5 mL of prepared alkaline water (pH 8) in a 10 mL evacuated blood collection tube using a 18 gauge x 25.4 mm hypodermic needle. All evacuated blood collection tubes were stored in an insulated container containing ice until all ruminal gas collections were completed for each day. The method for measuring H₂S is similar to the procedure described for experiment 1, and all samples were prepared at one time.

Immediately following the last ruminal gas collection at 6 h post-feeding, 0.5 mL DPD and 0.5 mL of ferric chloride solution were injected into each evacuated blood collection tube using separate 1 mL syringes and hypodermic needles. Calibration solutions were prepared using RAD171 to calculate a standard calibration curve

(Leibovich et al., 2009). A blank solution was prepared by adding 4 mL of DPD reagent followed by 4 mL of ferric chloride reagent to 40 mL of alkaline (pH 8) water.

After 30 min of reaction time in a dark room, 200 μ L of each calibration solution and sample were plated in triplicate into a 96-well plate, with the blank and calibration solutions plated in the first wells. Absorbance of each sample was read at a wavelength of 665 nm on a microplate reader (Beckman Coulter AD 340C Absorbance Detector; Beckman Coulter, Inc., Brea, CA). The known S^{-2} concentrations of the calibration solutions were divided by 0.9409 (H_2S has 94.09% S) to obtain H_2S concentration (μ g/mL). Absorbance of the blank solution was subtracted from all sample absorbance values to determine true absorbance of gas samples. The absorbance values and H_2S concentrations (μ g/mL) of the calibration solutions were regressed to obtain a standard curve and regression equation. The regression equation of the standard curve and true absorbance values were used to calculate H_2S concentration in each gas sample. Total μ g/mL H_2S was then converted to total μ mol/mL H_2S by dividing by the molecular weight of H_2S (34.08 g/mol).

Ruminal Fluid Collection and Ruminal Ammonia-Nitrogen Concentration – Experiment 2

On d 13 and 14, ruminal fluid samples were collected via rumen fistulae for ruminal NH_3 -N concentration. Ruminal grab samples were collected from cranial, caudal, left lateral, and right lateral areas of the rumen of each steer at 1 h prior to and 1, 2, 3, 4, and 6 h post-feed access (0730) to obtain a representative sample, mixed, and strained through three layers of cheesecloth into a 1,000 mL beaker. Ruminal fluid pH

was measured with a benchtop pH meter (Pinnacle M530 Benchtop pH meter; Corning Inc., Lowell, MA). One 20 mL ruminal fluid sample was retained in a plastic, screw-cap, 50 mL conical tube, stabilized with 5 mL H₂SO₄, and immediately stored at -20 C for analysis of ruminal NH₃-N concentration at the North Dakota State University Ruminant Nutrition Laboratory (Fargo, ND). Ruminal NH₃-N concentration was determined according to the procedure reported in Sigma Technical Bulletin #640. The concentration of NH₃-N was determined colorimetrically with a spectrophotometer (Beckman Coulter DU 800; Beckman Instruments, Inc.; Fullerton, CA) set at a wavelength of 570 nm.

Statistical Analyses – Experiment 1

Data were analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). *In vitro* gas production and H₂S release were analyzed as repeated measures using an autoregressive covariance structure. Fixed model effects included Mn concentration, hour, Mn concentration by hour interaction, and replicate. The random effect was flask. The linear model for these analyses is written as follows:

$$y_{ijkm} = \mu + \tau_m + \beta_i + \rho_j + \alpha_k + (\tau_m \times \alpha_k) + \varepsilon_{ijkm}$$

where,

y_{ijkm} represents observation _{$ijkm$} ; μ represents the overall mean; τ_m represents the fixed effect of concentration _{m} ; β_i represents the random effect of flask _{i} ; ρ_j represents the fixed effect of replicate _{j} ; α_k represents the fixed effect of hour _{k} ; and $(\tau_m \times \alpha_k)$ represents the

interaction of concentration_{*m*} and hour_{*k*}. The residual term ε_{ijkm} is assumed to be normally, independently, and identically distributed with variance σ^2_e .

Rates of gas production and H₂S release, final pH, and change in final pH were analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Fixed model effects included Mn concentration and replicate. The linear model for these analyses is written as follows:

$$y_{ij} = \mu + \rho_i + \alpha_j + \varepsilon_{ij}$$

where,

y_{ij} represents observation_{*ij*}; μ represents the overall mean; ρ_i represents the fixed effect of replicate_{*i*}; and α_j represents the fixed effect of concentration_{*j*}. The residual term ε_{ij} is assumed to be normally, independently, and identically distributed with variance σ^2_e .

Statistical significance was declared with P -values ≤ 0.05 , and trends were discussed with $0.05 < P$ -values ≤ 0.10 . The PDIFF option was used to separate least squares means when a significant F -test statistic was present, and the largest standard error of the mean is reported.

Statistical Analyses – Experiment 2

Data were analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Steer DMI and ruminal pH were analyzed as repeated measures using an autoregressive covariance structure. Fixed model effects included treatment, day, hour and treatment by hour interaction. Random effect was steer nested within treatment. Due to a better model fit, ruminal ammonia-N concentration and cumulative H₂S

concentration were analyzed as repeated measures using compound symmetry. Fixed model effects included treatment, day, hour, and treatment by hour interaction. Random effect was steer nested within treatment. The linear model for these analyses is written as follows:

$$y_{ijkm} = \mu + \tau_m + \beta(\tau)_{im} + \rho_j + \alpha_k + (\tau_m \times \alpha_k) + \varepsilon_{ijkm}$$

where,

y_{ijkm} represents observation $_{ijkm}$; μ represents the overall mean; τ_m represents the fixed effect of treatment $_m$; $\beta(\tau)_{im}$ represents the random effect of steer $_i$ within treatment $_m$; ρ_j represents the fixed effect of day $_j$; α_k represents the fixed effect of hour $_k$; and $(\tau_m \times \alpha_k)$ represents the interaction of treatment $_m$ and hour $_k$. The residual term ε_{ijkm} is assumed to be normally, independently, and identically distributed with variance σ_e^2 .

The area under the curve for ruminal H₂S concentration was calculated for each treatment and was analyzed using the MIXED procedure of SAS (SAS 9.2, SAS Institute, Inc.; Cary, NC). Fixed model effect was treatment and random effect was steer nested within treatment. The linear model for this analysis is written as follows:

$$y_{ij} = \mu + \tau_i + \beta(\tau)_{ij} + \varepsilon_{ij}$$

where,

y_{ij} represents observation $_{ij}$; μ represents the overall mean; τ_j represents the fixed effect of treatment $_j$; and $\beta(\tau)_{ij}$ represents the random effect of steer $_i$ within treatment $_j$. The residual term ε_{ij} is assumed to be normally, independently, and identically distributed with variance σ_e^2 . Statistical significance was declared with P -values ≤ 0.05 , and trends were discussed with $0.05 < P$ -values ≤ 0.10 . The PDIFF option was used to separate least

squares means when a significant *F*-test statistic was present, and the largest standard error of the mean is reported.

Results and Discussion

Experiment 1

Cumulative gas production (mL) over time for each treatment is reported in Table 1. There was a significant ($P = 0.02$) Mn concentration by h interaction; therefore, simple effects for gas production values are discussed at each h of collection. At 2-h post-inoculation, gas production was similar ($P \geq 0.09$) across all Mn treatment concentrations and averaged 83.2 mL. At 5-h post-inoculation, gas production was similar ($P \geq 0.25$) across all Mn concentrations and averaged 127.5 mL. However, by 10-h post-inoculation, gas production from 2,000 ppm Mn was greater ($P = 0.04$) than 500 ppm Mn (174.4 vs. 170.2 mL) but similar ($P \geq 0.14$) to 0, 1,000, 1,500, and 2,500 ppm Mn (171.8, 171.4, 172.2, and 172.9 mL, respectively). At 24-h post-inoculation, gas production from 2,000 ppm Mn was greater ($P = 0.03$) than 0 and 500 ppm Mn (216.8 vs. 212.2 and 212.3 mL) but similar ($P \geq 0.15$) to 1,000, 1,500, and 2,500 ppm Mn (214.2, 215.3, and 213.9 mL). It is unclear why 2,000 ppm Mn produced more gas than 0 or 500 ppm Mn concentrations. Although *in vitro* gas production is a reflection of microbial fermentation when incubating substrate with ruminal fluid (Getachew et al., 1998), differences observed in total gas production are small and may not be biologically significant.

Total gas production reported by May et al. (2010a) in diets containing 0, 15, or 30% WDGS in a steam-flaked corn (SFC)-based substrate incubated under similar batch culture conditions was lower and averaged 136.1, 133.3, and 126 mL, respectively, after 24-h of incubation. However, May et al. (2010a) measured total gas production only after 24-h of incubation in a 3:1 rather than a 1:1 solution of McDougall's buffer and ruminal fluid and did not vent head space pressure, similar to the technique described by Pell and Schofield (1993). Concentration of ruminal fluid in the inoculation solution is likely to influence microbial fermentation of substrate during an *in vitro* batch culture. Also, it has been argued that, according to Henry's Law, when gas pressure is allowed to accumulate in fermentation bottles, less gas may be released due to a proportion of gas remaining dissolved in the culture medium (Theodorou et al., 1994). Additionally, the accumulated head space pressure may reduce microbial activity if threshold levels of 48 kPa are exceeded (Theodorou et al., 1994). Others have reported frequent venting is critical for accurate *in vitro* gas production measurement, particularly with rapidly fermentable substrates in the first 12 h of incubation, so gas production is not limited due to high head space pressure (Tagliapietra et al., 2010). The differences in gas production observed in the current *in vitro* experiment compared to May et al. (2010a) may be attributed to differences in substrate composition, incubation solution, and gas measurement technique employed in which gas, as well as headspace pressure, was released at 2, 5, and 10-h post-inoculation.

The interaction of Mn concentration by h for H₂S release was not significant ($P = 0.19$); therefore, main effects of treatment for H₂S release are reported (Table 2).

Concentration of 1,000 ppm Mn released less ($P = 0.03$) H₂S than 0, 500, and 2,500 ppm Mn (2.64 vs. 3.37, 3.21, and 3.33 ± 0.17 μmol), but 1,000 ppm Mn released similar ($P \geq 0.19$) H₂S as 1,500 (2.96 μmol) and 2,000 ppm Mn (2.69 μmol). May et al. (2010a) replaced portions of steam-flaked corn with 15 or 30% WDGS and reported increased *in vitro* H₂S release as substrate S concentration increased from 0.13% S (1.23 μmol H₂S), 0.19% S (1.72 μmol H₂S), to 0.29% S (2.45 μmol H₂S) for substrate containing 0, 15, or 30% WDGS, respectively. Compared to the control containing 0.29% dietary S, 1.09% dietary S in substrate increased total 24-h *in vitro* gas production (95.1 vs. 98.6 mL) and H₂S (2.33 vs. 3.00 μmol) but did not affect VFA (139.9 vs. 137.3 mM), NH₃-N concentrations (49.3 vs. 46.7 mg/dL), VFA proportions, pH (6.29 vs. 6.31), or methane and hydrogen production in an *in vitro* experiment (Kung et al., 1998). Others have reported increasing *in vitro* H₂S release as S concentrations increase in substrate (Alves de Oliveira et al., 1997; Kung et al., 2000; Quinn et al., 2009; Smith et al., 2010), so it is logical to expect greater H₂S release in the current experiment compared to other experiments due to high S concentrations in all substrates. However, concentrations of supplemental Mn ranging from 1,000 to 2,000 ppm appeared to reduce total H₂S release perhaps through oxidation of H₂S into sulfate, S, and small amounts of thiosulfate (Herszage and Afonso, 2003), but it is unclear why the effect seems to be absent at 2,500 ppm Mn.

Rates of total gas production and H₂S release, as well as final pH and pH change, are reported in Table 2. The rate of H₂S release per mL of gas produced for 2,000 ppm Mn tended to be lower ($P = 0.09$) than rates for 0, 500, and 2,500 ppm Mn (0.027 vs.

0.033, 0.035, and 0.034 ± 0.002 $\mu\text{mol/mL}$) but similar ($P \geq 0.15$) to 1,000 ppm (0.028 $\mu\text{mol/mL}$) and 1,500 ppm (0.031 $\mu\text{mol/mL}$). Rate of gas production per min of incubation was similar ($P = 0.28$) and averaged 0.149 ± 0.001 mL/min across treatments. Rate of H_2S release per min of incubation was similar ($P = 0.12$) and averaged 0.005, 0.005, 0.004, 0.005, 0.004, and 0.005 ± 0.000 $\mu\text{mol/min}$ for 0, 500, 1,000, 1,500, 2,000, and 2,500 ppm Mn. Rate of gas production per mg of incubated substrate DM was similar ($P = 0.25$) and averaged 3.015, 3.015, 3.044, 3.063, 3.079, and 3.038 ± 0.022 mL gas/mg substrate DM for 0, 500, 1,000, 1,500, 2,000, and 2,500 ppm Mn. Rate of H_2S release per mg of incubated substrate DM was similar ($P = 0.12$) and averaged 0.100, 0.104, 0.086, 0.096, 0.082, and 0.103 ± 0.006 $\mu\text{mol H}_2\text{S/mg}$ substrate DM. Initial pH of the 1:1 solution of McDougall's saliva and rumen fluid was 6.69 across all treatments. Following 24-h incubation, final pH tended to be lower ($P = 0.06$) for 0 ppm Mn compared to 500, 1,000, and 1,500 ppm Mn (5.70 vs. 5.74, 5.73, and 5.74 ± 0.01) but was similar ($P \geq 0.13$) to 2,000 (5.72) and 2,500 (5.71) ppm Mn. Subsequently, overall pH change tended to be greater ($P = 0.06$) for 0 ppm Mn compared to 500, 1,000, and 1,500 ppm Mn (-0.995 vs. -0.955, -0.960, and -0.950 ± 0.010) but was similar ($P \geq 0.13$) to 2,000 (-0.973) and 2,500 (-0.978).

Experiment 2

Effects of supplementing 1,000 ppm Mn in high-S finishing diets containing DDGS on DMI, ruminal pH over time, and ruminal H_2S and $\text{NH}_3\text{-N}$ concentrations in feedlot steers are reported in Table 4. Daily DMI was similar ($P = 0.22$) across

treatments and averaged 8.63 vs. 8.91 ± 0.51 kg/d for steers consuming MNO and CON, respectively. High dietary S concentrations of finishing diets (Bolsen et al., 1973; Zinn et al., 1997; Uwituze et al., 2011) or sulfate concentrations of drinking water (Loneragan et al., 2001) have been reported to reduce performance and negatively affect some carcass characteristics of feedlot cattle. Ruminal pH was higher ($P = 0.02$) at 1 h prior to feeding in steers consuming MNO (6.29) compared to steers consuming CON (6.01). However, no pH differences were observed ($P \geq 0.18$) between treatments at other time points measured, and ruminal pH was equal in all steers by 6 h post-feeding (5.89 vs. 5.78, 5.81 vs. 5.66, 5.74 vs. 5.62, 5.69 vs. 5.63, and 5.62 vs. 5.62 ± 0.07 for MNO vs. CON at 1, 2, 3, 4, and 6 h post-feeding, respectively).

Average ruminal H₂S concentration tended to be lower ($P = 0.09$) in steers consuming diets containing MNO compared to the CON diet (0.190 vs. 0.227 ± 0.016 $\mu\text{mol/mL}$). This observation follows results observed in experiment 1 and could be attributed to higher ruminal pH in steers consuming 1,000 ppm Mn at 1 h prior to access to high-S finishing diets, thus promoting an initial ruminal environment less conducive to H₂S formation. The formation of H₂S is widely accepted to be pH-dependent, with greater formation occurring as pH is reduced (Gould, 1998). In contrast, Alves de Oliveira et al. (1997) reported no differences in sulfate or sulfide concentrations in a semi-continuous fermenter system when pH was reduced by 0.62 units, which may be representative of a typical pH reduction observed during chronic acidosis in feedlot cattle. *In vivo* values of ruminal sulfide concentration ranging from 0.07 to 0.35 $\mu\text{mol/mL}$ have been observed in growing goats consuming diets with S concentrations

close to requirements of 0.22% DM (Qi et al., 1993). Although the 0.46% dietary S concentration fed in the current experiment exceeds the maximum recommended S concentration for finishing diets (NRC, 2005), the values observed for ruminal H₂S concentration in the current experiment are within the range observed when dietary S concentrations met animal requirements (Qi et al., 1993). However, the values reported (main effects) in the current experiment are average ruminal H₂S concentrations from 1 h prior to access to feed through 6 h following access to feed and do not necessarily reflect maximum cumulative concentrations. Although cumulative ruminal H₂S concentrations (simple effects, data not shown) exceeded the range reported by Qi et al. (1993) as post-feeding time increased, no indications of S toxicity or PEM were observed in steers during this experiment.

Cummings et al. (1995) reported the capacity to generate H₂S from sulfate in steers increased after 10 to 12 d of feeding a high-S diet; however, Alves de Oliveira et al. (1997) reported 7 d of adaptation to a high-S diet in an *in vitro* semi-continuous fermenter system were sufficient to reach high sulfide production capacity. Dietary inorganic S consumed in the form of sulfates is a greater threat to ruminant health than organic sources of S because sulfates are more readily reduced to S²⁻ by sulfate-reducing bacterial populations in the rumen. Sulfides then combine with H⁺ through a dissimilatory reduction process to result in H₂S that may accumulate to toxic concentrations in the rumen (Gould et al., 2002; Kung, 2008). Calculated area under the curve for ruminal H₂S concentration in this experiment was similar ($P = 0.26$) between treatments and averaged 0.505 and 0.572 ± 0.041 $\mu\text{mol}\cdot\text{h}/\text{mL}$ for MNO and CON. It

appears supplemental MnO had minimal effects on reducing the formation of H₂S from dietary sulfates in the rumen. One explanation of this result may be attributed to dietary phosphate reducing the rate of sulfide oxidation by occupying the surface sites of the MnO molecule and preventing surface-controlled reduction of H₂S (Yao and Millero, 1993).

With an average decrease in ruminal pH from 7.0 to 6.0 during the feeding period, Gould et al. (1997) observed increased ruminal H₂S concentration after feedlot steers consumed diets containing 1.8% Na₂SO₄ for 5 d. Peak ruminal H₂S concentration was observed after 8 d, and PEM was induced in feedlot steers after 9, 11, and 12 d (Gould et al., 1997). In an *in vitro* culture system, daily production of sulfide collected in gas and liquid overflow was approximately five times greater with a high concentration of S (0.5%) compared to control S concentration (0.2%), and sulfide concentrations were lower at 6 h compared to 24 h (Alves de Oliveira et al., 1997). In feedlot cattle consuming excess dietary S, the volume and subsequent H₂S concentration of ruminal gas eructated and inhaled, as well as time relative to feed consumption, may influence the severity of S toxicity and potential for PEM. Thus, a precise and practical method for determining ruminal H₂S concentration is warranted. In contrast to H₂S concentration in ruminal fluid, H₂S concentration in the ruminal gas cap appears to change more readily and is likely a reflection of all anabolic and catabolic processes of S metabolism occurring in the fluid phase (Gould et al., 1997). Additionally, the concentration of H₂S in the ruminal gas cap is largely influenced by many factors including the volume of both the fluid and gas compartments; thus, accurate measurement is tedious and may need to

encompass sulfide concentration in the ruminal fluid, pH of the ruminal fluid, frequency of eructation, and absorption of H₂S across the ruminal mucosal (Gould et al., 1997).

Ruminal NH₃-N concentration was not different ($P = 0.32$) between treatments and averaged 10.4 and 8.9 mg/dL for MNO and CON. Ruminal NH₃-N concentrations in the current experiment were lower than values reported by Alves de Oliveira et al. (1997) when evaluating the effect of acidic conditions in a semi-continuous fermenter system on NH₃-N concentrations. Even when the pH of liquid outflow was reduced by 0.62 units (representative of chronic acidosis in feedlot cattle), the *in vitro* NH₃-N concentrations remained in the range of 15 to 21 mg/dL, which is considered to be adequate to satisfy microbial requirements (Alves de Oliveira et al., 1997). Wallace (1979) observed increased bacterial growth and subsequent increased *in situ* rates of DM and CP degradation of barley grain when ruminal fluid NH₃-N concentrations increased from 9.7 to 21.4 mg/dL, which is in agreement with Erdmann et al. (1986). In contrast, Satter and Slyter (1974) suggested *in vitro* ruminal NH₃-N concentrations greater than 5 mg/dL would meet requirements to allow for optimal microbial growth rates and fermentation. Differences in the reported optimal ruminal NH₃-N concentrations may be due to techniques employed, substrates evaluated, or criteria used for evaluation, particularly because N recycling back to the rumen can significantly alter the ruminal requirement for optimal NH₃-N concentrations and corresponding dietary CP concentration to meet these requirements (Pritchard and Males, 1985). The observed similar ruminal NH₃-N concentrations and DMI in the current experiment suggest microbial requirements for N

were met and fermentation was not limited in steers fed either treatment diet even though VFA production was not measured directly.

Conclusions

The volatility of the United States corn market and recent increases in costs of production may warrant increased feeding of cost-effective corn milling co-products in feedlot diets. As inclusion concentrations of corn milling co-products increase, there is potential for feedlot cattle to consume dietary S concentrations that exceed maximum tolerable concentrations. Because S toxicity can result in reduced animal performance and severe economic loss to the feedlot industry, developing methods for preventing negative effects of S toxicity and potential onset of S-induced PEM in feedlot cattle consuming high-S diets has been a recent research focus. Results from experiment 1 suggest substrate containing 2,000 ppm supplemental Mn (supplied as MnO) produced more *in vitro* fermentation gas and released total H₂S per mL of gas produced at a slower rate over a 24-h incubation period compared to substrate containing 0 and 500 ppm supplemental Mn. Additionally, 1,000 ppm Mn released less total H₂S over a 24-h incubation period compared to substrate containing 0 and 500 ppm supplemental Mn. Results from the *in vivo* experiment suggest steers consuming high-S finishing diets containing DDGS and 1,000 ppm supplemental Mn (supplied as MnO) may have a less acidic ruminal environment prior to feeding to result in a tendency for reduced average ruminal H₂S concentration without affecting DMI or ammonia-N concentrations. Although no indication of S toxicity or symptoms of PEM were observed in this

experiment, more research is warranted before Mn supplementation can be recommended as an effective method for preventing S toxicity in feedlot cattle consuming dietary S concentrations that exceed maximum tolerable recommendations.

Table 1. Cumulative gas production (mL) from *in vitro* fermentation of high-sulfur substrate containing dried distillers grains plus solubles and experimental concentrations of manganese supplied as manganese oxide (Experiment 1)¹.

Timepoint ²	Concentration of Mn, ppm					
	0	500	1,000	1,500	2,000	2,500
0	---	---	---	---	---	---
2	83.5	81.8	82.1	82.7	85.2	84.0
5	127.2	127.5	127.5	126.3	128.1	128.5
10	171.8 ^{ab}	170.2 ^a	171.4 ^{ab}	172.2 ^{ab}	174.4 ^b	172.9 ^{ab}
24	212.2 ^a	212.3 ^a	214.2 ^{ab}	215.3 ^{ab}	216.8 ^b	213.9 ^{ab}
SEM ³	1.2	1.2	1.2	1.5	1.5	1.2

¹*P*-values for cumulative *in vitro* gas production included: Mn concentration *P* = 0.57, h *P* < 0.01, and interaction of Mn concentration by h *P* = 0.02.

²Number of hours post-inoculation of the *in vitro* batch culture.

³Standard error of the mean within Mn concentration.

^{ab}Means within row with uncommon superscripts differ (*P* ≤ 0.05).

Table 2. Effects of *in vitro* fermentation of high-sulfur substrate containing dried distillers grains plus solubles and experimental concentrations of manganese supplied as manganese oxide on total hydrogen sulfide released, total hydrogen sulfide released per mL of gas produced, rates of gas production, rates of hydrogen sulfide production, final pH, and pH change (Experiment 1).

Item	Concentration of Mn, ppm						SEM ¹	P-Value ²
	0	500	1,000	1,500	2,000	2,500		
H ₂ S, μmol/24 h	3.37 ^a	3.21 ^{ab}	2.64 ^c	2.96 ^{ac}	2.69 ^{bc}	3.33 ^a	0.17	0.03
H ₂ S per mL Gas, μmol/mL	0.033 ^{ac}	0.035 ^a	0.028 ^{bc}	0.031 ^{ab}	0.027 ^b	0.034 ^a	0.002	0.09
Rate (Gas), mL/min	0.147	0.148	0.149	0.150	0.150	0.149	0.001	0.28
Rate (H ₂ S), μmol/min	0.005	0.005	0.004	0.005	0.004	0.005	0.000	0.12
Rate, mL gas/mg Diet DM	3.015	3.015	3.044	3.063	3.079	3.038	0.022	0.25
Rate, μmol H ₂ S/mg Diet DM	0.100	0.104	0.086	0.096	0.082	0.103	0.006	0.12
Final pH	5.70 ^b	5.74 ^a	5.73 ^a	5.74 ^a	5.72 ^{ab}	5.71 ^{ab}	0.01	0.06
pH Change	-0.995 ^b	-0.955 ^a	-0.960 ^a	-0.950 ^a	-0.973 ^{ab}	-0.978 ^{ab}	0.010	0.06

¹Standard error of the mean.

²Main effect of the treatment.

^{abc}Means within row with uncommon superscripts differ ($P \leq 0.05$).

Table 3. Formulated ingredient and analyzed chemical composition of the high-sulfur finishing diet fed to beef steers (Experiment 2).

Ingredient ¹	
Cracked Corn, %	65.0
DDGS ² , %	20.0
Bahia Grass Hay, %	8.2
Mineral Mix, %	0.2
White Salt, %	0.2
Liquid Supplement, %	5.0
CaSO ₄ ³ , %	1.4

Chemical ⁴	Mean	SD
DM, %	88.9	0.4
CP, %	15.0	1.3
NDF, %	22.4	5.8
ADF, %	12.4	3.9
TDN, %	79.0	3.4
NE _g , Mcal/kg	1.30	0.11
S, %	0.46	0.12
Ca, %	0.67	0.07
P, %	0.42	0.06
Mg, %	0.27	0.04
K, %	0.88	0.08
Na, %	0.10	0.04
Cu, ppm	14.3	5.7
Fe, ppm	133.5	34.9
Zn, ppm	47.5	6.5

¹Formulated ingredient composition reported on an as-is basis.

²Dried distillers grains plus solubles were sourced from First United Ethanol, LLC, Camilla, GA. Manganous oxide (600,000 ppm; Manganous Oxide 60 Feed Grade; Erachem, Baltimore, MD) was mixed in with the DDGS in the 1,000 ppm MNO treatment diet only. The MNO diet contained 959 ppm Mn and the CON diet contained 60 ppm Mn (analyzed by Dairy One Forage Analysis Laboratory).

³Calcium sulfate (Calcium sulfate dihydrate; Maximo Sulca - DH, Yesera Monterrey, S.A., Mexico) was added to the diet to increase dietary S to a targeted concentration of 0.5% DM.

⁴Diets were analyzed for chemical analysis by Dairy One Forage Analysis Laboratory (Ithaca, NY). Mean and standard deviation (SD) values are derived from the average of four diet samples analyzed by Dairy One Forage Analysis Laboratory. Values are reported on a DM-basis.

Table 4. Effects of supplementing 1,000 ppm manganese in high-sulfur finishing diets on dry matter intake, ruminal pH, and ruminal hydrogen sulfide and ammonia-nitrogen concentrations in beef steers (Experiment 2).

Item	Treatment ¹		SEM ³	P-Value ²		
	MNO	CON		Treatment	Time	Treatment x Time
DMI, kg/d	8.63	8.91	0.51	0.46	< 0.01	0.22
Ruminal pH ⁴						
-1 h	6.29 ^a	6.01 ^b	0.07	0.22	< 0.01	0.02
1 h	5.89	5.78				0.29
2 h	5.81	5.66				0.18
3 h	5.74	5.62				0.29
4 h	5.69	5.63				0.53
6 h	5.62	5.62				0.98
H ₂ S, µmol/mL	0.190	0.227	0.016	0.09	< 0.01	0.31
H ₂ S AUC, µmol*h/mL	0.505	0.572	0.041	0.26	---	---
NH ₃ -N, mg/dL	10.4	8.9	1.0	0.32	< 0.01	0.09

¹Treatments included finishing diets either containing 1,000 ppm supplemental Mn (MNO) or 0 ppm supplemental Mn (CON).

²Main effects of treatment are reported when Treatment x Time interaction *P*-values > 0.05; Simple effects are reported when Treatment x Time interaction *P*-values ≤ 0.05.

³Standard error of the mean.

⁴Time points listed are hours relative to time of access to feed by steers (0730 daily); thus, -1 h = average of pH values measured every five min between 0630 and 0730; 1 h = average of pH values measured every five min between 0830 and 0930; 2 h = average of pH values measured every five min between 0930 and 1030; 3 h = average of pH values measured every five min between 1030 and 1130; 4 h = average of pH values measured every five min between 1130 and 1230; and 6 h = average of pH values measured every five min between 1330 and 1430.

^{ab}Means within row with uncommon superscripts differ (*P* ≤ 0.05).

Bibliography

- Adams, T.E. and B.M. Adams. 1986. Gonadotrope function in ovariectomized ewes actively immunized against gonadotropin-releasing hormone (GnRH). *Biol. Reprod.* 35:360.
- Adams, T.E. and B.M. Adams. 1990. Reproductive function and feedlot performance of beef heifers actively immunized against GnRH1. *J. Anim. Sci.* 68:2793-2802.
- Adams, T.E., J.R. Dunbar, S.L. Berry, W.N. Garrett, T.R. Famula, and Y.B. Lee. 1990. Feedlot performance of beef heifers implanted with Synovex-H: effect of melengestrol acetate, ovariectomy or active immunization against GnRH. *J. Anim. Sci.* 68:3079-3085.
- Aines, G., T. Klopfenstein, and R. Stock. 1987. Distillers Grains. MP51, Nebraska Agric. Res. Div., Lincoln.
- Alves de Oliveira, L., C. Jean-Blain, S. Komisarczuk-Bony, A. Durix, and C. Durier. 1997. Microbial thiamin metabolism in the rumen simulating fermenter (RUSITEC): the effect of acidogenic conditions, a high sulfur level and added thiamin. *Br. J. Nutr.* 78:599-613.
- AOAC. 1996. Official methods of analysis of AOAC International. 16th ed. Association of Official Analytical Chemists, Arlington, VA.
- AOAC. 2000. Official methods of analysis of AOAC International. 17th ed. Association of Official Analytical Chemists, Arlington, VA.
- Bach Knudsen, K.E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. *Anim. Feed Sci. Tech.* 67:319-338.

- Barham, B.L. and T.R. Troxel. 2007. Factors affecting selling price of feeder cattle sold at Arkansas livestock auctions in 2005. *J. Anim. Sci.* 85:3434-3441.
- Baron, V.S., A. Campbell Dick, M. Bjorge, and G. Lastiwka. 2004. Stockpiling potential of perennial forage species adapted to the Canadian Western Prairie Parkland. *Agron. J.* 96:1545-1552.
- Beauchamp, R.O., J.S. Bus, J.A. Popp, C.J. Boreiko, and D.A. Andjelkovich. 1984. A critical review of the literature on hydrogen sulfide toxicity. *CRC Crit. Rev. Toxicol.* 13:25.
- Beck, P.A., C.B. Stewart, J.M. Phillips, K.B. Watkins, and S.A. Gunter. 2007. Effect of species of cool-season annual grass interseeded into Bermudagrass sod on the performance of growing calves. *J. Anim. Sci.* 85:536-544.
- Beck, P.A., D.S. Hubbell, K.B. Watkins, S.A. Gunter, and L.B. Daniels. 2005. Performance of stocker cattle grazing cool-season annual grass mixtures in northern Arkansas. *Prof. Anim. Sci.* 21:465-473.
- Berger, L.L. and M.L. Galyean. 2000. Evaluation of various implant programs on performance and carcass merit of finishing heifers. Revalor-IH Tech. Ref. 1. Intervet Inc., Millsboro, DE.
- Bird, P.R. 1972. Sulphur metabolism and excretion studies in ruminants. X. Sulphide toxicity in sheep. *Aust. J. Biol. Sci.* 25:1087-1098.
- Bishop-Hurley, G.J. and R.L. Kallenbach. 2001. The economics of grazing beef cows during winter. p. 274. *In* T. Terril (ed.) Proc. Am. Forage Grassland Council, Springdale, AR. 22-25 Apr. 2001. AFGC, Georgetown, TX.

- Bloss, R.E., J.I. Northam, L.W. Smith, and R.G. Zimbelman. 1966. Effects of oral melengestrol acetate on the performance of feedlot cattle. *J. Anim. Sci.* 25:1048.
- Bolsen, K.K., W. Woods, and T. Klopfenstein. 1973. Effect of methionine and ammonium sulfate upon performance of ruminants fed high corn rations. *J. Anim. Sci.* 36:1186-1190.
- Brandt, R.T., W.K. Rowland, E.G. Johnson, J. Johnson, G.E. Sides, J.P. Hutcheson, W.T. Nichols, and C.D. Reinhardt. 2000. Evaluation of implants containing reduced-dose combinations of trenbolone acetate and estradiol on performance and carcass merit of finishing heifers (Idaho). *Revalor-IH Tech. Bull.* 1. Intervet Inc., Millsboro, DE.
- Branine, M.E. and M.L. Galyean. 1990. Influence of grain and monensin supplementation on ruminal fermentation, intake, digesta kinetics and incidence and severity of frothy bloat in steers grazing winter wheat pasture. *J. Anim. Sci.* 68:1139-1150.
- Bray, A.C. and A.R. Till. 1975. Metabolism of sulfur in the gastro-intestinal tract. In I.W. McDonald and A.C.I. Warner, (Ed.) *Digestion and Metabolism in the Ruminant. Proceedings of the IV International Symposium on Ruminant Physiology.* pp. 243-260. The University of New England Publishing Unit, Armidale, Australia.
- Bremer, V.R., A.J. Liska, G.E. Erickson, K.G. Cassman, K.J. Hanford, and T.J. Klopfenstein. 2011*a*. Impact of distillers grains moisture and inclusion level on greenhouse gas emissions in the corn-ethanol-livestock life cycle. *Nebraska Beef Cattle Report.* MP94:42-43.

- Bremer, V.R., G.E. Erickson, and T.J. Klopfenstein. 2011*b*. Review: Lipid addition to corn finishing diets. Nebraska Beef Cattle Report. MP94:46-47.
- Brokken, R.F. and A.C. Bywater. 1982. Application of isoquant analysis to forage:grain ratios in cattle feeding. J. Anim. Sci. 54:463.
- Buckner, C.D., S.J. Vanness, G.E. Erickson, T.J. Klopfenstein, and J.R. Benton. 2008. Sampling wet distillers grains plus solubles to determine nutrient variability. Nebraska Beef Cattle Report. MP91:113-114.
- Buckner, C.D., T.J. Klopfenstein, G.E. Erickson, V.R. Bremer, and D.R. Mark. 2011. Economics for feeding distillers grains to finishing cattle. Nebraska Beef Cattle Report. MP94:37-39.
- Buckner, C.D., T.L. Mader, G.E. Erickson, S.L. Colgan, K.K. Karges, and M.L. Gibson. 2007. Optimum levels of dry distillers grains with solubles for finishing beef steers. Nebraska Beef Cattle Report. MP90:36-38.
- Burns, J.C. and D.S. Chamblee. 2000. Summer accumulation of tall fescue at low elevations in the humid Piedmont: II. Fall and winter changes in nutritive value. Agron. J. 92:217-224.
- Cammack, K.M., C.L. Wright, K.J. Austin, P.S. Johnson, R.R. Cockrum, K.L. Kessler, and K.C. Olson. 2010. Effects of high-sulfur water and clinoptilolite on health and growth performance of steers fed forage-based diets. J. Anim. Sci. 88:1777-1785.
- Cherney, D.J.R. and D.L. Robinson. 1985. Influence of climatic factors and forage age on the chemical components of ryegrass related to grass tetany. Agron. J. 77:827-830.

- Choat, W.T., C.R. Krehbiel, G.C. Duff, R.E. Kirksey, L.M. Lauriault, J.D. Rivera, B.M. Capitan, D.A. Walker, G.B. Donart, and C.L. Goad. 2003. Influence of grazing dormant native range or winter wheat pasture on subsequent finishing cattle performance, carcass characteristics and ruminal metabolism. *J. Anim. Sci.* 81:3130.
- Clark, J.H., M.R. Murphy, and B.A. Crooker. 1987. Symposium: alternative feed sources for dairy cattle. Supplying the protein needs of dairy cattle from by-product feeds. *J. Dairy Sci.* 70:1092-1109.
- Clary, G. 1992. Applying economics to forage-livestock systems – issues, problems, and needs. Proc. of the Southern Pasture and Forage Crop Improvement Conference. p. 42. Mississippi State, MS.
- Coffey, K.P., W.K. Coblenz, T.G. Montgomery, J.D. Shockey, K.J. Bryant, P.B. Francis, C.F. Rosenkrans, Jr., and S.A. Gunter. 2002. Growth performance of stocker calves backgrounded on sod-seeded winter annuals or hay and grain. *J. Anim. Sci.* 80:926-932.
- Corredor, D.Y., S.R. Bean, T. Schober, and D. Wang. 2006. Effect of decorticating sorghum on ethanol production and composition of DDGS. *Cereal Chem.* 83:17-21.
- Coulibaly, N., D.J. Bernardo, and G.W. Horn. 1996. Energy supplementation strategies for wheat pasture stocker cattle under uncertain forage availability. *J. Agric. Appl. Econ.* 28:172-179.

- Crouse, J.D., B.D. Schanbacher, H.R. Cross, S.C. Seiderman, and S.B. Smith. 1987. Growth and carcass traits of heifers as affected by hormonal treatment. *J. Anim. Sci.* 64:1434.
- Cummings, B.A., D.H. Gould, D.R. Caldwell, and D.W. Hamar. 1995. Ruminal microbial alterations associated with sulfide generation in steers with dietary sulfate-induced polioencephalomalacia. *Amer. J. Vet. Res.* 56:1390-1395.
- Cuomo, G.J., D.D. Redfearn, J.F. Beatty, R.A. Anders, F.B. Martin, and D.C. Blouin. 1999. Management of warm-season annual grass residue on annual ryegrass establishment and production. *Agron. J.* 91:666-671.
- Cuomo, G.J., M.V. Rudstrom, P.R. Peterson, D.G. Johnson, A. Singh, and C.C. Sheaffer. 2005. Initiation date and nitrogen rate for stockpiling smooth bromegrass in the North-Central USA. *Agron. J.* 97:1194.
- Decker, A.M. 1988. Maximizing the grazing season. p. 31-42. *In* J.B. Cropper (ed.) Pasture in the northeast region of the United States. Publ. No. 36. Northeast Regional Agricultural Engineering Serv., Ithaca, NY.
- DeHaan, K., T. Klopfenstein, and R. Stock. 1983. Corn gluten feed-protein and energy source for ruminants. *Nebraska Beef Cattle Report* MP44:19-21.
- de Mello Jr., A.S., B.E. Jenschke, and C.R. Calkins. 2008a. Effects of wet distillers grains finishing diets on fat content and marbling score in steers. *Nebraska Beef Cattle Report.* MP91:124-125.

- de Mello Jr., A.S., B.E. Jenschke, and C.R. Calkins. 2008*b*. Influence of feeding wet distillers grains on fatty acid composition of beef. Nebraska Beef Cattle Report. MP91:120-121.
- de Mello Jr., A.S., B.E. Jenschke, and C.R. Calkins. 2008*c*. Wet distillers grains plus solubles affect lipid oxidation and objective color of beef steaks. Nebraska Beef Cattle Report. MP91:122-123.
- de Mello Jr., A.S., C.R. Calkins, B.E. Jenschke, L.S. Senaratne, M.E.R. Dugan, T. Carr, and G.E. Erickson. 2009. Fatty acid profile of three beef muscles from yearlings and calf-fed steers fed wet distillers grains plus solubles. Nebraska Beef Cattle Report. MP92:107-109.
- Depenbusch, B.E., C.M. Coleman, J.J. Higgins, and J.S. Drouillard. 2009. Effects of increasing levels of dried corn distillers grains with solubles on growth performance, carcass characteristics, and meat quality of yearling heifers. J. Anim. Sci. 87:2653-2663.
- Depenbusch, B.E., E.R. Loe, M.J. Quinn, M.E. Corrigan, M.L. Gibson, K.K. Karges, and J.S. Drouillard. 2008. Corn distillers grains with solubles derived from a traditional or partial fractionation process: growth performance and carcass characteristics of finishing feedlot heifers. J. Anim. Sci. 86:2338-2343.
- Dinusson, W.E., F.N. Andrews, and W.M. Beeson. 1950. The effects of stilbestrol, testosterone, thyroid alteration and spaying on the growth and fattening of beef heifers. J. Anim. Sci. 9:321.

- D'Souza, G.E., E.W. Marshall, W.B. Bryan, and E.C. Prigge. 1990. Economics of extended grazing systems. *Am. J. Altern. Agric.* 5:120-125.
- Duckett, S.K., F.N. Owens, and J.G. Andrae. 1997. Effects of implants on performance and carcass traits of feedlot steers and heifers. P. 63 in Symposium: Impact of Implants on Performance and Carcass Value of Beef Cattle. Okla. Agric. Exp. Sta. Oklahoma State University. Stillwater.
- Duensing, W.J., A.B. Roskins, and R.J. Alexander. 2003. Corn dry milling: processes, products, and applications. In *Corn: Chemistry and Technology*. White, P.J., L.A. Johnson (eds.). American Association of Cereal Chemists, St. Paul, MN, pp. 407-447.
- Entz, M.H., V.S. Baron, P. Carr, P.M. McCaughey, S.R. Smith, and D. Cash. 2002. Potential of forages to diversify Canadian and American northern great plain cropping systems. *Agron. J.* 94:240-250.
- Erdmann, R.A., G.H. Proctor, and J.H. Vandersall. 1986. Effect of rumen ammonia concentration on in situ rate and extent of digestion of feedstuffs. *J. Dairy Sci.* 69:2312.
- Evers, G.W., G.R. Smith, and C.S. Hoveland. 1997. Ecology and production of annual ryegrass. p. 29-44. *In: F.M.J. Rouquette et al. (ed.) Ecology, production and management of Lolium for forage in the USA*. ASA, CSSA, and SSSA, Madison, WI.

- Ferrell, C.L. and T.G. Jenkins. 1998. Body composition and energy utilization by steers of diverse genotypes fed a high-concentrate diet during the finishing period. II. Angus, Boran, Brahman, Hereford, and Tuli sires. *J. Anim. Sci.* 76:647-657.
- Field, R., R. McCormick, V. Balasubramanian, D. Sanson, J. Wise, D. Hixon, M. Riley, and W. Russell. 1996. Growth, carcass, and tenderness characteristics of virgin, spayed, and single-calf heifers. *J. Anim. Sci.* 74:2178-2186.
- Field, R.A., G. Malorano, F.C. Hinds, W.J. Murdoch, and M.L. Riley. 1990. Bone ossification and carcass characteristics of wethers given silastic implants containing estradiol. *J. Anim. Sci.* 68:3663.
- Firkins, J.L., L.L. Berger, G.C. Fahey, Jr., and N.R. Merchen. 1984. Ruminant nitrogen degradability and escape of wet and dry distillers grains and wet and dry corn gluten feeds. *J. Dairy Sci.* 67:1936-1944.
- Follmer, J.D., T.B. Farran, G.E. Erickson, T.J. Klopfenstein, C.D. Reinhardt, B.D. Dicke, J.S. Drouillard, M.N. Streeter, and J.T. Vasconcelos. 2009. Evaluation of Revalor-IH and Revalor-IS as initial implants compared with traditional initial implants for finishing heifers and steers. *Prof. Anim. Sci.* 25:580-585.
- Gadberry, M.S., P.A. Beck, and S.A. Gunter. 2004. Forage intake and performance by beef heifers grazing cool-season pastures supplemented with de-oiled rice bran or corn. *Prof. Anim. Sci.* 20:394-400.
- Galyean, M.L. 1999. Review: restricted and programmed feeding of beef cattle – definitions, application, and research results. *Prof. Anim. Sci.* 15:1-6.

- Garber, M.J., R.A. Roeder, J.J. Combs, L. Eldridge, J.C. Miller, D.D. Hinman, and J.J. Ney. 1990. Efficacy of vaginal spaying and anabolic implants on growth performance and carcass characteristics in beef heifers. *J. Anim. Sci.* 68:1469-1475.
- Getachew, G., M. Blummel, H.P.S. Makkar, and K. Becker. 1998. In vitro gas measuring techniques for assessment of nutritional quality of feeds: a review. *Anim. Feed Sci. Technol.* 72:261-281.
- Gigax, J.A., B.L. Nuttleman, W.A. Griffin, G.E. Erickson, and T.J. Klopfenstein. 2011. Performance and carcass characteristics of finishing steers fed low-fat and normal-fat wet distillers grains. *Nebraska Beef Cattle Report.* MP94:44-45.
- Gould, D.H. 1998. Polioencephalomalacia. *J. Anim. Sci.* 76:309-314.
- Gould, D.H., B.A. Cummings, and D.W. Hamar. 1997. In vivo indicators of pathologic ruminal sulfide production in steers with diet-induced polioencephalomalacia. *J. Vet. Diagn. Invest.* 9:72-76.
- Gould, D.H., D.A. Dargatz, F.B. Garry, and D.W. Hamar. 2002. Potentially hazardous sulfur conditions on beef cattle ranches in the United States. *J. Am. Vet. Med. Assoc.* 221:673-677.
- Gould, D.H., M.M. McAllister, J.C. Savage, and D. Hamar. 1991. High sulfide concentrations in rumen fluid associated with nutritionally induced polioencephalomalacia in calves. *Am. J. Vet. Res.* 52:1164-1169.
- Guiroy, P.J., L.O. Tedeschi, D.G. Fox, and J.P. Hutcheson. 2002. The effects of implant strategy on finished body weight of beef cattle. *J. Anim. Sci.* 80:1791-1800.

- Gunn, P.J., A.D. Weaver, R.P. Lemenager, D.E. Gerrard, M.C. Claeys, and S.L. Lake. 2009. Effects of dietary fat and crude protein on feedlot performance, carcass characteristics, and meat quality in finishing steers fed differing levels of dried distillers grains with solubles. *J. Anim. Sci.* 87:2882-2890.
- Haack, A.L., A.S. de Mello Jr., S. Pokharel, L. Senaratne, J. Hergenreder, K. Varnold, C.R. Calkins, G.E. Erickson, T.P. Carr, and D.D. Johnson. 2011. Low-fat wet distillers grains and beef quality. *Nebraska Beef Cattle Report*. MP94:96-99.
- Haferkamp, M.R., M.D. MacNeil, E.E. Grings, and K.D. Klement. 2005. Heifer production on rangeland and seeded forages in the northern Great Plains. *Rangeland Ecol. Manage.* 58:495-504.
- Hafley, J.L. 1996. Comparison of Marshall and Surrey ryegrass for continuous and rotational grazing. *J. Anim. Sci.* 74:2269.
- Hamernik, D.L., J.R. Males, C.T. Gaskins, and J.J. Reeves. 1985. Feedlot performance of hysterectomized and ovariectomized heifers. *J. Anim. Sci.* 60:358-362.
- Herszage, J. and M.D.S. Afonso. 2003. Mechanism of hydrogen sulfide oxidation by manganese (IV) oxide in aqueous solutions. *Langmuir* 19:9684-9692.
- Horn, G.W., M.D. Cravey, F.T. McCollum, C.A. Strasia, E.G. Krenzer, Jr., and P.L. Claypool. 1995. Influence of high-starch vs. high-fiber energy supplement on performance of stocker cattle grazing wheat pasture and subsequent feedlot performance. *J. Anim. Sci.* 73:45-54.
- Horstman, L.A., C.J. Callahan, R.L. Morter, and H.E. Amstutz. 1982. Ovariectomy as a means of abortion and control of estrus in feedlot heifers. *Theriogenology* 17:273.

- Hoveland, C.S., D.R. Hardin, P.C. Worley, and E.E. Worley. 1991. Steer performance on perennial vs. winter annual pastures in North Georgia. *J. Prod. Agric.* 4:24-28.
- Hunter, R.A. and J.E. Vercoe. 1987. Reduction of energy requirements of steers fed on low quality-roughage diets using trenbolone acetate. *Br. J. Nutr.* 58:477-483.
- Hutcheson, D.P., J.R. Rains, and J.W. Paul. 1993. The effects of different implant and feed additive strategies on performance and carcass characteristics in finishing heifers: a review. *Prof. Anim. Sci.* 9:132.
- Hutcheson, J.P., D.E. Johnson, C.L. Gerken, J.B. Morgan, and J.D. Tatum. 1997. Anabolic implant effects on chemical body composition and estimated energetic efficiency in cloned (genetically identical) beef steers. *J. Anim. Sci.* 75:2620-2626.
- Janicek, B.N., P.J. Kononoff, A.M. Gehman, K. Karges, and M.L. Gibson. 2007. Short communication: effect of increasing levels of corn bran on milk yield and composition. *J. Dairy Sci.* 90:4313-4316.
- Kahlon, T.S., J.C. Meiske, and R.D. Goodrich. 1975. S metabolism in ruminants. I. In vitro availability of various chemical forms of S. *J. Anim. Sci.* 41:1147-1153.
- Kallenbach, R.L., G.J. Bishop-Hurley, M.D. Massie, M.S. Kerley, and C.A. Roberts. 2003. Stockpiled annual ryegrass for winter forage in the lower Midwestern USA. *Crop Sci.* 43:1414-1419.
- Kandyli, K. 1984. Toxicology of sulfur in ruminants. Review. *J. Dairy Sci.* 67:2179.

- Keatinge, J.D.H., M.K. Garrett, and R.H. Stewart. 1980. Responses of perennial and Italian ryegrass cultivars to temperature and soil water potential. *J. Agric. Sci.* 94:171-176.
- Kelzer, J.M., P.J. Kononoff, A.M. Gehman, L.O. Tedeschi, K. Karges, and M.L. Gibson. 2009. Effects of feeding three types of corn-milling coproducts on milk production and ruminal fermentation of lactating Holstein cattle. *J. Dairy Sci.* 92:5120-5132.
- Kelzer, J.M., P.J. Kononoff, L.O. Tedeschi, T.C. Jenkins, K. Karges, and M.L. Gibson. 2010. Evaluation of protein fractionation and ruminal and intestinal digestibility of corn milling co-products. *J. Dairy Sci.* 93:2803-2815.
- Kercher, C.J., R.C. Thompson, P.O. Stratton, C.O. Schoonover, J.A. Gorman, and N.W. Hilston. 1960. Comparison of feedlot performance and carcass value of open vs. spayed vs. bred heifers. *Wyoming Agric. Exp. Mimeo* 127:1.
- Kertz, A.F. 1998. Variability in delivery of nutrients to lactating dairy cows. *J. Dairy Sci.* 81:3075-3084.
- Kleinschmit, D.H., D.J. Schingoethe, K.F. Kalscheur, and A.R. Hippen. 2006. Evaluation of various sources of corn dried distillers grains plus solubles for lactating dairy cattle. *J. Dairy Sci.* 89:4784-4794.
- Kleinschmit, D.H., J.L. Anderson, D.J. Schingoethe, K.F. Kalscheur, and A.R. Hippen. 2007. Ruminal and intestinal degradability of distillers grains plus solubles varies by source. *J. Dairy Sci.* 90:2909-2918.

- Klindt, J. and J.D. Crouse. 1990. Effect of ovariectomy and ovariectomy with ovarian autotransplantation on feedlot performance and carcass characteristics of heifers. *J. Anim. Sci.* 68:3481-3487.
- Klopfenstein, T., J. Waller, N. Merchen, and L. Petersen. 1978. Distillers grains as a naturally protected protein for ruminants. *Distillers Feed Conference Proceedings* 33:38-46.
- Klopfenstein, T., R. Cooper, D.J. Jordon, D. Shain, T. Milton, C. Calkins, and C. Rossi. 2000. Effects of backgrounding and growing programs on beef carcass quality and yield. *J. Anim. Sci.* 77:1-11.
- Klopfenstein, T.J. 1996. Distillers grains as an energy source and effect of drying on protein availability. *Anim. Feed Sci. Tech.* 60:201-207.
- Klopfenstein, T.J., G.E. Erickson, and V.R. Bremer. 2008. Board-Invited Review: Use of distillers by-products in the beef cattle feeding industry. *J. Anim. Sci.* 86:1223-1231.
- Kung, L., A.O. Hession, and J.P. Bracht. 1998. Inhibition of sulfate reduction to sulfide by 9, 10-anthraquinone in in vitro ruminal fermentations. *J. Dairy Sci.* 81:2251-2256.
- Kung, L., J.P. Bracht, and J.Y. Tavares. 2000. Effects of various compounds on in vitro ruminal fermentation and production of sulfide. *Anim. Feed Sci. Technol.* 84:69-81.
- Kung, L. Jr. 2008. Metabolism of sulfur in the rumen. *J. Anim. Sci.* 86(E-Suppl. 3):57. (Abstr.).

- Lake, R.P., R.L. Hildebrand, D.C. Clanton, and L.E. Jones. 1974. Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. *J. Anim. Sci.* 39:827.
- Leibovich, J., J.T. Vasconcelos, and M.L. Galyean. 2009. Effects of corn processing method in diets containing sorghum wet distillers grains plus solubles on performance and carcass characteristics of finishing beef cattle and on in vitro fermentation of diets. *J. Anim. Sci.* 87:2124-2132.
- Leupp, J.L., G.P. Lardy, M.L. Bauer, K.K. Karges, M.L. Gibson, J.S. Caton, and R.J. Maddock. 2009. Effects of distillers dried grains with solubles on growing and finishing steer intake, performance, carcass characteristics, and steak color and sensory attributes. *J. Anim. Sci.* 87:4118-4124.
- Licitra, G., T.M. Hernandez, and P.J. Van Soest. 1996. Standardization of procedures for nitrogen fractionation of ruminant feeds. *Anim. Feed Sci. Technol.* 57:347-358.
- Lippke, H., T.D.A. Forbes, and W.C. Ellis. 2000. Effect of supplements on growth and forage intake by stocker steers grazing wheat pasture. *J. Anim. Sci.* 78:1625-1635.
- Loneragan, G.H., D.H. Gould, J.J. Wagner, F.B. Geary, and M. Thoren. 2001. Effects of water sulfate concentration on performance, water intake, and carcass characteristics of feedlot steers. *J. Anim. Sci.* 79:2941-2948.
- Loy, D., D. Maxwell, and G. Rouse. 1999. Effects of early weaning of beef calves on performance and carcass quality. Iowa State Univ. Beef Res. Rep. AS 641, Leaflet R1632, Ames. Pp. 22-24.

- Luther, III, G.W., B.T. Glazer, L. Hohman, J.I. Popp, M. Taillefert, T.F. Rozan, P.J. Brendel, S.M. Theberge, and D.B. Nuzzio. 2001. Sulfur speciation monitored *in situ* with solid state gold amalgam voltammetric microelectrodes: polysulfides as a special case in sediments, microbial mats and hydrothermal vent waters. *J. Environ. Monit.* 3:61-66.
- Macken, C.N., C.T. Milton, T.J. Klopfenstein, B.D. Dicke, and D.E. McClellan. 2003. Effects of final implant type and supplementation of melengestrol acetate on finishing feedlot heifer performance, carcass characteristics, and feeding economics. *Prof. Anim. Sci.* 19:159-170.
- Mader, T.L. 1994. Effect of implant sequence and dose on feedlot cattle performance. *J. Anim. Sci.* 72:277-282.
- Mader, T.L. and K.F. Lechtenberg. 2000. Growth-promoting systems for heifer calves and yearlings finished in the feedlot. *J. Anim. Sci.* 78:2485-2496.
- Matches, A.G. and J.C. Burns. 1995. Systems of grazing management. p. 179-192. *In* R.F. Barnes et al. (ed.) *Forages. Volume II. The science of grassland agriculture.* Iowa State Univ. Press, Ames.
- May, M.L., J.C. DeClerck, J. Leibovich, M.J. Quinn, N. DiLorenzo, D.R. Smith, K.E. Hales, and M.L. Galyean. 2010a. Corn or sorghum wet distillers grains with solubles in combination with steam-flaked corn: *In vitro* fermentation and hydrogen sulfide production. *J. Anim. Sci.* 88:2425-2432.

- May, M.L., M.J. Quinn, B.E. Depenbusch, C.D. Reinhardt, M.L. Gibson, K.K. Karges, N.A. Cole, and J.S. Drouillard. 2010*b*. Dried distillers grains with solubles with reduced corn silage levels in beef finishing diets. *J. Anim. Sci.* 88:2456-2463.
- Mayland, H.F., G.E. Shewmaker, P.A. Harrison, and N.J. Chatterton. 2000. Nonstructural carbohydrates in tall fescue cultivars: relationship to animal preference. *Agron. J.* 92:1203.
- McCaughey, W.P. 1997. Winter swath grazing in Manitoba. p. 39-50. *In: Proc. Manitoba Agri-Forum '97*. Winnipeg, Manitoba, Canada.
- McDougall, E.I. 1948. Studies on ruminant saliva. I. The composition and output of sheep's saliva. *Biochem. J.* 43:99-109.
- Moore, J.E., M.H. Brant, W.E. Kunkle, and D.I. Hopkins. 1999. Effects of supplementation on voluntary forage intake, diet digestibility and animal performance. *J. Anim. Sci.* 77(Suppl. 2):122.
- Mooso, G.D., J.I. Feazel, and D.G. Morrison. 1990. Effect of sodseeding method on ryegrass-clover mixtures for grazing beef animals. *J. Prod. Agric.* 3:470-474.
- Morgan, J.B. 1997. Implant program effects on USDA beef carcass quality grade traits and meat tenderness. Pages 147-154 in *Proc. Symp. Impact Implants Perform. Carcass Value Beef Cattle*, Oklahoma State Univ., Stillwater.
- Moyer, J.L. and K.P. Coffey. 2000. Forage quality and production of small grains interseeded into bermudagrass sod or grown in monoculture. *Agron. J.* 92:748-753.

- Munson, C.L., J.C. Whittier, D.N. Schutz, and R.L. Anderson. 1999. Reducing annual cow cost by grazing windrowed millet. *Prof. Anim. Sci.* 15:40-45.
- Murthy, G.S., E.D. Sall, S.G. Metz, G. Foster, and V. Singh. 2009. Evaluation of a dry corn fractionation process for ethanol production with different hybrids. *Ind. Crops Prod.* 29:67.
- Murthy, G.S., V. Singh, D B. Johnston, K.D. Rausch, and M.E. Tumbleson. 2006. Evaluation and strategies to improve fermentation characteristics of modified dry-grind corn processes. *Cereal Chem.* 83:455-459.
- Myers, S.E., D.B. Faulkner, T.G. Nash, L.L. Berger, D.F. Farrett, and F.K. McKeith. 1999. Performance and carcass traits of early-weaned steers receiving either a pasture growing period or a finishing diet at weaning. *J. Anim. Sci.* 77:311-322.
- Nakamura, T., T.J. Klopfenstein, and R.A. Britton. 1994. Evaluation of acid detergent insoluble nitrogen as an indicator of protein quality in nonforage proteins. *J. Anim. Sci.* 72:1043-1048.
- Nelson, C.J. and L.E. Moser. 2004. Plant factors affecting forage quality. p. 115-154. *In: Forage Quality, Evaluation, and Utilization.* Amer. Soc. Agron. and Crop Sci. Soc. of Amer., Madison, WI.
- Nelson, L.R., S. Ward, and J. Crowder. 1993. Oat, rye and wheat forage variety tests at Overton in 1991-92. *Prog. Rep. Tex. Agric. Exp. Sta.* PR-5021:23-25.
- Nichols, C.A., K.M. Rolfe, C.D. Buckner, G.E. Erickson, and T.J. Klopfenstein. 2011. Effect of source and level of sulfur on rumen metabolism and finishing performance. *Nebraska Beef Cattle Report.* MP94:60-61.

- NRC (National Research Council). 1996. Nutrient requirements of beef cattle. 7th ed. Natl. Academy Press, Washington, D.C.
- NRC (National Research Council). 2000. Nutrient Requirements of Beef Cattle: Update 2000. 7th ed. Nat'l Acad. Press, Washington, D.C.
- NRC (National Research Council). 2005. Mineral Tolerance of Animals: Second Revised Edition. Nat'l Acad. Press, Washington, D.C.
- Nygaard, L.J. and L.B. Embry. 1966. Response of spayed and nonspayed heifers to diethylstilbestrol and Synovex implants. South Dakota 10th Annu. Beef Cattle Field Day. A.S. Series 66-13:70.
- O'Brien, C.A., R.E. Bloss, and E.F. Nicks. 1968. Effect of melengestrol acetate on the growth and reproductive physiology of fattening heifers. J. Anim. Sci. 27:664-667.
- Ocuppaugh, W. and A.G. Matches. 1977. Autumn-winter yield and quality of tall fescue. Agron. J. 69:639-643.
- Peel, D.S. 2000. Stocker cattle: Shock absorber for the beef industry. Oklahoma State Univ. Dep. Agric. Econ. Visions 72:1.
- Pell, A.N. and P. Schofield. 1993. Computerized monitoring of gas production to measure forage digestion in vitro. J. Dairy Sci. 76:1063-1073.
- Phillips, W.A. and D.L. VonTungeln. 1995. Dry matter intake of freshly harvested wheat forage and supplemental dry matter. Sheep Goat Res. 7:150.

- Phillips, W.A., M.A. Brown, A.H. Brown, Jr., and S.W. Coleman. 2001. Genotype x environment interactions for postweaning performance in crossbred calves grazing winter wheat or dormant native pasture. *J. Anim. Sci.* 79:1370.
- Phillips, W.A., M.A. Brown, and L.A. Appeddu. 2000. Changes in body weight of stocker cattle during the adaptation period on winter wheat pasture. *In Proc. 1st Natl. Conf. Grazing Lands, Las Vegas, Nevada.* p. 375. Grazing Lands Conservation Initiative, Davis, OK.
- Phillips, W.A., M.A. Brown, J.W. Holloway, and B. Warrington. 2004. Influence of live weight gain during the winter grazing period on subsequent grazing and feedlot performance. *Prof. Anim. Sci.* 20:401-412.
- Plascencia, A., G.D. Mendoza, C. Vásquez, and R.A. Zinn. 2003. Relationship between body weight and level of fat supplementation on fatty acid digestion in feedlot cattle. *J. Anim. Sci.* 81:2653-2659.
- Platter, W.J., J.D. Tatum, K.E. Belk, J.A. Scanga, and G.C. Smith. 2003. Effects of repetitive use of hormonal implants on beef carcass quality, tenderness, and consumer ratings of beef palatability. *J. Anim. Sci.* 81:984-996.
- Ponnampalam, E., D.B. Steele, D. Burgdorf, and D. McCalla. 2004. Effect of germ and fiber removal on production of ethanol from corn. *Appl. Biochem. and Biotech.* 115:837-842.
- Poore, M.H., G.A. Benson, M.E. Scott, and J.T. Green. 2000. Production and utilization of stockpiled fescue to reduce beef cattle production costs. *J. Anim. Sci.* 79(Suppl.):1-11.

- Premachandra, G.S., H. Saneoka, K. Fujita, and S. Ogata. 1993. Seasonal changes in leaf water relations and cell membrane stability in orchardgrass (*Dactylis glomerata*). J. Agric. Sci. (Cambridge) 121:169-175.
- Pritchard, R.H. and J.R. Males. 1985. Effect of crude protein and ruminal ammonia-N on digestibility and ruminal outflow in beef cattle fed wheat straw. J. Anim. Sci. 60:822-831.
- Qi, K., C.D. Lu, and F.N. Owens. 1993. Sulfate supplementation of growing goats: effects on performance, acid-base balance, and nutrient digestibilities. J. Anim. Sci. 71:1579-1587.
- Quinn, M.J., M.L. May, K.E. Hales, N. DiLorenzo, J. Leibovich, D.R. Smith, and M.L. Galyean. 2009. Effects of ionophores and antibiotics on *in vitro* hydrogen sulfide production, dry matter disappearance, and total gas production in cultures with a steam-flaked corn-based substrate with or without added sulfur. J. Anim. Sci. 87:1705-1713.
- Redfearn, D.D., B.C. Venuto, W.D. Pitman, M.W. Alison, and J.D. Ward. 2002. Cultivar and environment effects on annual ryegrass forage yield, yield distribution, and nutritive value. Crop Sci. 42:2049.
- Redmon, L.A., F.T. McCollum, III, G.W. Horn, M.D. Cravey, S.A. Gunter, P.A. Beck, J.M. Mieres, and R. San Julian. 1995. Forage intake by beef steers grazing winter wheat with varied herbage allowances. J. Range Manage. 48:198-201.

- Reiling, B.A. and D.D. Johnson. 2003. Effects of implant regimens (trenbolone acetate-estradiol administered alone or in combination with zeranol) and vitamin D₃ on fresh beef color and quality. *J. Anim. Sci.* 81:135-142.
- Renewable Fuels Association. 2011. Annual industry outlook.
<http://www.ethanolrfa.org/pages/annual-industry-outlook>. Accessed Feb. 15, 2011.
- Riesterer, J.L., D.J. Undersander, M.D. Casler, and D.K. Combs. 2000. Forage yield of stockpiled perennial grasses in the Upper Midwest USA. *Agron. J.* 92:740-747.
- Robertson, I.S., J.C. Wilson, and H.M. Fraser. 1979. Immunological castration in male cattle. *Vet. Rec.* 105:556.
- Roe, M.B. and C.J. Sniffen. 1990. Techniques for measuring protein fractions in feedstuffs. Pages 81-88 in *Proc. Cornell Nutr. Conf.*, Rochester, NY, Cornell University, Ithaca, NY.
- Roeber, D.L., R.K. Gill, and A. DiCostanzo. 2005. Meat quality responses to feeding distillers grains to finishing Holstein steers. *J. Anim. Sci.* 83:2455-2460.
- Rouquette, F.M.J., D.I. Bransby, and M.E. Riewe. 1997. Grazing management and use of ryegrass. p. 79-100. *In: F.M.J. Rouquette et al. (ed.) Ecology, production, and management of Lolium for forage in the USA.* ASA, CSSA, and SSSA, Madison, WI.
- Rupp, G.P. and C.V. Kimberling. 1982. A new approach for spaying heifers. *Vet. Med. Small Anim. Clin.* 77:561.

- Russell, J.B., J.D. O'Connor, D.G. Fox, P.J. Van Soest, and C.J. Sniffen. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminant fermentation. *J. Anim. Sci.* 70:3551-3561.
- Sainz, R.D., F. De la Torre, and J.W. Oltjen. 1995. Compensatory growth and carcass quality in growth-restricted and refed beef steers. *J. Anim. Sci.* 73:2971-2979.
- Sarturi, J.O., G.E. Erickson, T.J. Klopfenstein, J.T. Vasconcelos, J.R. Benton, and W.A. Griffin. 2011. Effects of sulfur concentration in distillers grains with solubles in finishing cattle diets. *Nebraska Beef Cattle Report.* MP94:62-64.
- Satter, L.D. and L.L. Slyter. 1974. Effect of ammonia concentrations on rumen microbial protein production in-vitro. *Brit. J. Nutr.* 32:199.
- Scaglia, G., H.T. Boland, and W.E. Wyatt. 2008. Effects of time of supplementation on beef stocker calves grazing ryegrass. II. Grazing behavior and dry matter intake. *Prof. Anim. Sci.* 25:749-756.
- Schneider, B.A., J.D. Tatum, T.E. Engle, and T.C. Bryant. 2007. Effects of heifer finishing implants on beef carcass traits and longissimus tenderness. *J. Anim. Sci.* 85:2019-2030.
- Schwab, C.G., T.P. Tylutki, R.S. Ordway, C. Sheaffer, and M.D. Stern. 2003. Characterization of protein in feeds. *J. Dairy Sci.* 86:(E. Suppl.):E88-E103.
- Shain, D., T. Klopfenstein, D.J. Jordan, and R. Stock. 1998. Summer and fall forage grazing combinations: Five-year summary. *Nebraska Beef Cattle Report.* MP69-A:66-69.

- Sheehy, J.E., F. Gastal, P.L. Mitchell, J.L. Durand, G. Lemaire, and F.J. Woodward. 1996. A nitrogen-led model of grass growth. *Ann. Bot.* 77:165-177.
- Shreve, B., N. Thiex, and M. Wolf. 2006. National Forage Testing Association Reference Method: Dry matter by oven drying for 3 hours at 105°C. NFTA Reference Methods. National Forage Testing Association, Omaha, NE, www.foragetesting.org.
- Siegel, L.M. 1965. A microdetermination method for sulfide. *Anal. Biochem.* 11:126-132.
- Sigma Technical Bulletin #640. The colorimetric determination of urea nitrogen. Sigma Diagnostics, St. Louis, MO, 63178.
- Sindt, M., R. Stock, and T. Klopfenstein. 1991. Calf versus yearling finishing. *Nebraska Beef Cattle Report.* MP56:42-43.
- Sirois, P.K., M.J. Reuter, C.M. Laughlin, and P.J. Lockwood. 1994. A method for determining macro and micro elements in forages and feeds by inductively coupled plasma atomic emission spectrometry. *Spectroscopist* 3:6-9.
- Sissom, E.K., C.D. Reinhardt, and B.J. Johnson. 2006. Melengestrol acetate alters muscle cell proliferation in heifers and steers. *J. Anim. Sci.* 84:2950.
- Sladden, S.E. and D.I. Bransby. 1992. Stocking rate-gain relationships for sheep and cattle on ryegrass. p. 51-54. *Proc. Am. Forage Grassland Council*, Grand Rapids, MI. 5-9 April. 1992. AFGC, Georgetown, TX.
- Smith, D. 1969. Removing and analyzing total nonstructural carbohydrates from plant tissue. *Wisconsin Agric. Exp. Stn. Res. Rep.* 41. Madison.

- Smith, D.R., N. DiLorenzo, J. Leibovich, M.L. May, M.J. Quinn, J.W. Himm, and M.L. Galyean. 2010. Effects of sulfur and monensin concentrations on in vitro dry matter disappearance, hydrogen sulfide production, and volatile fatty acid concentrations in batch culture ruminal fermentations. *J. Anim. Sci.* 88:1503-1512.
- Smith, G.C., J.W. Savell, J.B. Morgan, and T.E. Lawrence. 2006. Final report of national beef quality audit-2005: A new benchmark for the US beef industry. Natl. Cattlemen's Beef Assoc., Centennial, CO.
- Smith, S.B. and J.D. Crouse. 1984. Relative contributions of acetate, lactate, and glucose to lipogenesis in bovine intramuscular and subcutaneous adipose tissue. *J. Nutr.* 114:792-800.
- Smith, S.R. Jr., J.H. Bouton, and C.S. Hoveland. 1989. Alfalfa persistence and regrowth potential under continuous grazing. *Agron. J.* 81:960.
- Spears, J.W. and K. Lloyd. 2005. Effects of dietary sulfur and sodium bicarbonate on performance of growing and finishing steers. *J. Anim. Sci.* 83(Suppl. 1):224. (Abstr.).
- Spiehs, M.J., M.H. Whitney, and G.C. Shurson. 2002. Nutrient database for distillers dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. *J. Anim. Sci.* 80:2639-2645.
- Stein, H.H. and G.C. Shurson. 2009. Review: The use and application of distillers dried grains with solubles in swine. *J. Anim. Sci.* 87:1292-1303.

- Stock, R.A., J.M. Lewis, T.J. Klopfenstein, and C.T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. <http://www.asas.org/JAS/symposia/proceedings/0924.pdf>.
- Surber, G., T. Fisher, D. Cash, P. Dixon, and J. Moore. 2001. Swath/windrow grazing: an alternative livestock feeding technique. Montana State University Extension Service, MONTGUIDE, MT200106.
- Tagliapietra, F., M. Cattani, L. Bailoni, and S. Schiavon. 2010. In vitro rumen fermentation: Effect of headspace pressure on the gas production kinetics of cornmeal and meadow hay. *Anim. Feed Sci. and Technol.* 158:197-201.
- Taliaferro, C.M., F.M. Rouquette, Jr., and P. Mislevy. 2004. Bermudagrass and stargrass. p. 417-475. *In: L.E. Moser et al. (ed.) Warm-season (C₄) grasses.* ASA, CSSA, and SSSA, Madison, WI.
- Taylor, T.H. and W.C. Templeton. 1976. Stockpiling Kentucky bluegrass and tall fescue forage for winter pasturage. *Agron. J.* 68:235-239.
- Theodorou, M.K., B.A. Williams, M.S. Dhanoa, A.B. McAllan, and J. France. 1994. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. *Anim. Feed Sci. Technol.* 48:185-197.
- Tolley, E.A., M.W. Tess, T. Johnson, and K.R. Pond. 1988. Effect of switching diets on growth and digesta kinetics of cattle. *J. Anim. Sci.* 66:2551.
- Trenkle, A. 1997. Mechanisms of action of estrogens and androgens on performance of cattle: Hormonal basis. Pages 15-22 in *Proc. Symp.: Impact of Implants on*

Performance and Carcass Value of Beef Cattle. Oklahoma Agric. Exp. Stn. Publ. No. P-957. Stillwater.

Troxel, T.R., M.S. Gadberry, S. Cline, J. Foley, G. Ford, D. Urell, and R. Wiedower. 2002. Factors affecting the selling price of feeder cattle sold at Arkansas livestock auctions. *Prof. Anim. Sci.* 18:227-236.

Utley, P.R., H.D. Chapman, and W.C. McCormick. 1972. Feedlot performance of heifers fed melengestrol acetate and oxytetracycline separately and in combination. *J. Anim. Sci.* 34:339-341.

Utley, P.R., M.H. Marchant, and W.C. McCormick. 1976. Evaluation of annual grass forages in prepared seedbeds and overseeded into perennial sods. *J. Anim. Sci.* 42:16-20.

Uwituze, S., G.L. Parsons, C.J. Schneider, K.K. Karges, M.L. Gibson, L.C. Hollis, J.J. Higgins, and J.S. Drouillard. 2011. Evaluation of sulfur content of dried distillers grains with solubles in finishing diets based on steam-flaked corn or dry-rolled corn. *J. Anim. Sci.* 1910.doi:10.2527/jas.2010-3103.

Vander Pol, K.J., G.E. Erickson, T.J. Klopfenstein, M.A. Greenquist, and T. Robb. 2006. Effect of dietary inclusion of wet distillers grains on feedlot performance of finishing cattle and energy value relative to corn. *Nebraska Beef Cattle Report.* MP88-A:51-53.

Van Keuren, R.W. 1970. All-season grazing for beef cows. *Ohio Agric. Res. Dev. Cent. Res. Summary* 43:1-6.

- Vanness, S.J., N.F. Meyer, T.J. Klopfenstein, and G.E. Erickson. 2009*a*. Hydrogen sulfide gas levels post-feeding. Nebraska Beef Cattle Report. MP92:84-85.
- Vanness, S.J., N.F. Meyer, T.J. Klopfenstein, and G.E. Erickson. 2009*b*. Ruminal sulfide levels in corn byproduct diets with varying roughage levels. Nebraska Beef Cattle Report. MP92:81-83.
- Vanness, S.J., T.J. Klopfenstein, G.E. Erickson, and K.K. Karges. 2009*c*. Sulfur in distillers grains. Nebraska Beef Cattle Report. MP92:79-80.
- Van Soest, P.J., J.B. Robertson, and B.A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583-3597.
- Vendramini, J.M.B., L.E. Sollenberger, A. Adesogan, J.C.B. Dubeux, Jr., S.M. Interrante, R.L. Stewart, Jr., and J.D. Arthington. 2008*a*. Protein fractions of Tifton 85 and rye-ryegrass due to sward management practices. *Agron. J.* 100:463-469.
- Vendramini, J.M.B., L.E. Sollenberger, J.C.B. Dubeux, Jr., S.M. Interrante, R.L. Stewart, Jr., and J.D. Arthington. 2006. Concentrate supplementation effects on forage characteristics and performance of early weaned calves grazing rye-ryegrass pastures. *Crop Sci.* 46:1595-1600.
- Vendramini, J.M.B., L.E. Sollenberger, J.C.B. Dubeux, Jr., S.M. Interrante, R.L. Stewart, Jr., and J.D. Arthington. 2007. Concentrate supplementation effects on forage characteristics and performance of early weaned calves grazing Tifton 85 bermudagrass pastures. *Agron. J.* 99:399-404.

- Vendramini, J.M.B., L.E. Sollenberger, J.C.B. Dubeux, Jr., S.M. Interrante, R.L. Stewart, Jr., and J.D. Arthington. 2008*b*. Sward management effects on forage component responses in a production system for early weaned calves. *Agron. J.* 100:1781-1786.
- Volesky, J.D., D.C. Adams, and R.T. Clark. 2002. Windrow grazing and baled-hay feeding strategies for wintering calves. *J. Range Manage.* 55:23-32.
- Wagner, J.J., N.E. Davis, and C.D. Reinhardt. 2007. A meta-analysis evaluation of feeding melengestrol acetate to feedlot heifers implanted with estradiol, trenbolone acetate, or the combination of estradiol and trenbolone acetate. *Prof. Anim. Sci.* 23:625-631.
- Walker, R.S., S. Bird, R.D. Mathison, and G.C. Lamb. 2007. Windrow grazing demonstration study. University of Minnesota. *Proc. MN Beef Cow/Calf Days* p. 52.
- Walker, R.S., S.L. Bird, P.R. Peterson, and R.D. Mathison. 2009. Evaluating fall grazing systems on forage quality and beef cattle performance – a two-year study. University of Minnesota. *Proc. MN Beef Cow/Calf Days* pp. 57.
- Wallace, R.J. 1979. Effect of ammonia concentration on the composition, hydrolytic activity and nitrogen metabolism of the microbial flora of the rumen. *J. Appl. Bacteriol.* 47:443.
- Wang, P., V. Singh, H. Xue, D.B. Johnston, K.D. Rausch, and M.E. Tumbleson. 2007. Comparison of raw starch hydrolyzing enzyme with conventional liquefaction and saccharification enzymes in dry-grind corn processing. *Cereal Chem.* 84:10-14.

- Weeth, H.J. and D.L. Capps. 1972. Tolerance of growing cattle for sulfate-water. *J. Anim. Sci.* 34:256-260.
- Weeth, H.J. and J.E. Hunter. 1971. Drinking of sulfate-water by cattle. *J. Anim. Sci.* 32:277-281.
- Wertz, A.E., L.L. Berger, D.B. Faulkner, and T.G. Nash. 2001*a*. Intake restriction strategies and sources of energy and protein during the growing period affect nutrient disappearance, feedlot performance, and carcass characteristics of crossbred heifers. *J. Anim. Sci.* 79:1598-1610.
- Wertz, A.E., L.L. Berger, P.M. Walker, D.B. Faulkner, F.K. McKeith, and S.L. Rodriguez-Zas. 2002. Early-weaning and postweaning nutritional management affect feedlot performance, carcass merit, and the relationship of 12th-rib fat, marbling score, and feed efficiency among Angus and Wagyu heifers. *J. Anim. Sci.* 80:28-37.
- Wertz, E., L.L. Berger, P.M. Walker, D.B. Faulkner, F.K. McKeith, and S. Rodriguez-Zas. 2001*b*. Early weaning and postweaning nutritional management affect feedlot performance of angus x simmental heifers and the relationship of 12th rib fat and marbling score to feed efficiency. *J. Anim. Sci.* 79:1660-1669.
- Wester, T.J., R.A. Britton, T.J. Klopfenstein, G.A. Ham, D.T. Hickok, and C.R. Krehbiel. 1995. Differential effects of plane of nutrition on visceral organ and hormones in lambs. *J. Anim. Sci.* 73:1674-1688.

- Widmer, M.R., L.M. McGinnis, and H.H. Stein. 2007. Energy, phosphorus, and amino acid digestibility of high-protein distillers dried grains and corn germ fed to growing pigs. *J. Anim. Sci.* 85: 2994-3003.
- Widmer, M.R., L.M. McGinnis, D.M. Wulf, and H.H. Stein. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork. *J. Anim. Sci.* 86:1819-1831.
- Wilken, M.F., M.K. Luebke, G.E. Erickson, T.J. Klopfenstein, and J.R. Benton. 2009. Effects of feeding high levels of byproducts in different combinations to finishing steers. *Nebraska Beef Cattle Report*. MP92:76-78.
- Williams, W.L., L.O. Tedeschi, P.J. Kononoff, T.R. Callaway, S.E. Dowd, K. Karges, and M.L. Gibson. 2010. Evaluation of in vitro gas production and rumen bacterial populations fermenting corn milling (co)products. *J. Dairy Sci.* 93:4735-4743.
- Yao, W. and F.J. Millero. 1993. The rate of sulfide oxidation by δ -MnO₂ in seawater. *Geochim. Cosmochim. Acta.* 57:3359-3365.
- Zimbelman, R.G. and L.W. Smith. 1966. Control of ovulation in cattle with melengestrol acetate. II. Effects on follicular size and activity. *J. Reprod. Fertil.* 11:193.
- Zinn, R.A., E. Alvarez, M. Mendez, M. Montaña, E. Ramirez, and Y. Shen. 1997. Influence of dietary sulfur level on growth performance and digestive function in feedlot cattle. *J. Anim. Sci.* 75: 1723-1728.

Zinn, R.A., E. Alvarez, M. Montaña, and E. Ramirez. 1999. Toxic effects of high dietary sulfur on growth performance of feedlot calves during the early growing phase. *J. Anim. Sci.* 77(Suppl. 1):115. (Abstr.).

Zinn, R.A, S.K. Gulai, A. Plascencia, and J. Salinas. 2000. Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. *J. Anim. Sci.* 78:1738-1746.