Effects of source and concentration of NDF from roughage on performance and carcass characteristics in finishing feedlot diets

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ABSTRACT

A meta-analysis was performed to investigate the effects of neutral detergent fiber from various dietary constituents (total, TNDF, forage, FNDF, co-products, CNDF, and grain, GNDF) on performance and carcass characteristics in finishing feedlot cattle. Backward elimination procedures were used on mixed models to determine effect of concentration and source of NDF on feedlot and carcass performance. Significant effect ($P < 0.05$) covariates representing use of growth technology (implants and ionophores), gender, days on feed and initial BW were permitted in the model. Models containing total, co-product and grain NDF concentration and source were least useful (based on reductions in AIC values) in describing the relationship between NDF and performance than forage NDF. Feeding any forage increased DMI ($P < 0.03$) compared to feeding no forage, and increasing concentration of FNDF tended to increase DMI quadratically (P =.10). Increasing concentration of FNDF decreased ADG ($P = 0.02$) and gain-to-feed ratio. ($P = 0.01$). Concentration of FNDF was quadratically related to quality grade ($P < .0001$). Yet, feeding a greater FNDF concentration was positively correlated to decreasing liver abscesses ($P = 0.001$). Fiber constituents associated with forage NDF were more consistently associated with finishing and carcass performance response than those constituents associated with total NDF.

Keywords: forage, roughage source, roughage concentration, finishing cattle, neutral detergent fiber,

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INTRODUCTION

Bovine of the family *Bovidae* subfamily *Bovinae*, are noted for the IV-compartment stomach, which includes the reticulum, rumen, omasum, and abomasum. The rumen is an anaerobic fermentation chamber containing microbes including bacteria, fungi, and protozoa. While protozoa and fungi contribute to ruminal digestive processes, the bulk of fermentation in the rumen is performed by ruminal bacteria (Huntington, 1997). The presence of microbes in the rumen enables the symbiotic host to ingest, digest, and subsist on high-forage diets unlike monogastric species, which may digest a small amount of fiber in the cecum. This ability to consume and maintain production on what would be considered low-quality feedstuffs is the basis of the beef cow-calf industry. Grazing or consuming stored forages comprises most beef cow diets. However, except for a few small niche markets, once cattle enter a feedlot, forage comprises a small proportion of the diet. Higher energy feedstuffs support greater daily gain, at similar feed intake (better feed conversion efficiency), and contribute to a reduction in cost of gain compared with higher forage diets (Markham et al., 2004; Benton et al., 2007). Consumer preference also favors beef flavors associated with cattle finished on a high-energy grain-based diet (Chail et al., 2016).

The first section of this review will provide definitions of fiber and the evolution of different components of fiber over time, alternative sources to forage, and common digestive disturbances associated with feeding cattle high energy diets. The second section will characterize various sources and concentrations of fiber (NDF) used in finishing cattle diets. The last section will review the economic impact of feeding fiber in finishing cattle diets from years 2002 to 2017.

FIBER USE IN FEEDLOTS

Grains are the main constituents of high-concentrate diets and are often processed to increase ruminal and total digestibility and ME concentration (Krehbiel et al., 2006). Fiber, often supplied from a roughage source, is used at low concentrations in feedlot finishing diets to prevent digestive upsets such as acidosis, bloat, and the incidence of liver abscesses (Wise et al., 1968) and to increase feed intake and average daily gain (ADG) by maximizing NE_g intake by cattle, (Cole et al., 1976; Defoor et al., 2002). This response can be partially attributed to the effect that roughage has on stimulating rumination and the subsequent increase in salivary buffering. Increases in salivary buffering can be beneficial as it may help to lessen the time the rumen is at a pH level < 5.5. Intake of readily degradable carbohydrates results in increased VFA concentrations thereby leading to a reduction in pH; a pH < 5.5 represents the level at which cattle would be considered to be experiencing subacute acidosis (Horn et al., 1979; Harmon et al., 1985; Burrin and Britton, 1986; Stock et al., 1990; Krehbiel et al., 1995; Goad et al., 1998). The major determinant of ruminal pH is the balance of fermentation acid production and buffer secretion (Allen, 1997). However, difficulty and cost of handling characteristics of forages favor minimizing forage inclusion (Brown et al., 2006). Additionally, roughage inclusion in finishing cattle diets reduces dietary NE_g and increases the cost per unit of ME (Turgeon et al. 2010).

Results from three surveys of consulting nutritionists on attitude toward roughage inclusion and type revealed that typical roughage concentration in feedlot diets was reported to be between 0 and 13.5% (Galyean and Gleghorn, 2001; Vasconcelos and Galyean, 2007; Samuelson et al., 2016). Roughage concentration varied by season as roughage concentration in the diets formulated in the summer was lower than that in diets formulated in winter. Despite this observation, the 0% roughage concentration in the diet was reported as only being used in the winter (Vasconcelos and Galyean, 2007). It is deducted that a minimal inclusion (reported at 4.5%) of roughage in diets formulated by the consultants surveyed in the summer is used as a means to help prevent digestive upsets, i.e. acidosis, that are associated with temperature increases, heat stress, and variation in dry matter intake (DMI) during the summer. Crude fiber (CF), acid detergent fiber (ADF), and neutral detergent fiber (NDF) were all listed as methods of fiber analysis used by feedlot consultants in the most recent survey (Samuelson et al. 2016); however, values reported in this section were reflective of roughage inclusion not fiber as determined by any of these procedures.

Definitions of Fiber

Fiber is defined as the insoluble organic matter indigestible by animal enzymes (Van Soest and Wine, 1967). Crude fiber originally was meant to define the indigestible portion of forage and has been in use for over 200 years (Van Soest, 1964). This analysis is a component of the proximate analysis and TDN calculations. While crude fiber remains a legal means of defining fiber in a feedstuff or a ration, there are challenges with using this system to compare fiber concentration in feedstuffs.

The term crude fiber is ambiguous and does not separate the various components of a plant cell wall, i.e., cellulose, hemi-cellulose, and lignin, while the term fiber itself does not define a nutritionally, chemically, or physically uniform material (Van Soest et al., 1991). Cellulose and hemicellulose are digestible fibers by microbial action in both the rumen and the cecum while lignin is mostly indigestible by ruminants and non-ruminants alike (Van Soest, 1966a).

Crude fiber analysis does not distinguish between the various fibrous components of a feedstuff and does not take into account the effect of maturity or type of forage or the effects on degradation and digestion by forage-digesting rumen microbes. In addition, during the analytical procedure for determining crude fiber, various portions of lignin, cellulose, and hemicellulose are dissolved, 50 to 90%, 0 to 50%, and up to 85%, respectively (Van Soest and Robertson, 1979), leading to inaccurate estimates of the true digestibility of a feedstuff.

Acid detergent fiber (ADF) consists of cellulose and lignin. The procedure for ADF was first described by Van Soest (1963). Because hemicellulose is removed during the ADF procedure ADF is only useful in determining the quality of a forage or feedstuff for a ruminant as it provides a measure of digestibility or indigestibility dictated by lignin content.

Unlike ADF, neutral detergent fiber (NDF) is a measure of the entire plant cell wall; cellulose, hemicellulose, and lignin. The procedure for NDF was described by Van Soest and Wine (1967), and estimates a fiber value for ruminants and non-ruminants alike as well as for feedstuffs other than forage. Neutral detergent fiber is closely related to feed intake because it contains all the fiber components that occupy space in the rumen and are slowly digested (Ensminger, et al., 1990). Ruminants require coarse insoluble fiber for normal rumen function, specifically NDF from forages (Van Soest et al., 1991). Total dietary NDF would not necessarily provide an accurate estimation of whether there is adequate NDF from fiber sources to stimulate proper rumen function and promote rumen health in high-concentrate or dairy lactation diets. High-fiber co-products and processed forages contribute to fiber value, but less than long forages (Armentano and Pereira, 1997). Firkins (1997), reported that NDF from non-forage sources are two-thirds as effective as NDF from forage in increasing total tract NDF digestion, and Defoor et. al. (2002) postulated that roughage sources with higher concentrations of NDF might have a higher roughage value.

Effective NDF and Physically Effective NDF

Armentano and Pereira (1997) defined two measures of fiber effectiveness. The first, physically effective NDF, peNDF, being defined by the macrophysical characteristics of long forage sources, measured by animal response attributes, i.e. the effect a forage source would have on chewing time or rumen mat consistency. More simply, Allen (1997) described physically effective fiber as the fraction of feed that stimulates chewing activity. The second measure of fiber effectiveness, per Armentano and Pereira (1997), would be the animal response to forage or non-forage NDF, such as rumen pH, alterations in rumen VFA production, or milk fat concentration. Together, peNDF and animal response would define effective NDF (eNDF).

Physically effective NDF has been studied in lactating dairy rations for its effects on feed intake behavior, ruminal mat formation, rumination and salivation, fermentation characteristics, digesta passage rate, and nutrient intake and absorption (Zebeli et al., 2012). Slater et al. (2000), investigated different concentrations of NDF from forage with portions of the forage NDF being replaced by soyhulls or whole cottonseed to lactating dairy cows compared to a control group comprised of cattle fed an alfalfa silage and corn silage forage-based diet. Time spent eating and ruminating was reported to be highest for the control compared with the treatments with soyhulls or whole cottonseed as a partial forage replacement, even though total dietary NDF was lowest for the forage-based treatment. Firkins (1997) noted that passage rates of non-fiber sources were higher from the rumen of high-producing dairy cows compared with forage. Confounding the increased passage rate is the slower rate of digestion for non-forage sources of NDF compared with digestion rate of forage NDF (Firkins, 1997). The increase in total time spent chewing and ruminating could be expected to lead to a higher ruminal pH. Allen (1997) reported that ruminal pH was positively related to forage NDF. Additionally, in a regression analysis of published literature with varying amounts of reported dietary NDF, Armentano and Pereira (1997), reported that rumen pH was negatively correlated to non-forage NDF. This negative effect on rumen pH in part could be explained by the increase in passage rate and slower digestion rate of non-forage NDF sources. Total dietary NDF may be perceived as adequate to maintain rumen pH, stimulate rumination, and maintain production, however a reduction or lack of peNDF can shift digestion of NDF from the rumen to the hindgut (Firkins, 1997), ultimately reducing the positive effects of forage NDF in the rumen.

The bulk of published research on eNDF is concentrated on lactating dairy animals. Work by Defoor et al., (2002) evaluated different sources and concentrations of forage or non-forage roughage in steam-flaked corn-based diets. They reported that exchanging alfalfa hay or cottonseed hulls on an equal NDF basis resulted in no difference in heifer performance. However, exchanging alfalfa hay or sorghum Sudan silage on an equal NDF retained basis, described as particle size > 2.36 mm, resulted in similar heifer performance. Formulating high-concentrate diets to equal effect of NDF from forage or non-forage roughage sources to provide similar performance in feedlot cattle meets the definition of eNDF postulated by Armentano and Pereira (1997).

Alternatives to Feeding Roughage

Replacing some or all of the roughage in feedlot diets has been studied extensively with varying results. In a review of finishing cattle on all-concentrate rations, Wise et al. (1968) noted that scientists have been investigating diets containing no roughage since as early as 1897. More recently, Turgeon et al. (2010) conducted a series of large pen feedlot trials evaluating whole corn with no roughage compared to either dry-rolled or high-moisture corn diets containing low concentrations of forage or non-forage sources of roughage. Results were mixed within the trials, however, feeding whole corn with no source of roughage tended to reduce final body weight, daily gain, and daily intake. However, gain-to-feed ratio was better for whole corn no roughage diets when compared with more conventional feedlot diets with low concentrations of forage or non-forage sources of roughage. Commercially all concentrate diets, commonly referred to as corn and pellet diets have been utilized over the past 50 years. These types of diets are often utilized by producers without the size and scope for equipment or feedstuff availability, feeding dairy-beef cattle, or operations where finishing cattle is not the main source of income on the farm. As corn grain price has become more volatile over the last decade, utilization of these diets is reviewed for cost-to-benefit as the corn grain market fluctuates. There are challenges associated with feeding all-concentrate diets such as, rumen parakeratosis, liver abscesses, decreased feed intake, founder and bloat (Wise et. al., 1968).

Some of these challenges may well be attributed to the lack of “scratch factor” associated with all-concentrate diets. The scratch factor is perceived to maintain rumen health through physical stimulation of the rumen epithelium by microbial activity from feeding coarse feedstuffs.

Alternative means of providing adequate scratch in the diet have been investigated. Loerch (1991) reported on the efficacy of inserting pot scrubbers orally into the rumen of steers fed all-concentrate diets compared to steers fed either an all-concentrate diet only or steers fed a 15% corn silage diet. There was no difference in daily gain from day 0 to 112 across treatments; however, from day 113 to 167 daily gain for steers fed the all-concentrate diet with pot scrubbers was similar to that of steers fed the 15% corn silage diet. Gain by cattle on both diets was significantly higher than that by steers fed the all-concentrate diet only. Upon dissection, sections of rumen walls from steers fed either corn silage or all-concentrate diet with pot scrubbers were noted to have papillae that were dense and uniform in size, compared to sections of rumen walls of steers fed all-concentrate diets only. In these steers, the papillae were sloughed, clumped, and irregular in size.

Horiguchi and Takahaski (2001), investigated the effectiveness of inserting three artificial mechanical stimulating brushes via rumen fistula in Holstein steers and its effects on rumen digesta kinetics in low-forage diets. The authors reported no difference in dry matter intake, time spent eating, time spent ruminating, total VFA concentrations, or ruminal pH. However, rumen passage rate was significantly higher for steers with the artificial mechanical stimulating brushes compared to steers with no ruminal artificial mechanical stimulating brushes. The lack of difference between the treatment and control diets for rumen parameters could be attributed to the relatively short experimental period

(18 d). In the experiments performed by Loerch (1991), the increased performance from using pot scrubbers was not realized until later in the treatments. This response would indicate that the negative effects of reduced or no roughage in high-concentrate diets manifest over time affecting overall performance, and would not necessarily be elucidated in shorter studies or cattle fed short-term in the feedlot.

Acidosis

Grain overload, founder, overeating, and grain engorgement fall under the general term acidosis that collectively describes digestive disturbances in the rumen and intestines (Owens et al., 1998). A typical acidosis definition would include a decrease in ruminal pH an increase in VFA concentration, and likely a subsequent increase in lactate concentration in the rumen, leading to depression of intake, poor animal performance, and in severe cases, death (May, 2008). Cattle may exhibit variable intake, anorexia, diarrhea, and lethargy (Owens et al., 1998) when dealing with acidosis. Cattle entering the feedlot are most likely to experience acidosis during the receiving phase, transition, or adaptation from roughage-based to concentrate-based diets (Goad et al., 1998; Owens et al., 1998; Brown et al., 2006). During this time, cattle typically experience changes in diet and environment such as adaptation to pen mates or social hierarchy, and water source; all of which can contribute to variable daily feed intake. Reduction in feed intake from excessive grain consumption by cattle not adapted to consuming grain is highly related to average daily ruminal pH from the preceding day (Brown et al. 2000). Other factors such as grain processing, bunk management, variability in mixing or feed delivery, and weather patterns can all lead to variable intake and contribute to the likelihood of cattle experiencing a bout of acidosis. Beyond the challenges of dealing with acute acidosis, perhaps the most concerning would be a pen or group of cattle falling into a repeating cycle of overconsumption followed by a drastic reduction in ruminal pH (Brown et al. 2006) and a subsequent decrease in intake. These changes create a yo-yo effect on intake and negatively affects intake and daily gain throughout the feeding period. Altering roughage concentration, processing grains less thoroughly, the use of ionophores or buffers, and bunk management have been suggested as measures to reduce the incidence of acidosis (Owens et al. 1998). Performance and economic factors associated with greater roughage concentration, reduction in grain processing, and increases in labor costs would need to be considered as well.

Bloat

Bloat is another metabolic disorder associated with increasing concentration of dietary starch, decreasing concentration of roughage and is defined as the accumulation of excess gas within the rumen. Bloat can be classified into two types: free-gas or frothy bloat (Cheng et al. 1998). In both cases, the ability to eruct or dispel gas within the rumen is impaired. An increase in concentration of concentrate was associated with less frequent rumen contractions (Leedle et al. 1995; Brown et al. 2006). Of the two bloat types, 90% of feedlot bloats are classified as frothy bloat (Howarth et al. 1991). However, free-gas bloat is most commonly associated following a case of acidosis (Cheng et al., 1998), likely due to the sudden onset of bloat as a result of slug-feeding of a high-concentrate diet. Dietary roughage concentration, grain processing, proper adaptation period, ionophore use, and bunk management are all factors in preventing bloat in feedlot cattle (Cheng et al., 1998).

Liver Abscesses

High-concentrate, low-roughage diets are known to contribute to the incidence of liver abscesses in feedlot cattle. Brink et al. (1990) reported the incident of liver abscesses to be between 32.1 and 77.7% in feedlot cattle. Liver abscesses reduce feed intake and daily gain and decrease feed efficiency and dressing percentage (Nagaraja and Chengappa, 1998). Unlike acidosis and bloat, which have clinical signs, liver abscess severity can only be diagnosed after slaughter. If the incidence of abscesses is severe enough, the liver can be condemned as well as additional trimming of the carcass around the liver. Nagaraja and Chengappa (1998) published a summary of 10 studies demonstrating that *Fusobacterium necrophorum* and *Actinomyces pyogenes*, respectively are the first and second most common bacteria associated with liver abscesses. Incidence of rumen lesions are predisposing factors for liver abscesses (Jensen et. al., 1954b). Tylosin (Tylan) and chlortetracycline (Aureomycin) are two antibiotics currently approved for use in prevention of liver abscesses. Tylosin is the most common and most effective antibiotic (Nagaraja and Chengappa, 1998); however, both antibiotics now fall under the veterinary feed directive. How this new legislation will alter use of these antibiotics in the United States is yet to be determined. Grain type and processing, roughage concentration and source, breed, and sex have all been reported as factors pre-disposing cattle in the feedlot to liver abscesses (Nagaraja and Chengappa, 1998).

SOURCES AND CONCENTRATIONS OF NDF IN FEEDLOTS

Total dietary NDF in a finishing feedlot diet would be comprised by NDF from the various ingredients in the ration: grain(s), roughage(s), co-products(s), and supplement ingredients. In the U.S., corn is the primary energy source while corn silage, alfalfa hay, (Galyean and Gleghorn, 2001; Vasconcelos and Galyean 2007; Samuelson et al. 2016) and alfalfa silage are considered typical forage sources (Mader et al. 1991). The majority of dietary NDF is derived from a combination of corn, corn silage, and alfalfa hay. Roughage NDF from forage historically was considered the main contributor in maintaining rumen health. The optimal roughage concentration in feedlot diets changes continuously for many reasons, such as source, availability, price, and interaction with other ingredients in the diet (Hales et al. 2014). Defoor et al. (2002), noted physical and chemical characteristics of roughages, such as bulk density and concentrations of fiber, (e.g. NDF), and the effects of roughage on DMI also seem to be associated with differences in ruminal fermentation and digesta kinetics (Galyean and Defoor, 2003). Sourcing a roughage to provide NDF in finishing feedlot diets that is economically advantageous is one opportunity to reduce cost of gains (COG) and increase profits. For these and other reasons roughage sources in the feedlot vary, depending on regional or local factors.

Sources

In a set of two experiments (Moore et al. 1990), investigated three roughage sources, two forage and one non-forage source, and their effects on digestion and passage in steers fed a 65% concentrate diet. Dietary treatments consisted of steam-flaked milo with 1) chopped alfalfa hay, 2) 1:1 cottonseed hulls:alfalfa hay, and 3) 1:1 chopped wheat straw:alfalfa hay. Total dietary NDF was 22.9, 30.3, and 24.2% DM for alfalfa hay, cottonseed hulls:alfalfa, and wheat straw:alfalfa diets, respectively. Feeding the cottonseed hulls:alfalfa diet resulted in higher DMI and passage rate compared with the alfalfa hay diet. The apparent digestion coefficients for DM and NDF were significantly lower for the cottonseed hulls:alfalfa diet compared with the alfalfa hay and wheat straw:alfalfa treatments, likely due to the increased passage rate for the cottonseed hulls diet. Rate of passage competes with rate of digestion for fiber particles and are inversely related (Mertens, 1997). Steers fed the wheat straw:alfalfa diet exhibited greater time spent ruminating compared to the cottonseed hulls:alfalfa and alfalfa diets.

In the second experiment by Moore et al. (1990), three mature cannulated crossbred beef steers were used to investigate the influence of roughage source on *in situ* digestion of DM and NDF. There was no effect of roughage source or NDF concentration on mean ruminal pH. Proportion of total tract DM digestion in the rumen was greatest for the alfalfa hay diet and no difference was noted between the cottonseed hulls:alfalfa and wheat straw:alfalfa diets. However, the proportion of total tract NDF digestion in the rumen was highest in wheat straw:alfalfa diet. The authors speculated that the increase in rumination and rumen retention time, and the slower passage rate of the wheat straw:alfalfa diet led to an increase in ruminal NDF digestion of the steam-flaked milo and alfalfa hay components of the wheat straw:alfalfa diet, resulting in greater total tract NDF digestion. Poore et al. (1990) hypothesized that a lower quality forage may be more dependent on rumination to reach a particle size necessary for passage from the rumen than high-quality forage or grain. During ruminal evacuation, contents of the cottonseed hulls:alfalfa diet were noted to be relatively homogenous compared with distinct layers of stratification in the alfalfa hay and wheat straw:alfalfa diets. Ruminal stratification may help slow rate of passage by trapping feed particles in the rumen mat (Moore et al., 1990) and play a role in rumination (Galyean and Defoor, 2003).

In a series of four feeding trials, Mader et al. (1991) investigated various forage sources: corn silage, alfalfa hay, alfalfa silage, and various corn processing methods: dry whole corn, dry-rolled corn, ground high-moisture corn, and whole high-moisture corn in beef steers. Digestion coefficients were calculated in each trial for starch, NDF, DM, and OM. Feeding alfalfa, silage or hay, improved DMI compared with corn silage when fed with ground high moisture corn. Conversely, cattle fed dry-rolled corn exhibited greater DMI with alfalfa silage, intermediate with corn silage, and poorest with alfalfa hay. Cattle fed dry-rolled corn tended to have greater ADG than those fed ground high-moisture corn with either corn or alfalfa silage. However, feeding alfalfa hay as the forage source resulted in no difference in ADG between dry-rolled corn or ground high-moisture corn. Feed-to-gain ratio was improved (lower) for dry-rolled corn diets compared with ground high-moisture corn for all forage sources. Within ground high-moisture corn treatments, feeding corn silage resulted in superior feed-to-gain ratios compared to alfalfa, silage or hay. Feeding ground high-moisture corn tended to decrease NDF digestibility relative to dry-rolled corn; conversely ground high-moisture corn increased starch digestibility compared to dry-rolled corn. Additionally, corn silage decreased NDF digestibility compared with alfalfa hay, but increased NDF digestibility compared with alfalfa silage in ground high-moisture corn diets.

Cattle fed whole high-moisture corn or whole dry corn exhibited numerically greater DMI with corn silage compared with alfalfa, silage or hay. Dry matter intake was similar in both whole high-moisture corn or whole dry corn treatments fed with either alfalfa silage or hay. Similarly, feeding corn silage with whole high-moisture corn or whole dry corn increased ADG compared with either corn grain source with alfalfa, silage or hay. Alfalfa hay resulted in greater ADG compared with alfalfa silage in dry whole corn diets; however, in whole high-moisture corn diets alfalfa silage improved ADG compared to alfalfa hay. Feed-to-gain ratio was numerically improved in whole dry corn diets feeding alfalfa hay, intermediate with corn silage, and poorest for alfalfa silage. In contrast, cattle fed whole high-moisture corn resulted in a feed-to-gain ratio lowest for alfalfa silage, intermediate for corn silage, and greatest for alfalfa hay. Feeding whole dry corn to cattle increased NDF digestibility in alfalfa silage diets compared with corn silage or alfalfa hay, but there was no reported effect on starch digestibility. Conversely, cattle fed whole high-moisture corn did not exhibit any differences in NDF digestibility across forage sources, but alfalfa hay increased starch digestibility compared to corn or alfalfa silage. The authors concluded an interaction exists between forage source and moisture level of corn grain in finishing diets. In general, feeding whole corn grain with corn silage increased DMI and ADG compared with alfalfa, silage or hay. Interestingly, starch digestibility was greater in whole high-moisture corn diets when fed with alfalfa hay. The increase in performance feeding corn silage compared to alfalfa silage or hay, but increased starch digestibility with alfalfa hay is likely an effect of increased passage rate feeding corn silage. Increased passage rate increases DMI but decreases digestion (Moore et al., 1990). As corn grain processing increased, feeding a source of alfalfa improved DMI compared to corn silage. These results indicate that alfalfa, silage or hay, when fed with rolled dry-corn or ground high-moisture corn may provide benefit in maintaining a more stable rumen pH compared to corn silage. In contrast, in whole corn grain diets, rumen pH may not decrease as rapidly as processed corn grain, resulting in the improvements shown with corn silage compared to alfalfa silage or hay. In diets fed to cattle with fermented corn grain, alfalfa silage generally improved performance compared with alfalfa hay regardless of processing. Conversely, in dry whole corn diets alfalfa hay resulted in greater performance compared to alfalfa silage. These results indicate in dry whole corn diets, alfalfa hay may increase rumination, resulting in greater reduction of the corn kernel through mastication and increased digestibility.

Shain, et al. (1999) investigated whether similar concentrations of forage NDF from wheat straw or alfalfa hay would affect performance or ruminal fermentation. Alfalfa hay or wheat straw, ground through either 0.95-, 7.6-, or 12.7-cm screens, was fed with dry rolled corn at 10 or 5.2% DM, respectively. A diet containing dry rolled corn with no forage served as a negative control. Feeding wheat straw or alfalfa hay, regardless of screen size, led to greater DMI. Cattle fed diets containing alfalfa hay had greater ADG and feed conversion efficiency than those fed wheat straw or no forage. There was no effect of forage process length, or eNDF on DMI, starch intake, ADG, or feed conversion efficiency. However, in a subsequent metabolism trial (Shain et al., 1999) comparing chop length for steers fed alfalfa hay, wheat straw, corn cobs, or no forage, steers fed alfalfa hay ground through a 12.7 cm screen had a tendency to consume more DM than those fed wheat straw ground through a 12.7 cm screen or corn cobs ground through a .95 cm screen. Cattle fed wheat straw diets tended to maintain a higher mean ruminal pH. Wheat straw ground through either a 2.54 or 12.7 cm screen increased rumination time and total chewing time. An increase in rumination time typically leads to greater salivary buffering and a higher pH. Consequently, cattle fed wheat straw diets had higher molar proportions of acetate.

Theurer et al., (1999) evaluated effects of roughage sources and steam-flaked sorghum density on performance and digestion of feedlot cattle. One hundred twenty-six cross-bred steers were fed steam-flaked sorghum diets with alfalfa hay, cottonseed hulls:alfalfa hay, or wheat straw:alfalfa hay. All diets were balanced to supply the same concentration of NDF from roughage (5%). Dry matter intake was greater for cattle fed diets containing cottonseed hulls:alfalfa hay or wheat straw:alfalfa hay; however, there was no roughage source effect on average daily gain. Subsequently, feed efficiency was better for cattle fed diets containing alfalfa hay only. As flake density decreased, NDF intake decreased linearly for cattle fed wheat straw:alfalfa hay and alfalfa hay only. In contrast, NDF intake increased linearly for cattle fed cottonseed hulls:alfalfa hay as flake density decreased. For cattle fed wheat straw:alfalfa hay diets, there was a linear increase in starch digestibility as flake density decreased. However, there was no effect of flake density on NDF digestibility for wheat straw:alfalfa hay or alfalfa hay only diets. Diets with cottonseed hulls:alfalfa hay increased NDF digestibility linearly as flake density decreased. This observation would contrast with Moore et al. (1990), who found NDF digestibility to be the lowest for diets containing cottonseed hulls in steam-flaked milo diets.

Defoor et al. (2002) evaluated the effects of roughage source and NDF concentrations. One hundred-five beef heifers were fed diets with steam-flaked corn containing either alfalfa hay, sorghum Sudan silage, or cottonseed hulls. The control diet contained alfalfa hay at 12.5% DM inclusion. Treatments diets consisted of sorghum Sudan silage or cottonseed hulls fed at one of three inclusions: 1) sorghum Sudan silage or cottonseed hulls fed to heifers to an equal DM inclusion as alfalfa hay (12.5%). 2) sorghum Sudan silage or cottonseed hulls fed to an equal concentration of NDF from roughage as alfalfa hay (5.2%). 3) sorghum Sudan silage or cottonseed hulls fed to an equal percentage retained NDF as alfalfa hay (defined as particles size greater than 2.36 mm). Roughage sources fed to the same percent DM inclusion resulted in heifers exhibiting improvements in DMI, ADG, gain-to-feed ratio, and NE_g intake/kg of $BW^{0.75}$ for diets with cottonseed hulls or sorghum Sudan silage compared with alfalfa hay. Diets fed to equal NDF from roughage resulted in improved performance for heifers fed sorghum Sudan silage, but no difference for heifers fed either cottonseed hulls or alfalfa hay. It was suggested that exchanging cottonseed hulls and alfalfa hay on an equal roughage NDF basis in high-concentrate diets would provide similar performance. Heifers fed diets to equal percentage NDF retained exhibited similar performance for the sorghum Sudan silage and alfalfa hay treatments, but experienced reduced performance in the cottonseed hulls treatment. Authors concluded that exchanging sorghum Sudan silage or alfalfa hay on an equal percentage NDF retained would result in similar performance to cattle fed high-concentrate diets. Results from this study illustrate that benefits of roughage in high-concentrate diets are dependent on roughage quality, particle length, and dietary inclusion to optimize performance.

Concentrations

Cole et. al. (1976), fed four concentrations (0, 7, 14, or 21%) of cottonseed hulls in whole-shelled corn, isonitrogenous diets to determine effects of roughage concentration on digestion in beef steers. Diets were fed at 90% of ad libitum intake. Overall, the authors noted that as concentration of roughage increased, DMI increased linearly. Cellulose intake and digestion were greater as roughage concentration increased. In contrast, total starch intake was similar for cattle fed 0 through 14% cottonseed hulls, but lower for those fed 21% cottonseed hulls. Ruminal starch digestion was greater when cattle were fed 0% roughage but as roughage concentration increased, intestinal starch digestion was greater, thereby offsetting lower ruminal starch digestion in treatments containing cottonseed hulls. Passage rate increased as roughage concentration increased linearly from 0 to 14% and decreased thereafter. Cole et al. (1976) noted that an increase in passage rate was likely a response of greater ruminal motility, which may be reflected by greater rumination time. They also investigated the effects of roughage concentration and two corn processing methods on microbial protein synthesis. In the first trial, treatments were the same as the study previously referenced (Cole et al., 1976): whole shell corn with 0, 7, 14, or 21% cottonseed hulls were fed to ruminal and abomasal cannulated steers. Inclusion rates of 0 or 21% cottonseed hulls with either dry-rolled corn or steam-flaked corn were the focus in the second trial. As previously noted, (Cole et al., 1976) as roughage concentration increased so did DMI. Similarly, as roughage concentration increased, so did nitrogen N intake. Total N passage through the abomasum was greater for the 14 and 21% roughage diets, as well as for dry rolled corn diets. Lower total N passage observed for the no roughage treatment was likely due to lower N intake as well as a decrease in N recycling due to a decrease in saliva flow. Saliva flow was affected by roughage inclusion. Along with a decrease in salivary buffering on the all-concentrate diets, there was likely a subsequent decrease in rumen pH, which could lead to a reduction in fibrolytic bacteria. Fermentable carbohydrates may increase the need for total nitrogen in the form of ammonia and amino acids (Hoover, 1986).

Poore et al. (1990) evaluated effects of increasing grain as steam-flaked sorghum on passage rate and digestion of NDF in ruminally cannulated steers. Diets contained 70, 40, and 10% forage as 50:50 wheat straw and alfalfa hay, respectively. Dry matter intake increased as dietary roughage decreased from 70 to 40% inclusion. As the proportion of steam-flaked sorghum inclusion increased, the potential digestibility of NDF in the diets increased. However, as inclusion of steam-flaked sorghum increased, the proportion of ruminal digestible NDF for wheat straw, alfalfa hay, and steam-flaked sorghum decreased. This observation revealed that as total dietary NDF decreased, as dietary roughage inclusion decreased, digested NDF decreased numerically. This could potentially be the effect of increasing grain concentration on ruminal pH. As inclusion of steam-flaked sorghum increased, ruminal minimum pH decreased linearly, and time spent below a pH of 6.0 increased; this is the pH at which fiber digestion may be impaired (Hoover, 1986). Rare earth markers were used to calculate individual particulate passage rates. Passage rate for alfalfa hay and wheat straw were significantly decreased as roughage inclusion decreased from 40 to 10%, 4.7 to 4.1 and 3.0 to 2.2%/hour, respectively. However, the effect was more pronounced for wheat straw. This led the authors to conclude that increasing concentrate inclusion in the diet may have a greater impact on passage rate of low-quality sources of roughage.

Kreikemeier et al. (1990) evaluated concentrations of a 50:50 blend of corn silage and alfalfa hay in steam-rolled wheat diets. Dietary roughage concentrations were 0, 5, 10, or 15% DM. There was a tendency for DMI to increase linearly as roughage concentration increased. Daily gain, feed-to-gain, and carcass weight responded in a quadratic fashion. Steers fed 5 or 10% roughage exhibited increased daily gain, improved feed-to-gain, and heavier carcass weights compared with the 0 and 15% roughage diets. Both net energy for maintenance (NE_m) and net energy for gain (NE_g) tended to be greater at 5 and 10% roughage inclusion compared with the 0 and 15% roughage diets. In a separate experiment using ruminally cannulated steers, Kreikemeier et al. (1990) studied effects of various concentrations of alfalfa hay and the effects on rumen metabolism in steam-rolled wheat based diets. Treatments contained either 0, 5, or 15% inclusion of alfalfa hay on a DM basis. Steers were fed at either 2x or 3x NE_m. Percent of NDF in ruminal digesta increased linearly as roughage increased in the diets. As roughage level increased, passage rate of alfalfa hay increased. Similarly, a tendency was noted for passage rate of alfalfa hay to increase as DMI increased. Steers fed at 3x NE_m exhibited lower molar proportions of acetate and butyrate and increased molar proportions of propionate. Total VFA concentrations were greater for steers fed 3x NE_m compared with steers fed 2x NE_m. However, there was no effect on ruminal pH for steers fed 3x NE_m compared with steers fed 2x NE_m. The authors speculated this was an effect of increased saliva production, which possibly provided buffering in the rumen.

A combination of sorghum Sudangrass hay and alfalfa hay were fed at 10 or 20% of diet DM to 80 crossbred steers for 56 days by Zinn et al. (1994) in steam-flaked corn based diets. Steers fed the 10% roughage diet exhibited increases in ADG and better feed-to-gain conversions compared with those fed 20% roughage. In this experiment, increasing roughage from 10 to 20% had no effect on daily DMI. In a metabolism trial using the same dietary treatments, increasing roughage concentration from 10 to 20% significantly increased ruminal pH, molar proportions of acetate, and decreased molar proportions of propionate. Increasing roughage concentration also decreased total tract digestion of organic matter and increased total tract digestion of starch.

Loerch and Fluharty (1998) studied effects of varying roughage concentration and timing of roughage inclusion on performance and carcass characteristics. One hundred-eight steers were fed one of four dietary treatments for 186 d, namely: 100% concentrate and 0% roughage for 186 d, 85% concentrate and 15% roughage from corn silage for 186 d, 85% concentrate and 15% roughage from corn silage for 84 d, followed by feeding 100% concentrate for 102 d, or 100% concentrate, no roughage, for 84 d, followed by feeding 85% concentrate and 15% roughage from corn silage for 102 d. During the 84-day growing phase, steers fed the 15% roughage exhibited an increase in daily intake and poorer feed efficiency than steers fed 0% roughage. During the 102-day finishing phase, steers switched from the 0% roughage diet to the 15% roughage diet had greater intakes compared with steers remaining on 0% roughage and those continuously fed 15% roughage diets. Over the entire feeding period steers fed 0% roughage had the greatest gain-to-feed ratio, steers that were switched roughage levels on day 84 had gain-to-feed ratio that was intermediate, and steers fed continually on the 15% roughage diets had the lowest feed-to-gain ratio. There was no effect on overall ADG or quality or yield grades. Incidence of condemned livers were highest for steers fed 0% roughage compared with those fed the 15% roughage diets. Authors hypothesized that an increase in liver abscesses were due to a deficiency of roughage in the finishing phase. Increasing dietary roughage during the feeding period stimulated DMI, but had no effect on daily gains (Loerch and Fluharty, 1998).

Defoor et al. (2002), fed 12 heifers in a 4 x 4 Latin square design with various roughage sources and concentrations. Alfalfa hay, Sudan hay, wheat straw, or cottonseed hulls were fed at 5, 10, or 15% of diet DM basis in steam-flaked corn diets. Intake of NE_g/kg of $BW^{0.75}$ increased as NDF from roughage increased. Intake of NE_g/kg of $BW^{0.75}$ was greater for diets containing cottonseed hulls compared with alfalfa hay. Cattle fed wheat straw and Sudan hay tended to have greater for NE_g intake/kg of $BW^{0.75}$ compared with alfalfa hay, leading the authors to conclude that cottonseed hulls, Sudan hay, and wheat straw have a higher roughage value than alfalfa hay when fed at equal roughage concentrations. This conclusion is supported by those roughage sources having higher NDF 86, 66, 80, vs. 40% respectively. Both cottonseed hulls and wheat straw, containing 86 and 80% NDF respectively, had similar effects on intake of NE_g/kg of $BW^{0.75}$. Within each roughage concentration, NDF from roughage accounted for the majority of variation in NE_g intake/kg of $BW^{0.75}$ among roughage sources.

Galyean and Defoor (2003) published a review on effects of roughage source and concentration on intake of feedlot cattle. In the review a meta-analysis was performed to determine if roughage source and concentration, NDF from roughage, or effective NDF (eNDF) from roughage affected daily intake by feedlot cattle. Eleven trials from 7 studies with a total of 48 treatment means were used in the meta-analysis. Tabular values (NRC 1996) were used to calculate NDF, eNDF, and NE_g from roughage. Roughage concentration, and roughage NDF and eNDF elicited changes in dry matter intake. However, results from their regression analysis revealed that both roughage NDF and eNDF were more highly correlated with DMI than roughage concentration, R^2 of 0.920, 0.931, and 0.699 respectively. They concluded that NDF concentration of roughage should be used instead of dietary roughage concentration when evaluating effects of roughage source or concentration on DMI. Due to the slight improvement on modeling DMI of using roughage eNDF vs. NDF, the authors hypothesized that using roughage eNDF. instead of roughage NDF would not be worthwhile in practice. In high concentrate diets, NDF supplied from roughage accounts for most of the variation in intake caused by roughage source and concentration (Galyean and Defoor, 2003).

ECONOMICS ASSOCIATED WITH ROUGHAGE IN FEEDLOT DIETS

On an energy basis, roughage is considered to be one of the most expensive ingredients (Crawford et al., 2008); given handling requirements of forages complicates inclusion in high-grain diets (Brown et al., 2006). Roughage sources, particularly hay, require additional processing prior to inclusion in feedlot diets. In addition to processing, transportation, storage, loading, labor, losses, storage facilities, interest and maintenance on facilities and equipment (Tyson and Graves, 2012) all contribute to the additional cost of utilizing roughage in feedlot diets.

Storing roughage is accomplished through various methods including bunkers, piles, ag-bags, and silos that are common for fermented feeds, such as corn silage or haylage. In the upper Midwest, all four types of storage are utilized. As the size of the feedlot increases, bunkers and piles are more commonly utilized. Hay sheds, commodity sheds, wrapped bales, and round bales stored outside represent common means of storing dry roughage on a feedlot. At regular intervals, long hay stored in round or squared bales in a hay shed is moved out of storage for processing by a rented or owned hay grinder then re-stored in a commodity shed or outside in a pile. Material losses, also referred colloquially as shrink, occur at various levels during storage and processing of dry or fermented forages. Shrink on chopped alfalfa hay may reach between 10 and 20% or between 5 and 10% for a pile left uncovered or for a 3-sided commodity shed respectively (Kertz, 1998). Losses from corn silage stored in a bunker may reach between 10 and 50% (Loy, 2010). Shrink on round bales wrapped in plastic or stored outside with no protection reached 7.5 to 10% or 20% respectively (Heslop and Bilanski, 1986).

Costs of transportation, storage, shrink and labor, associated with the use of roughage, can be highly variable. In the High and Central Plains regions, feedlots tend to be larger dedicated cattle feeding enterprises. These enterprises may or may not own some or all the acres dedicated to production of grain or roughage ingredients used in feeding cattle; therefore, these ingredients are more likely to be purchased. In the upper Midwest region, feedlots tend to be smaller in size. Generally, some of the acreage owned by the feedlot are dedicated to row crop and hay production; it is this characteristic that led to the term farmer-feeder. This has led to a perception that feeding cattle in the upper Midwest is less expensive than it is in the high plains. Production of grain and forage, the ethanol industry, and feed suppliers are heavily concentrated in the upper Midwest providing feedlot operators with easier access to sources of grain, roughage, and co-products resulting in cheaper costs of gains compared to the Central and High plains. However, some of this advantage is off-set in part by scale of operations in the High and Central Plains, use of steam-flaked grains, weather, and the fact that slaughter facilities relocated to those regions long ago.

There is a perception in the feedlot industry that costs associated with roughage procurement, storage, and processing are high relative to costs associated with other feed ingredients such as grain, particularly if forage feeding is done only to maintain ruminal health. In order to determine the financial burden of purchasing and processing roughage in a feedlot, a comparative cost analysis was performed between the High plains region (Texas and Kansas) and the Upper Midwest region, (eastern Nebraska, Iowa, and Minnesota).

Monthly average reports by USDA for corn grain (yellow #2) and hay (grass and alfalfa, rated fair and good) from January 2001 through June 2017 were obtained from Texas and Kansas (High Plains), Nebraska, Iowa, South Dakota, and Minnesota (Upper Midwest). A simple monthly average for states encompassing each region for corn (Fig. 2) and hay (Fig. 3) was calculated. Corn silage price was derived yearly for both the High Plains and Upper Midwest from reports for corn silage production costs on cash rent by Texas A&M and the University of Minnesota, respectively.

Live steer and heifer slaughter, slaughter weight, and price ($/cwt) were collected from January 2003 thru May 2017 from USDA historical reports. Weighted price and weight averages were determined from reports for states representing each region.

Performance closeout data was provided from a subset of the Benchmark database (Elanco, IN). Closeout data was by region, defined in Benchmark as High Plains (Texas, Oklahoma, and New Mexico), Central Plains (Kansas and Colorado), and Midwest (eastern Nebraska, eastern South Dakota, eastern North Dakota, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, and Ohio) were procured. The High Plains and Central Plains closeout regions were combined into one region: High Plains. Performance response by heifers or steers were kept separate. Days on feed and DMI reported for each group and month were used to define a feeding period for which to apply feed ingredient costs based on pre-defined forage inclusion (see below); values were weighted by number of cattle fed during that time period.

Based on a survey of consultant practices both published (Vasconcelos and Galyean, 2007; Samuelson et al., 2015; High Plains) and unpublished (P. J. Gunn, D. H. Shain, K.

E. Tjardes, C. M. Zehnder, personal communication, September 18, 2017; Upper Midwest), average roughage inclusion (DM basis) for cattle fed was chosen to be 8.6% in the High Plains or 11.5% in the Upper Midwest. Similarly, primary roughage source derived from the surveys for both regions was determined to be alfalfa hay while the secondary roughage source was corn silage. These feeds were fed in an average ratio of 60:40 hay:silage. For determination of amounts and cost of roughage in the feedlot, dry matter selected for hay and corn silage was 85 and 35%, respectively. Costs of grinding per ton were assigned yearly from a published survey (Edwards and Smith, 2007, 2008; Edwards, Smith, and Johanns, 2009; Edwards and Johanns, 2010; Edwards, Johanns, Chamra, 2012; Edwards, 2013; Edwards, Johanns, and Neighbor, 2014; Plastina, Johanns, and Weets, 2015; Plastina, Johanns and Erwin, 2016; Plastina, Johanns, and Wood, 2017; Iowa Farm Custom Rate Survey). Consideration for roughage calculation included an adjustment for corn silage (CS) of 50% (Ladely et al., 1991; Owens et al., 1997).

Based on these data, roughage amount and cost used to finish steers and heifers monthly in each region were calculated. Lastly, roughage cost was divided by total gross return to determine the proportion of gross income dedicated to cover roughage feeding costs. This ratio was determined for steers and heifers in the High Plains and the Upper Midwest from January 2003 to May 2017 (figure 4).

$$\frac{\text{(Total \$ roughage/hd.} = \text{DMI} * \text{DOF} * \text{(Roughage Inclusions \% (\$ Hay*.6 + \$ C.S.*.4))}}{\text{Live Total Gross \$/hd.}}$$

Perception in the feedlot industry would state producers in the Upper Midwest benefit from ease of access to feed inputs, while producers in the Central and High Plains benefit from economies of scale, weather, and packer density, as noted above. Forage or other sources of roughage are included in feedlot diets at low concentrations to optimize performance while maintaining animal health (Galyean and Hubert, 2014). Reducing roughage concentration without negatively impacting performance is viewed as an opportunity to reduce dietary and labor cost, optimize production, improve performance, resulting in increased profitability in the feedlot sector (Loerch, 1991; Bartle et al., 1994; Huntington, 1997; Brown et al., 2006; Turgeon et al., 2010). Present analysis shows that forage inclusion in feedlot diets from January 2002 to June 2017 represents an expense of 0.75 to 2.28% per head. During this period, average input cost to feed forage ($/hd) to a feedlot operator in the Upper Midwest was $18.17 for heifers or $19.04 for steers and the High Plains was $17.02 or $19.13 for heifers or steers, respectively (data not shown). Range of forage expense in the Upper Midwest was $9.02 to $35.65 or $10.51 to $37.28 per hd for heifers or steers, respectively, while the range of forage expense per hd in the High Plains for heifers was $9.88 to $31.50 and $10.05 to $36.44 for steers. Conversely, data from Texas A&M (2001) reported an increase in treatment cost of $44.55/hd per incidence of sickness in the feedlot. Factoring in loss of performance due to illness, healthy cattle returned an additional $151.18 compared with cattle that had to be treated. During this same period, average gross $/hd in the Upper Midwest was $1,363.76 or $1495.43 and in the High Plains was $1,267.47 or $1405.05 for heifers or steers, respectively. For steers, each $10/hd increase in forage expense represented an average increase in cost of 0.71 or 0.67% for High Plains or Upper Midwest, respectively. For heifers, each $10/hd increase in forage expenses represented an average increase in cost of 0.79 or 0.73% for High Plains or Upper Midwest, respectively. Current analysis demonstrates that a reduction in forage concentration may incrementally increase gross return to the feedlot producer. However, the slight increase in gross return would need to be considered against the loss of performance and increased incidence of sickness associated with reduced forage concentration in high-concentrate feedlot diets.

The lower expense for forage in the Upper Midwest region does not equate to a higher gross return and tends to be offset by the higher roughage inclusion level when compared with the High Plains region. Exceptions can be attributed to regional droughts and loss of forage producing acres in the Upper Midwest in the early 2010's as a result of increasing row crop production, creating a more acute increase in forage price. Interestingly, within each region, the ratio of roughage cost $/hd to total gross live $/hd are very similar for steers and heifers. One possible explanation for the similarity is that the decrease in dry matter intake associated with feeding heifers compared to steers is off-set by the reduction in out body weight and the reduced live price that heifers typically receive compared to steers.

SUMMARY

Roughage is utilized in minimal amounts in high-concentrate diets to prevent digestive upsets and improve performance of cattle in feedlots. A meta-analysis by Galyean and Defoor (2003) reviewed the effects of roughage source and concentration on dry matter intake. The authors postulated that exchanging roughage sources to provide a similar NDF concentration from roughage would be more effective. Economics associated with feeding forage between the High Plains and Upper Midwest are surprisingly similar over the course of time. Furthermore, current forage concentrations in high-concentrate diets represent a small percentage of expense to the feedlot operator. As cattle feeding economics shift and forage prices increase relative to return per hd, reducing roughage inclusion will likely be explored as an opportunity to reduce input costs. Based on the economic analysis that has been presented, nutritionists and feedlot operators alike should consider the opportunity costs of reducing roughage concentration. The potential $10/hd savings will not equate to greater profitability if labor and veterinary costs increase and cattle performance suffers as a result of greater incidence of metabolic disorders associated with reduced roughage concentration in feedlot diets.

Figure 1.1. Factors associated with the effects of dietary roughage concentration and sources in beef cattle feedlot diets. A:P acetate:propionate ratio. Adapted from Gaylean and Hubert (2014).

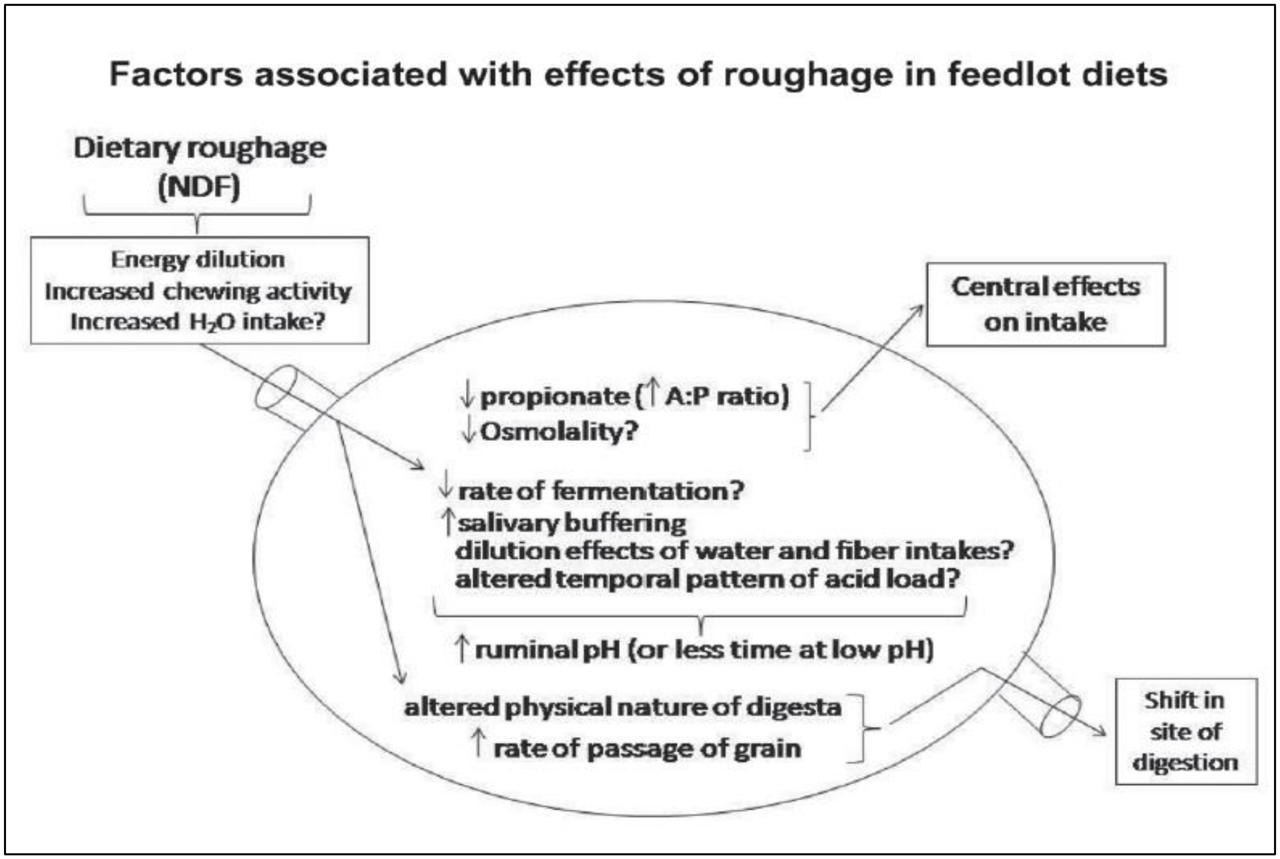


Figure 1.2. The $/ton hay compared to $/bushel corn. High Plains January 2002- June 2017.

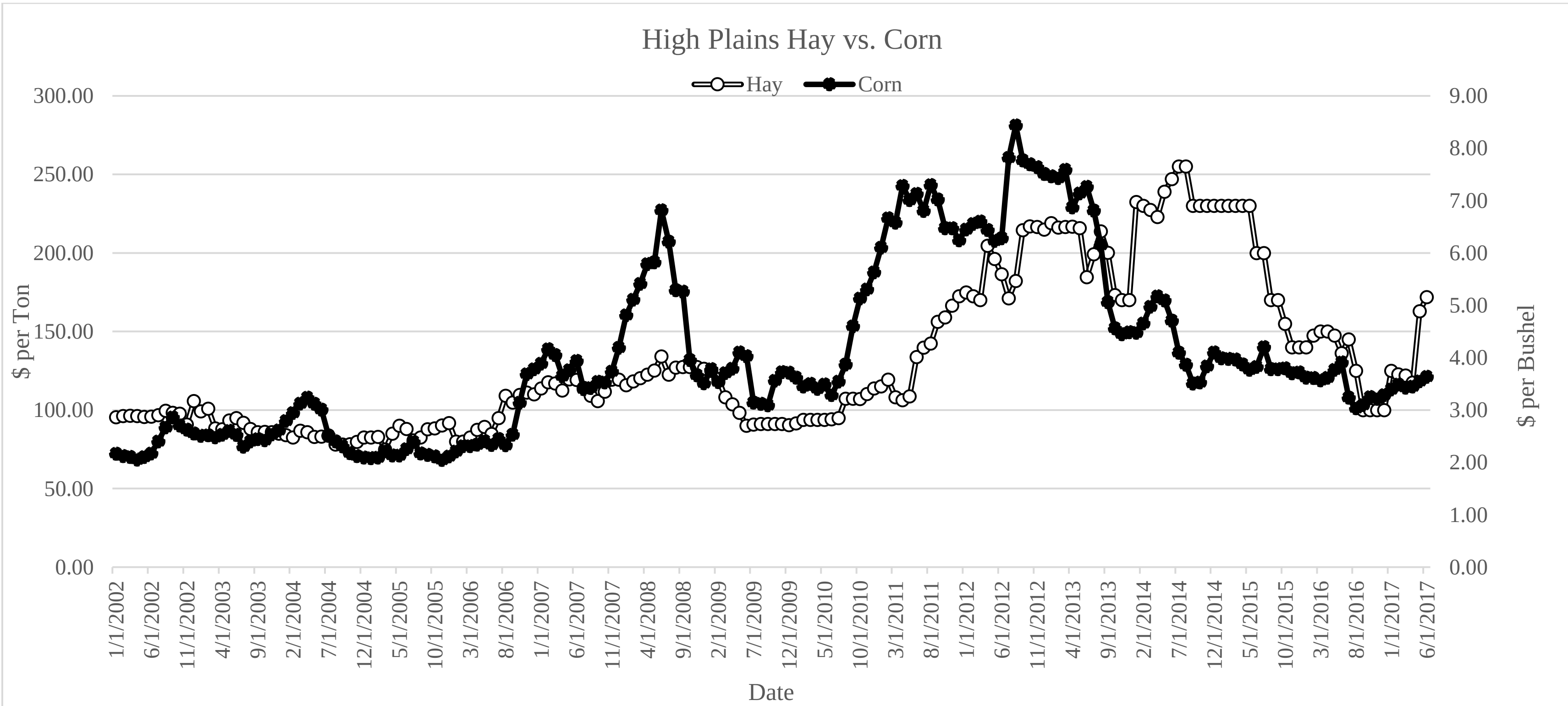


Figure 1.3. The $/ton hay compared to $/bushel corn. Upper Midwest January 2002- June 2017.

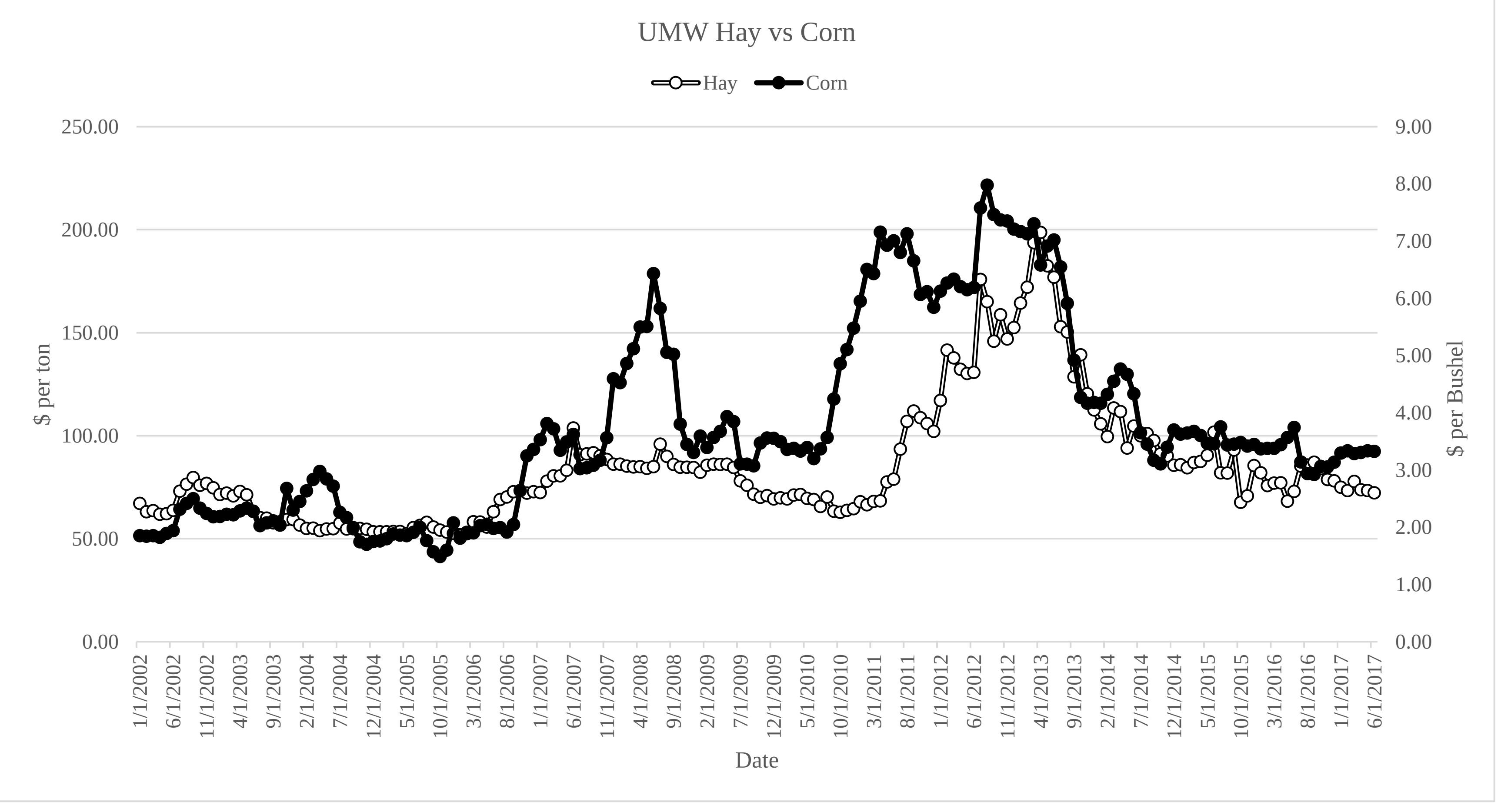
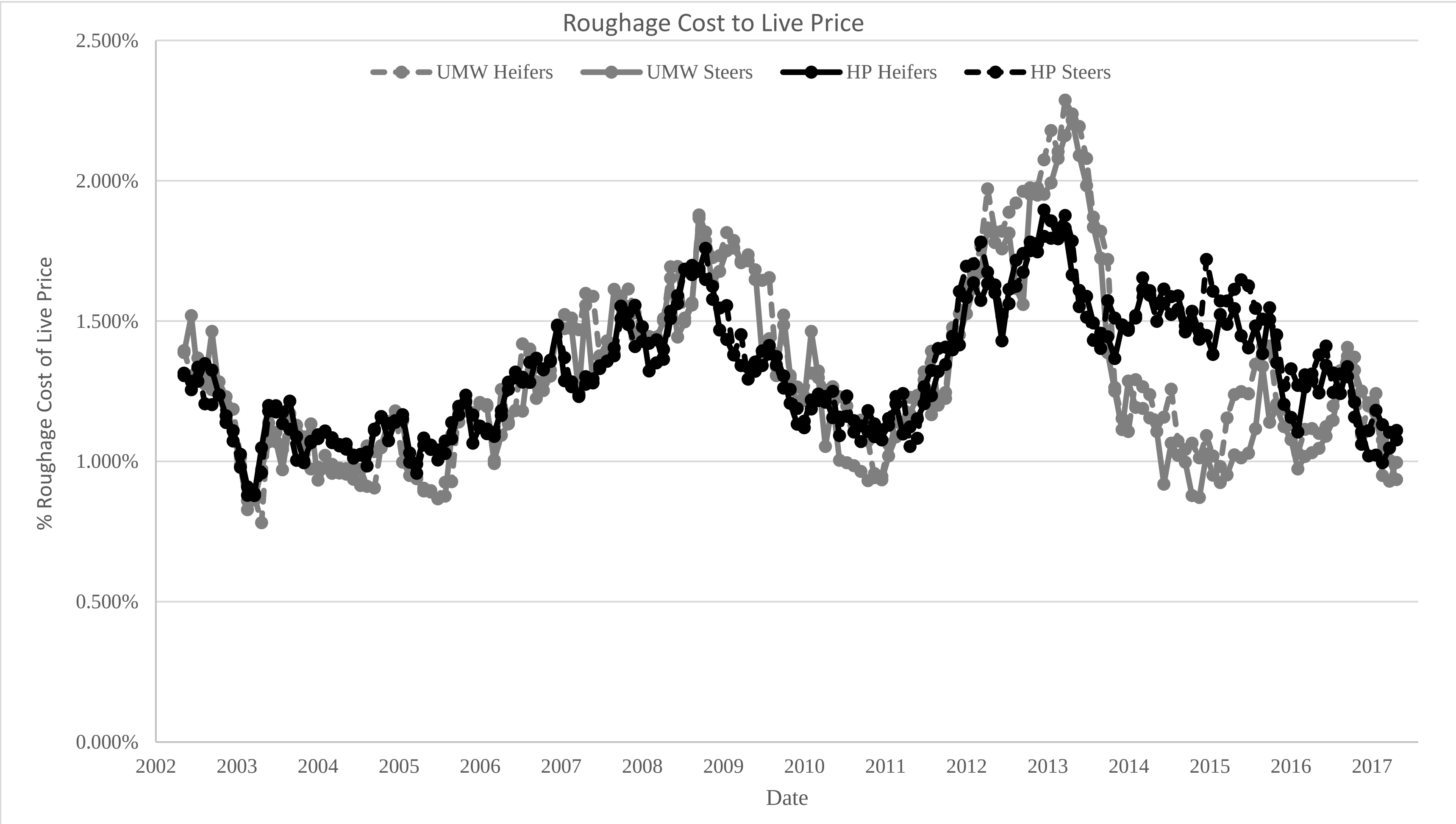


Figure 1.4. The total cost of roughage in a feedlot diet as percent of gross live value of marketed cattle. UMW compared to HP.

UMW=Upper Midwest, HP=High Plains.



META-ANALYSIS: Effects of source and concentration of NDF from roughage on performance and carcass characteristics in finishing feedlot cattle

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Abstract: Roughage in finishing feedlot diets is fed to maintain rumen health, maximize caloric intake from grain, and optimize performance. The objective of this study was to investigate effects of neutral detergent fiber from various diet constituents on performance and carcass characteristics in finishing feedlot cattle. Data from 37 trials published in peer-reviewed and university reports between 2003 and 2015 were used to build a dataset of 205 observations. Criteria for inclusion in the dataset were studies evaluating effects of source or concentration of roughage in finishing cattle trials. Roughage source included alfalfa hay (AH), corn silage (CS), crop residue, grass hays, and cereal silages. Backward elimination procedures were used on mixed models to determine effect of concentration and source of NDF on feedlot and carcass performance. Significant effect ($P < 0.05$) covariates representing use of growth technology (implants and ionophores), sex, days on feed and initial BW were permitted in the model. Average dietary dry matter (DM) inclusion of forage was 12.3%, with a range of 0 to 55%. Co-product NDF (CNDF) contributions of dried distillers grains from corn or sorghum (DDG), wet distillers grains from corn or sorghum (WDG), wet corn gluten feed (WCG), and cottonseed hulls (CSH) were also evaluated. Average DM inclusion of coproducts was 21.9%, with a range from 0 to 65%. Tabular values were used to estimate total dietary NDF (TNDF), FNDF, CNDF, and grain NDF (GNDF). Contributions of TNDF, FNDF, CNDF and GNDF to effects of NDF on dry matter intake (DMI), average daily gain (ADG), final body weight (OutBW), gain to feed (G:F), total metabolizable energy intake (MEI), hot carcass weight (HCW), dressing percent (DP), quality grade (QG), longissimus muscle area (REA), marbling scores (MS), and liver abscesses (LA) were evaluated. Models containing total, co-product and grain NDF concentration and source were less useful (based on reductions in AIC values) in describing the relationship between NDF and performance than forage NDF (FNDF). Concentration of FNDF displayed a trend to affect DMI quadratically ($P = 0.10$) but decreased ADG ($P = 0.02$) and G:F ($P = 0.01$). Dressing percentage tended ($P = 0.10$) to be negatively affected by FNDF but increased QG quadratically ($P < 0.0001$) Feeding greater FNDF concentration was positively correlated to decreasing LA ($P = 0.0003$). Fiber constituents associated with forage NDF were more consistently associated with finishing and carcass performance response than those constituents associated with total NDF.

Keywords: forage, roughage source, roughage concentration, finishing cattle, neutral detergent fiber,

INTRODUCTION

Roughage is used at low concentrations in feedlot finishing diets to prevent digestive upsets and maximize NE_g intake by cattle (Defoor et al., 2002). However, on an energy basis, roughage is one of the most expensive ingredients (Crawford et al., 2008), and source varies depending on regional or local supply and economics. Source, availability, price, and digestive interaction with other ingredients in the diet (Hale et al., 2014) are important considerations in optimizing roughage concentration to maximize performance in finishing cattle diets. Furthermore, Defoor et al. (2002) noted physical and chemical characteristics of roughages, such as bulk density and concentration of fiber (e.g. NDF) impact DMI.

The term roughage is generic and does not accurately describe a particular feedstuff. In feedlot cattle nutrition, an ingredient is assigned a roughage value, an estimate of the effectiveness of the NDF (eNDF) on performance and rumen health. In the literature, the term roughage value has been applied to forages, fibrous by-products such as CSH, corncob (CC), and soybean hulls (SBH), and co-products of the ethanol industries. Since 2003, regional droughts have negatively impacted forage and alternative roughage prices (Galyean and Hubbert, 2014). Additionally, growth of the ethanol industries increased the utilization of co-products used in finishing feedlot diets (Depenbusch et al., 2008). Whether NDF supplied from co-products provides similar ruminal benefit as forage in finishing feedlot diets to warrant replacement of forage is not clear. Non-forage fiber sources have faster passage rates and slower rates of NDF digestion compared with forages (Firkins, 1997), possibly reducing the effectiveness of the supplied NDF on rumen health. More recently, Galyean and Hubbert (2014), summarized that the NDF contributions of WCG and WDG did not justify reducing dietary roughage concentrations.

A previous review investigated the effect of FNDF (Galyean and Defoor, 2003) on DMI. The authors noted that small increases in the concentration of fiber from forage can alter DMI in feedlot cattle and suggested exchanging forage sources on an equivalent NDF concentration basis would eliminate most of the variation in DMI. More recently, Galyean and Hubert (2014) reviewed work by Galyean and Abney (2006) on the effects of TNDF and FNDF on DMI and NE_g intake. They reported that TNDF and FNDF both linearly increased DMI per unit of BW. However, TNDF better accounted for variation in NE_g intake compared to FNDF. The latest published survey of practicing feedlot consulting nutritionists (Samuelson et al. 2015) reported 54% of respondents indicated that NDF was the method of choice for fiber analysis used in formulating feedlot rations. The purpose of this meta-analysis is to investigate the impact of source and concentration of FNDF and the effects on performance parameters and carcass characteristics in finishing feedlot cattle utilizing results from research efforts since the last published review in 2003.

MATERIALS AND METHODS

All data used in the analyses were from previously published literature. No live animals were used in this study; therefore, Animal Care and Use Committee approval was not sought.

Literature Database

Data used in this meta-analysis were obtained from 37 published manuscripts from 2003 to 2015. The manuscripts utilized were compiled from the *Journal of Animal Science* (n = 14), the *Professional Animal Scientist* (n = 1), *Animal Feed and Science Technology* (n = 1), the *Canadian Journal of Animal Science* (n = 2), and various university reports (n = 19). University reports were from North Dakota State University (n = 3), University of Minnesota (n = 1), University of Nebraska (n = 11), Iowa State

University (n = 1), Texas Tech University (n = 1), and Oklahoma State University (n = 2).

Criteria for inclusion in the analysis were studies evaluating effects of diets with differing sources of forage, various concentrations of the same forage source, or combination of various sources and concentrations of forage in finishing cattle studies. Included in the analysis were pen and individual animal studies, primarily consisting of crossbred beef steers and heifers, and 1 study with Holstein steers. The 37 studies represented 205 observations and a total 9,949 head. Reported average in body weight and out body weight were 370 and 586 kg, respectively. Average DM inclusion of roughage in the diets was 12.3%, with a range of 0 to 55%. Average DM inclusion of grain in the diets was 57.6%, with a range of 0 to 87%. Average DM inclusion of co-products was 21.9%, with a range of 0 to 65%. Average days of feed (DOF) was 135, with a minimum and maximum of 85 and 183 DOF, respectively.

Of the 37 studies included, 18 reported total NDF (TNDF), and 6 reported either forage NDF (FNDF) in the diet or NDF of the individual forage sources used in the treatments. Therefore, tabular values (NRC, 1996) were used to calculate TNDF and components of TNDF: FNDF, co-product NDF (CNDF), grain NDF (GNDF). Metabolizable energy of diets (ME), or ME of each ingredient is seldom reported. Therefore, expected metabolizable energy (MEX) was also derived for each dietary treatment reported using tabular values. Concentrations of NDF for common use ingredients were 46, 50, 90 and 46% for corn silage CS, alfalfa hay (AH), cottonseed hulls (CSH), and dried distillers grains and solubles (DDG), respectively. Using tabular values is well accepted for analysis based on published literature when values were not reported by the authors (Firkins, 1997; Galyean and Defoor, 2003; Krehbiel et al., 2006; and Galyean and Tedeschi, 2014); in this study over 50% of the manuscripts did not report NDF concentrations.

Statistical Analysis

Eleven dependent variables were analyzed using PROC MIXED (continuous variables) or PROC GLIMMIX (discrete variables) of SAS version 9.4 (SAS Inst. Inc., Cary, NC). Dry matter intake (DMI), average daily gain (ADG), out body weight (OutBW), gain to feed (G:F), observed metabolizable energy intake (MEI), hot carcass weight (HCW), dressing percentage (DP), ribeye area (REA), and marbling score (MS) were analyzed using PROC MIXED. Quality grade (QG) and incidence of liver abscesses (LA) were analyzed using PROC GLIMMIX.

To account for differences in study conditions, and random variables such as time of year, weather, location, and other unknown factors, manuscripts were classified by state, year of publication (year), lead research group investigator (group), and a class variable reflecting total dietary NDF (NDF level; to represent intent or conditions of the study). The interaction of group x year x NDF level was used as the subject of the random statement. Class variables were created to further condense the data given various sources of grain, forages, and co-products within manuscripts. Three classifications represented concentration of NDF and were defined as forage ID (F-ID): high NDF, low NDF, and none (no forage fed, n = 20 observations). The high NDF classification consisted of grass hays, crop residue, and treated crop residues (n = 64 observations). The low NDF classification consisted of AH, CS, and cereal silage (n =

121 observations). Grain fermentation rate (FERM) originally consisted of 3 classifications; fast, medium and slow. Fast FERM consisted of steam flaked (SF) or high moisture grain HM (n = 86 observations). The medium classification included dry-rolled (DR) or cracked grain (n = 110 observations), and the slow classification included whole grain (WC) (n = 7 observations). Due to low number of observations for this classification, a decision was made to combine the medium and slow classifications into one FERM class, medium. Two observations from one study contained no grain source and were subsequently excluded from analysis. Classifications for co-product ID (CO-ID) were seed hull (n = 156 observations), oil (n = 9 observations), or none (no co-product fed, n = 13 observations). The seed hull classification included 156 observations in total. Over 80% of co-products were corn-based, DDG, modified DDG, wet DDG, or WCG (n = 127 observations).

Additional class variables were sex and additive (ADD). Additive defined use of Rumensin, Tylan or both; no additives (n = 32 observations) and monensin or monensin and tylosin (n = 173 observations). Sex of cattle was primarily steers (n = 149 observations), followed by heifers (n = 28 observations), and mixed sex (n = 2 observations). The mixed sex observations were eventually removed from the analysis because they were so few. Continuous variables included days on feed (DOF), in body-weight (InBW), MEX, TNDF, FNDF, CNDF, and GNDF. Linear and quadratic terms were included in the analysis for each component of NDF. The initial model statement for each dependent variable (X) was as follows:

$$X = \text{Ferm} + \text{component NDF} + \text{component NDF}^2 + \text{Sex} + \text{Add} + \text{InBW} + \text{DOF} + \text{MEX}$$

Both TNDF and FNDF models also included the class variable F-ID, and the CNDF model included CO-ID. Study covariates Sex, ADD, InBW, DOF, and MEX described inherent conditions of the study and were needed to account for effects of these variables on dependent variables when significant; the results of these effects on dependent variables will not be presented as they are not the focus of the review.

Total, forage, co-product, and grain NDF models were evaluated independently and a backward elimination analysis was performed to select the independent variables to be included in the final models for each dependent variable. Means for class variables in the final models were separated by least square means procedures. A *P* value between 0.05 to 0.10 was considered a tendency and a *P* value of 0.05 or less was declared significant.

RESULTS AND DISCUSSION

Dry Matter Intake

One hundred eighty-two observations were included in the final DMI analysis. Results of the final models for DMI are presented in Table 2.1. Increasing FNDF tended to increase DMI linearly ($P < 0.08$) at a decreasing rate ($P = 0.10$). Total NDF did not affect DMI ($P = 0.75$).   Feeding no forage led to lower DMI ($P < 0.03$); however, forage source had no effect on DMI ($P > 0.35$). Krekemeier et al. (1990) reported that increasing concentration of FNDF tended to increase DMI, whereas Zinn et al. (1994) reported no effect of increased FNDF on DMI. Feeding increased concentrations of FNDF from sorghum Sudan silage exhibited a quadratic effect on DMI (Defoor et al., 2002), similar to current results. Contrasting reported effects on DMI as FNDF increases, partially reflects inherent differences of FNDF digestibility from different forage sources and effects on passage rate and rumen fill. Kreikemeier et al. (1990) noted an increase in rumen passage rate as concentration of AH increased in steam-rolled wheat diets fed to steers at 3x maintenance. Defoor et al. (2002) hypothesized that the quadratic effect on DMI was a result of an increase in as-fed bulk density and volume as sorghum Sudan silage concentration increased. Shain et al. (1999) reported increasing DMI in steers fed a DR corn-based diet with AH or wheat straw (WS) compared with an all-concentrate diet and no effect on DMI when comparing AH to WS. Theurer et al., (1999) reported a decrease in DMI to steers fed AH compared with CSH or WS in SF sorghum-based diets. In both studies, diets were formulated to provide similar FNDF concentrations across treatments. In contrast, Mader et al. (1991) noted a decrease in DMI in feedlot steers fed CS compared with alfalfa silage at similar DM inclusion. Lack of statistical significance between low F-ID and high F-ID confirms that concentrations of FNDF accounts for variation in DMI more than forage source in finishing feedlot diets.

Increasing CNDF exhibited a quadratic effect on DMI ($P < 0.04$). Luebbe et al. (2012) reported a linear increase in DMI as corn WDG increased from 0 to 30% DM inclusion. The increasing concentration of corn WDG as it replaced corn grain in the diets led to increased TNDF supplied from increasing corn WDG concentrations. Yang et al. (2012) reported that DMI increased numerically in a quadratic manner as wheat DDG concentration increased from 0 to 35% and concentration of barley silage decreased from 15 to 0%. These authors reported similar TNDF across treatments and linearly decreasing concentrations of peNDF as concentrations of wheat DDG increased and barley silage decreased. The decrease in DMI at a greater concentration of wheat DDG can partly be attributed to decreased peNDF increasing the probability of incidences of ruminal upset due to low rumen pH. Decreasing peNDF decreases rumination and salivary buffering, reducing rumen pH, and decreasing DMI (Allen, 1997). Included in the CNDF model are non-forage fiber by-products such as CSH that in other analysis have been included under the more generic roughage classification (Galyean and Defoor, 2003; Galyean and Abney, 2006). Cottonseed hulls would contribute a greater amount of NDF compared to ethanol co-products contributing to the quadratic response observed in the current analysis. In the current analysis, increases of FNDF had a greater numerical effect on DMI than CNDF.

Fermentation rate of dietary grain decreased DMI 1.13 kg/d ($P < 0.02$). Owens et al. (1997) reported similar decreases in DMI of 1.10 kg/d when cattle were fed SF corn compared with DR. Mader et al. (1991) reported a decrease in DMI of .72 kg/day for steers fed ground HM corn compared with those fed DR corn in diets with CS as the source of forage. Processing grain through mechanical means, fermentation, or adding steam generally increases ruminal and total tract digestibility (Huntington, 1997) and for that reason SF grain is widely used in commercial feedlots (Theurer et al., 1999) even though increasing starch availability and digestibility generally decreases DMI.

Fermentation rate of grain inhibited DMI to a greater extent than FNDF and F-ID. A regression analysis was performed for DMI as a % of BW (data not shown). Dry matter intake increased at a rate equal to 0.0158 for each 1% increase in FNDF concentration. This slope is less than the values of 0.0275 and 0.0199 proposed by Galyean and Defoor, (2003) and Turgeon et al., (2010) respectively, in part due to the quadratic effect reported in the current study. Previous analysis by Galyean and Abney

(2006) reported that FNDF and TNDF linearly related to DMI, whereas we found that increasing FNDF increased DMI linearly at a decreasing rate and TNDF did not have a significant effect on DMI. Analyses performed by Galyean and Defoor (2003) and Galyean and Abney (2006) included CSH as the primary source of roughage in 25% of treatments. Cottonseed hulls increases DMI compared to AH and wheat straw in high concentrate diets (Moore et al., 1990; Bartle et al, 1994; and Theurer et al., 1999). Current analysis included sources of forage exclusively in the FNDF model. The difference in effect on DMI between sources of forage and CSH might explain why previous analysis did not report a quadratic effect of increased FNDF on DMI. This would also explain differences in slope estimates between the current and previous analyses. In the current analysis, maximum forage inclusion was 55% and forage inclusion in diets was 20% or greater in 19% of the observations. Due to physical differences, effects on passage rate, and NDF digestion in the rumen between forages and non-forage fiber sources, cattle fed increasing concentrations of forage would increase DMI until physical fill became a limiting factor. Dry matter intake in cattle fed non-forage fiber sources would increase until limited by chemostatic regulation (Kriehbiel et al., 2006) or acid load (Galyean and Defoor, 2003). Galyean and Abney (2006) reported that both TNDF and FNDF are linearly related and highly correlated to DMI ($r^2 = 0.937$ and 0.92, respectively). The reason for lack of effect of TNDF on DMI compared to previous analysis is not clear. In part, the lack of effect of TNDF may simply be that other factors such as fermentation rate of grain, feeding an ionophore, calves vs. yearlings, exhibit a greater effect on DMI than TNDF in feedlot cattle fed high-concentrate diets. Current data would disagree that using either TNDF or FNDF would yield similar DMI response when formulating feedlot diets as concluded by Galyean and Abney (2006). The current analysis would agree with Galyean and Defoor (2003), that variations in concentration of FNDF and forage sources fed at differing concentrations of FNDF are associated with changes in DMI in feedlot cattle. Formulating diets to provide equivalent concentrations of FNDF from various forage sources would reduce variation in DMI in finishing feedlot diets.

Average Daily Gain

For the ADG models, 182 observations were included and results are presented in Table 2.2. Increasing concentrations of TNDF ($P = 0.002$) and FNDF ($P < 0.03$) linearly reduced ADG by 0.006 kg. Feeding forage led to 0.09 kg greater ADG ($P < 0.02$) compared with no forage, however source of FNDF did not affect ADG ($P = 0.58$). Zinn et al. (1994) reported a decrease in ADG as forage concentration increased from 10 to 20%. The authors reported that an increase in forage concentration decreased molar proportions of propionate and total VFA, and Cole et al. (1976) reported an increase in proportions of propionate for steers fed 0% CSH compared with 7, 14, and 21%. Propionate is the primary VFA utilized for glucose synthesis and ruminal fermentation of starch supplied 44% of glucose to a steer fed a high concentrate diet (Huntington, 1997). A decrease in rumen molar proportions of propionate resulting from an increase in FNDF concentration decreases ME available for ADG. Vance et al. (1972) and Kreikemeier et al. (1990) reported that increasing levels of FNDF increased ADG quadratically in steers fed crimped corn or SF wheat-based diets, respectively. As concentration of FNDF increased ME decreased. Cattle will increase DMI to maintain a constant ME (Kriehbiel et al. 2006) until rumen fill becomes a limiting factor and decreases ME available for

ADG. In agreement with the current analysis, Shain et al. (1999) reported increases in ADG for steers fed AH or WS compared with no forage in DR corn-based diets. In contrast to current findings, steers fed AH exhibited increases in ADG compared with steers fed WS. Steers fed WS increased their starch intake compared with steers fed AH, however the increase in starch intake did not result in an increase in ADG. Theurer et al. (1999) reported steers fed AH, CSH, or WS to equivalent FNDF concentrations in SF sorghum grain-based diets exhibited no difference in ADG. In the current analysis, average FNDF concentrations in low F-ID and high F-ID were 7.4 and 11.3% respectively. The null effect of low F-ID compared to high F-ID could be an indication that the different concentration levels of F-ID in this analysis were not sufficient to effect ADG.

Co-product NDF tended to increase ADG (linear; $P = 0.07$) at a decreasing rate (quadratic; $P = 0.09$). Loza et al. (2010) reported a quadratic effect on ADG as concentration of a 1:1 blend of WCG and corn WDG increased from 0 to 75%. Luebbe et al. (2012) reported a linear increase in ADG as corn WDG concentration increased from 0 to 30%. Yang et al. (2012) reported a numeric quadratic increase in ADG in steers fed increasing concentrations of wheat DDG and decreasing levels of barley silage. Co-product NDF increases passage rate compared with FNDF (Firkins, 1997), increasing DMI and possibly MEI, which would result in greater energy for ADG. The negative quadratic response of increasing CNDF could be a factor of co-product concentration in the diet reaching a level where grain concentration has been decreased to a level where ADG is reduced; similar to the findings of Loza et al. (2010). Alternatively, an increasing CNDF concentration replaces FNDF concentration to a level that no longer maintains optimal rumen function (Galyean and Hubert 2014), decreasing DMI and MEI. Yang et al. (2012) hypothesized that substituting wheat DDG for barley grain and barley silage reduced digestibility and decreased ruminal pH resulting in a decrease in ADG.

Fermentation rate of grain decreased ADG 0.26 kg ($P < 0.001$). Owens et al. (1997) reviewed processing methods of different sources of grains and reported ADG to be greatest for DR, intermediate for SF, and least for HM. Processing grain increases starch availability to microbial attack increasing digestibility (Huntington 1997), increasing ME content (Owens et al. 1997). Gain increases at a decreasing rate as ME concentration increases (Krehbiel et al. 2006). Similar to DMI, fermentation rate of grain exhibited the greatest effect on ADG, which can be attributed to a reduction in DMI with an increase in processing of grain.

Out Body Weight

One hundred eighty-two observations were included in the OutBW analysis. Results of the independent variables evaluated in the final models for OutBW are presented in Table 2.3. Total NDF ($P = 0.94$), FNDF ($P = 0.84$), and forage source ($P > .18$) had no effect on OutBW. Zinn et al. (1994) reported no effect on OutBW as FNDF concentration increased from 10 to 20% in SF corn-based diets. Loerch and Fluharty (1998) reported no effect on OutBW in an all-concentrate diet compared with a HM corn-based diet with 15% CS. Theurer et al. (1999) reported no effect on OutBW in SF sorghum diets with either AH, CSH, or WS as the source of forage. Conversely, Bartle et al. (1994) noted a tendency for OutBW to decrease as a result of greater forage inclusion. However, source of forage (AH) or roughage (CSH) did not affect OutBW in

SF sorghum diets. Turgeon et al. (2010) reported greater OutBW in SF grain-based diets with AH compared to no forage. When feeding a source of forage, the numeric increase in OutBW is a result of an increase in DMI and ADG compared to all-concentrate diets. A review of all-concentrate diets reported an OutBW difference of 20 kg compared with conventional feedlot finishing diets (Wise et al. 1967).

Co-product NDF linearly increased OutBW ($P < 0.04$) at a decreasing rate (quadratic, $P < 0.02$). Loza et al. (2010) reported a similar quadratic increase in OutBW as co-product inclusion increased from 0 to 30% and reduced OutBW from 30 to 60% inclusion. Luebbe et al. (2012) noted a numeric increase for OutBW as corn WDG inclusion increased from 0 to 15% and reduced OutBW as corn WDG inclusion increased from 15 to 30%. In contrast, Vander Pol et al. (2009) reported no effect on OutBW as corn DDG inclusion increased from 0 to 40%, an increasing inclusion of co-products would lead to an increase in CNDF concentration. Whether CNDF reaches a concentration great enough to reduce OutBW or other factors associated with increased inclusion of co-products is debatable. As co-product concentration increases, generally crude protein and dietary fat concentration increase. Gunn et al. (2009) noted that increasing concentrations of DDG increases crude protein and dietary fat, both of which are associated with decreased performance in feedlot cattle. Excess CP is either converted to energy or urea to be excreted in the urine. Increasing dietary fat linearly decreased DMI, ADG, and MEI (Zinn and Plascencia, 2002).

Fermentation rate of grain reduced OutBW 45.5 kg ($P < 0.0001$). The decrease in OutBW reported in the current analysis is greater than results reported by Mader et al. (1990). Those authors reported a reduction in OutBW of 24 kg when feeding ground HM corn compared with DR corn, and NDF digestibility decreased in diets with ground HM corn compared with DR corn. Ruminal pH was not measured, however a decrease in NDF digestibility would be an indicator of a decrease in rumen pH. Fiber digestion is impaired as pH falls below 6.0 (Hoover, 1986). Decreased ruminal pH decreases DMI, resulting in reduced ADG. In practice lower ADG would reduce OutBW in cattle fed to similar DOF or would result in longer DOF to reach desired OutBW.

Gain to Feed

One hundred eighty-two observations were included in the final models to analyze G:F (Table 2.4). An increase in TNDF concentration tended to decrease G:F ($P = 0.08$) and FNDF concentration decreased G:F ($P = 0.01$). Source of forage did not affect G:F ($P > 0.52$), which is the measurement of ADG divided by DMI. In this analysis, the decrease in ADG due to an increase in FNDF concentrations was greater than the increase in DMI. Greater levels of FNDF concentration from AH decreased G:F (Zinn et al., 1994; Felix and Loerch, 2011). Bartle et al. (1994) reported that G:F decreased linearly as forage concentration increased from 10 to 20 to 30% in SF sorghum diets. Defoor et al. (2002) reported no effect on G:F as sorghum Sudan silage inclusion increased from 3.2 to 7.1 to 12.5% while G:F improved for all three dietary inclusions of sorghum Sudan silage compared with AH. Previous work from Bartle et al. (1994) and Shain et al. (1999) showed a response of forage source on G:F; steers fed AH exhibited greater G:F when compared with CSH and WS, respectively. Comparing AH to WS fed at equal FNDF concentrations, steers fed DR corn-based diets with WS exhibited greater starch intake compared with steers fed AH but had poorer ADG and G:F (Shain et al., 1999). Wheat straw decreased total VFA, decreased numeric molar proportion of propionate, increased time spent ruminating, and increased pH numerically compared with AH (Shain et al., 1999). These findings indicate that different forage sources may alter starch utilization within the rumen, as hypothesized by the authors. However, part of the increase in starch intake could be attributed to the dietary inclusion of WS being numerically less than AH, providing equal levels of FNDF and increasing dietary concentrate in the WS diet. Wheat straw may have inhibited starch digestion because of a decrease in forage digestibility compared with AH and resulted in poorer ADG and G:F. Stock et al. (1990) hypothesized that addition of roughage to a diet should reduce G:F, a result of reduced fiber digestion in high concentrate diets. Less digestible sources of forage may further inhibit digestion. However, if acidotic conditions are present, coarser less digestible forages may provide greater benefit in stabilizing rumen pH. Mader et al. (1990) reported that AH improved G:F compared with CS in DR corn diets. In ground HM corn diets, CS improved G:F compared with AH and no difference in G:F in whole corn diets when CS or AH was the forage source. The interaction of forage source with grain source appears to be related to the fermentation rate of grain. In ground HM corn diets, starch is more readily available in the rumen and a more readily fermentable source of forage such as CS may improve starch digestibility provided rumen pH is not drastically reduced. Conversely, with a slower fermented grain source such as DR corn, AH would provide more benefit than CS in reducing rumen passage rate, allowing for an increase and more complete starch digestion. In the current analysis, there were no difference between forages sources (low F-ID vs. high F-ID), not wholly unexpected based on the lack of effect of forage source on DMI or ADG. Interestingly, current analysis found no effect of forage source on G:F compared to all-concentrate diets. All-concentrate diets improve G:F (Wise et al., 1967). However, more recent work has shown conflicting results. Shain et al. (1999) found no effect on G:F in all-concentrate diets compared to diets with AH or WS. Turgeon et al. (2010) reported mixed effects on G:F when replacing forage with whole corn in SF milo or SF wheat based diets. Feeding no forage improved G:F in 2 of the 4 trials. These recent findings indicate as utilization of processed grain sources increases there is a reduction in the benefit of completely removing FNDF in order to increase G:F.

Co-product NDF exhibited a quadratic decrease on DMI and quadratic increase on ADG but did not affect G:F ($P = .28$). Current results agree with previous research (Vander Pol et al., 2009; Luebbe et al., 2012; Yang et al., 2012) that increasing concentration of co-products do not affect G:F. Loza et al. (2010) reported a decrease in G:F at co-product inclusion of 75%. Maximum inclusion level in the current analysis was 65%.

Fermentation rate of grain increased G:F ($P < 0.05$). In general, increases in grain processing improves G:F (Owens et al., 1998). The latest survey of feedlot consultants reported that primary grain sources utilized were SF grain, HM grain, and DR grain 70.8, 16.7, and 12.5% respectively. Despite the elevated risks associated with greater fermentation rate of grain and the resulting decrease in DMI and ADG, responses reflect the value placed on efficiency of gain in commercial cattle feeding.

Metabolizable Energy Intake

One hundred eighty-eight observations were included in the MEI models and results are presented in Table 2.5. Total NDF concentration decreased MEI in a linear fashion (P = 0.007). Forage NDF concentration did not affect MEI (P = 0.14). The difference in effect of TNDF and FNDF on MEI is the opposite of the effect on DMI. Total NDF concentration did not affect DMI, but decreased MEI 0.06 Mcal for every 1% increase in TNDF. Conversely, FNDF increased DMI, and did not subsequently increase MEI. These findings disagree with the hypothesis that small increases in FNDF increase DMI more than expected as a result of energy dilution alone, thereby increasing total MEI, agreeing with results of Krehbiel et al. (2006). Because increases in FNDF concentration dilutes dietary ME, DMI would increase only to a level where MEI is maintained until physical fill becomes limiting and DMI decreases. This concept is illustrated by Hales et al. (2014). Steers were fed ad libitum a DR corn-based diet with 25% corn WDG at 4 levels of AH concentration, 2, 6, 10, or 14% respectively. As AH concentration increased, DMI responded in a numeric quadratic fashion. Increasing AH concentration from 2 to 6% increased DMI and then decreased linearly at 10 and 14%. Metabolizable energy intake was numerically similar between the 2 and 6% AH diets, 25.0 and 24.9 Mcal respectively. As AH concentration increased from 6 to 10 or 14%, MEI decreased to 22.4 and 21.3 Mcal respectively. Findings from the current analysis should only be applied to FNDF concentration and are not necessarily applicable to non-forage fiber sources such as CSH. To the extent that non-forage fiber sources would exhibit similar effects on DMI and MEI in feedlot cattle fed high concentrate diets is not clear (Galyean and Hubert, 2014). Allen (1997) reported FNDF provided a better predictor of time spent chewing than TNDF. Removing FNDF from TNDF, the resulting NDF would include non-forage fiber sources. Similar to DMI, forage source increased MEI. Low NDF forage sources increased MEI 1.65 Mcal and high NDF forage sources increased MEI 1.56 Mcal (*P* < 0.0001) compared with no forage, however MEI between forages sources was not different (*P* = 0.74). Unlike DMI, low NDF forage sources numerically increased MEI compared with high NDF forage sources. The numeric increase in MEI from low NDF compared with high NDF forage source suggests that less digestible sources of forage may alter digestion of starch in high concentrate diets as fermentation rate increases as previously discussed in the gain to feed subsection of this manuscript.

Co-product NDF concentration tended to increase MEI linearly (*P* = 0.06) at a decreasing rate (*P* < 0.04). Vander Pol et al. (2009) reported numeric increases in observed diet NE_g at greater dietary concentrations of corn WDG across DMI, increasing total NE_g intake. Yang et al. (2012) reported a linear increase of observed NE_g as concentration of wheat DDG increased. When DMI differences were accounted for, total NE_g responded quadratically to elevated concentrations of wheat DDG. Distillers grains are highly digestible and contain greater concentrations of NDF than grains (Klopfenstein, 1996). Greater dietary co-product concentrations would increase TNDF compared with grain, decrease total starch intake, and possibly decrease rumen acid load. However, distillers grains are acidic in nature and could contribute to low rumen pH (Walter et al., 2012). In addition, the role of fiber from co-products for feedlot cattle is not well defined (Galyean and Hubert, 2014). It is unclear whether increases in DMI, ADG, OutBW, and MEI observed in the current study are a direct effect of an increase in CNDF.

Similar to other performance parameters, increases in fermentation rate of grain exhibited the greatest effect compared with other independent variables, decreasing MEI

4.5 Mcal (*P* < .0001). The negative effect of rate of fermentation on MEI is a result of reduced DMI, although percent decrease is numerically higher for MEI than DMI at 13.4 and 12.8% respectively. Krehbiel et al. (2006) reported that DMI decreased as ME concentration of diet increased. Owens et al. (1997) noted SF and HM grain increased observed ME concentration compared to DR grain.

Hot Carcass Weight

One hundred eighty-two observations were used to analyze HCW (Table 2.6). Total NDF reduced HCW (*P* < 0.02). Each 1% increase in TNDF decreased HCW 0.50 kg. Forage NDF concentration (*P* = 0.26) and source (F-ID, *P* > 0.10) did not affect HCW. Feeding a source of forage numerically improved HCW compared with feeding no forage, at 14.7 and 12.3 kg, respectively. An increase in concentration of TNDF decreased dietary ME concentration resulting in less energy for gain. The effect of reduced ME concentration is incrementally greater for HCW than OutBW on a % basis, and would explain why TNDF affected HCW and not OutBW. Bartle et al. (1994) and Theurer et al. (1999) reported no effect of forage source on HCW. Similarly, Loerch and Fluharty (1998) reported no effect of FNDF concentration on HCW. Recent work reported that HCW improved as alfalfa haylage inclusion increased (Felix and Loerch, 2011), which the authors attributed to greater OutBW because of alfalfa haylage inclusion, in contrast to findings in this study.

Co-product NDF concentration increased HCW 2.75 kg (linear *P* < 0.010) at a decreasing rate (quadratic *P* < 0.001). Similar to current results, Loza et al. (2010) reported a quadratic effect on HCW in steers fed increasing concentrations of co-product.

Luebbe et al. (2012) reported that an increase in concentrations of corn WDG improved HCW linearly in steers fed in the winter but did not impact HCW in steers fed in the summer. Conversely, two separate experiments by Vander Pol et al. (2009) found no difference in HCW feeding 0, 20, or 40% corn WDG to steers or heifers, respectively. Depenbusch et al. (2008) reported a decrease in HCW in heifers fed 25.5% corn WDG compared with negative control in SF corn diets. Conflicting results could be due to the inherent variability of co-products from ethanol production between production facilities (Gunn et al., 2009) and is similar to the variability not only from different production facilities but between deliveries from the same facility in a commercial setting.

Fermentation rate of grain reduced HCW ($P < 0.01$). Huck et al. (1998) and LaBrune et al. (2008) reported greater HCW as fermentation rate of grain increased. Conversely, Leibovich et al. (2009) found no effect on HCW feeding DR corn compared to SF corn, and Theurer et al. (1999) reported reducing flake density of SF sorghum numerically reduced HCW. Studies exhibiting increased HCW also reported increased ADG and OutBW. In this analysis, faster fermentation rates of grain reduced DMI, ADG, OutBW, MEI, eliciting a reduction in HCW.

Dressing Percentage

One hundred eighty-four observations were used in the DP analysis and results are presented in Table 2.7. Total NDF concentration decreased DP ($P < 0.03$). There were no effects of FNDF concentration ($P = 0.15$) or forage source on DP (F-ID, $P > 0.10$). Kreikemeier et al. (1990) and Bartle et al. (1994) reported no effect of DP as forage concentration increased. Recent work by Felix and Loerch (2011) reported greater

DP in steers fed 10% haylage compared with the control. Theurer et al. (1999) reported no effect on DP when feeding AH, CSH, or WS. In the current study greater concentration of TNDF did not affect OutBW but reduced HCW leading to a reduction in DP as TNDF concentration increased.

Co-product NDF increased DP (linearly, $P < 0.01$) at a decreasing rate (quadratic, $P < 0.04$). Beliveau and McKinnon (2008) reported a tendency for DP to respond in a quadratic manner as concentration of wheat DDG increased. In disagreement with current findings, Loza et al. (2010) and Yang et al. (2012) reported no effect on DP as co-product concentrations increased. Additionally, Depenbusch et al. (2008) and Leibovich et al. (2009) reported a decrease in DP as a result of feeding corn WDG or sorghum WDG, compared with no co-product, respectively. In the current analysis, concentration of co-products increased HCW increased 2x compared to OutBW, resulting in increased DP.

Fermentation rate of grain did not affect DP ($P > 0.10$), consistent with results of Leibovich et al. (2009). Reduction in OutBW and HCW from fermentation rate of grain were 7.4 and 6.3%, respectively. These results indicate the percent reduction as a result of fermentation rate of grain were similar resulting in no effect on DP.

Quality Grade

Ninety-nine observations were used to analyze QG and results are presented in Table 2.8. Both TNDF and FNDF concentration improved QG (linear, $P < 0.0001$) at a decreasing rate (quadratic, $P < 0.0001$). Low NDF forage sources improved QG ($P = 0.001$), however high NDF forage sources had no effect on QG ($P > 0.10$) while grain

NDF concentration improved QG ($P < 0.0001$). Similar to current findings, Kreikemeier et al. (1990) and Bartle et al. (1994) reported increasing forage concentration exhibited a quadratic effect on QG. Theuer et al. (1999) found no improvement on QG feeding AH, CSH, or WS. Moore et al. (1990) found that AH improved total tract digestion compared with WS and CSH. Shain et al. (1999) reported a greater concentrate intake in steers fed WS but poorer performance and steers fed AH exhibited an improvement in concentrate efficiency. Results demonstrate that more digestible sources of forage and minimal increases in concentration of FNDF and TNDF improve digestion of high concentrate diets, improving performance, and ostensibly improving QG. Defoor et al. (2002) noted that NE_g intake was positively related to minimal FNDF concentrations.

Concentration of co-product reduced QG ($P = 0.006$) with a tendency for a quadratic effect ($P = 0.07$). Feeding no source of co-product ($P = 0.004$) or oil-based co-products ($P < 0.04$) reduced QG. Loza et al. (2010) reported that increases in concentration of co-products improved QG quadratically. Depenbusch et al. (2008) reported poorer QG in cattle fed corn WDG. In contrast to current results, Gunn et al. (2009) reported that cattle fed no co-product exhibited an improvement in QG compared with diets with corn DDG, vegetable oil, or corn gluten meal. The authors hypothesized that the decrease in QG was in part related to elevated dietary fat and CP concentrations when feeding co-products. Inhibited ruminal starch digestion from elevated levels of fat and reduced efficiency from excess protein resulted in the decrease in performance.

Fermentation rate of grain exhibited a slight tendency to increase QG in the FNDF model only ($P = 0.10$) but was not significant in the other three models ($P > 0.10$). When the dependent variable FERM was added back to the TNDF, CNDF, and GNDF models, estimates of the slopes were highly variable and non-significant, 0.0273 (P = 0.67), -0.00849 (P = 0.9), and 0.03369 (P = 0.6), respectively. Leibovich et al. (2009) reported that steers fed DR corn diets numerically improved QG compared with SF corn. Stock et al. (1990) reported no effect on quality grade in 3 separate trials feeding HM corn compared to DR sorghum, different ratios of DR corn:sorghum, or DR corn compared to DR wheat, respectively. Huck et al. (1998) fed equal concentrations of DR corn, HM corn, SF corn, or SF sorghum to steers and found no effect on QG. Owens and Gardner (2000) reported that SF grain decreased QG compared with DR or HM grain, and concluded heavier InBW and higher protein concentrate were the two biggest factors associated with QG. The contradicting result of fermentation rate between models in the current analysis and previous research is not clear. These results indicate that increases in fermentation rate of grain may compensate for dilution of dietary ME concentration and increases in ruminal passage rate as forage concentration increases.

Longissimus Muscle Area

Total observations for the REA analysis were 177 and results are presented in table 2.9. Total NDF and FNDF concentration, forage source, and fermentation rate of grain did not affect REA ($P > 0.10$). Results from the current study for FNDF concentration and forage source agree with previous research. Bartle et al. (1994) and Theurer el al. (1999) reported that forage source and concentration did not affect REA. Conversely, Felix and Loerch (2011) reported that an increase in forage concentration improved REA as a result of greater HCW. In the current study, source or concentration of forage did not affect HCW. In a review by Krehbiel et al. (2006) with 69 trials representing 8,251 cattle, they found that dietary ME did not affect REA. Similarly, higher ME from increased fermentation rate of grain did not affect REA in the current study (P > 0.10).

Co-product NDF improved REA (linearly, $P < 0.02$) at a decreasing rate (quadratically, $P < 0.05$). Leibovich et al. (2009) reported a tendency for increasing concentrations of sorghum WDG to reduce REA. Conversely co-product source and concentration did not affect REA (Loza et al., 2010; Luebbe et al., 2012; Yang et al., 2012). Owens and Gardner (2000) reported that REA was related to dietary fat concentrations of 2 to 4%. LaBrune et al. (2008) found dietary inclusion of 4% tallow in SF or DR corn diets increased REA. Conversely, Vander Pol et al. (2009) found that increasing concentrations of tallow had no effect on REA. Gunn et al. (2009) reported no effect on REA feeding dietary concentrations of ether extract above 9% from vegetable oil or corn DDG. Zinn and Plascencia (2002) reported a dietary fat concentration above 6% reduced ADG and MEI. The lack of effect on REA reported by Gunn et al. (2009) suggests that increasing lipids from co-products in part compensated for the decrease in ruminal starch digestion associated with elevated dietary fat concentrations.

Marbling Score

One hundred and sixty observations were included in the MS analysis for TNDF, FNDF, and GNDF. One hundred and fifty-eight observations were used in the CNDF analysis. The class variable FERM was retained in the CNDF model, reducing the number of observations as a result of 2 observations feeding no source of grain. Results for MS are presented in Table 2.10. Total NDF concentration reduced MS ($P < 0.03$) and FNDF concentration ($P = 0.08$) tended to decrease MS. There was an effect of source of forage on MS (*P* < 0.04), high F-ID reduced MS compared with low F-ID. Previous work found no effect on MS from forage source or concentration (Kreikemeier et al., 1990; Theurer et al., 1999; Felix and Loerch, 2009). In agreement with current findings, Bartle et al. (1994) reported AH improved MS compared with CSH. High concentrate levels increase MS (Owen and Gardner, 2000). Minimal concentrations of AH and CS increase concentrate intake and improve total tract starch digestibility (Stock et al., 1990). Alfalfa hay increases molar proportions of propionate compared with WS (Shain et al., 1999). Greater concentrate intake, improved total tract digestibility, and increased molar proportions of propionate associated with minimal concentrations of low NDF forages found in previous studies, may contribute to improvement of MS found in the current study.

Co-product NDF concentration (*P* < 0.05) and fermentation rate of grain (*P* < 0.05) reduced MS. Similar to current data, Owens and Gardner (2000) reported that SF grain reduced MS compared with HM and DR grain. Reduction in MS resulting from fermentation rate may be attributed to lower rumen pH, increased incidence of ruminal upset, and reduced MEI. LaBrune et al. (2008) reported that an increase in tallow supplementation improved MS. Owen and Gardner (2000) reported that elevated levels of dietary protein improved MS. Conversely, Gunn et al. (2009) reported a reduction in MS as dietary fat and protein increased. In the current study, increased concentration of co-products reduced MS, in agreement with Gunn et al. (2009), possibly as a result of an increase in dietary protein and fat reducing efficiency of ruminal starch digestion.

Liver Abscesses

Seventy-three observations were used to analyze LA and results are presented in Table 2.11. Total NDF concentration increased incidence of LA (linear, $P < 0.0001$) at a decreasing rate (quadratic, $P < 0.0001$). Forage NDF concentration and low NDF forage sources decreased LA ($P < 0.001$). Grain NDF concentration decreased severity of LA ($P < 0.00001$) at an increased rate (quadratic, $P = 0.003$). Liver abscesses are a secondary infection as a result of an infection in the ruminal wall (Nagaraja and Chengappa, 1998). Forage NDF concentration increased salivary buffering, resulting in greater rumen pH, and improved DMI (Galyean and Hubert, 2014). Dry matter intake is positively correlated to an increase in water intake (NRC, 1996). Low NDF forage sources increase passage rate compared with high NDF sources potentially diluting ruminal acid load thereby reducing the incidence rumen wall insult.

Co-product NDF concentration reduced incidence of LA ($P < 0.05$) while fermentation rate of grain increased incidents of LA ($P < 0.01$). Feeding no source of co-product tended to reduce incidence of LA ($P = 0.07$). Mader et al. (1991) and Huck et al. (1998) reported fermentation rate of grain did not increase severity of LA. Nagaraja and Chengappa, (1998) reported grains that are rapidly fermented in the rumen increase the incidence of LA. Liver abscesses are associated with decreases in DMI, ADG, HCW, and QG. In this study, fermentation rate of grain reduced HCW, REA, QG, MS and all evaluated performance parameters except G:F. Negative effects on performance and carcass characteristics may be attributed to an increase in rumen upset associated with fast fermentable grain sources and greater incidence and severity of LA. Leibovich et al. (2009) reported feeding sorghum WDGs increased incidence of LA. Depenbusch et al. (2008) reported no increase in severity of LA when feeding corn WDG in SF corn diets.

In this study, greater CNDF concentration decreased incident of LA. As CNDF concentrations increase and subsequently reduce dietary starch concentration, fiber digestion may increase as a result of higher ruminal pH, helping to reduce the negative effects associated with higher starch diets (Gaylean and Hubert, 2014).

Conclusions

This analysis evaluated total NDF and the individual contributions from grain, forage, and co-product on the effects of feedlot and carcass performance in finishing cattle diets. Feeding a minimal concentration of forage is superior to all-concentrate diets due to improvements in dry matter intake, average daily gain, ME intake, hot carcass weight, quality grade, and decreased incidence of liver abscesses. Forage NDF concentration increased DMI quadratically but did not affect MEI, implying that increases in forage concentration will increase DMI as a result of dilution of ME to maintain a constant MEI until gut fill becomes limiting. Neutral detergent fiber from co-products quadratically decreased dry matter intake and exhibited a quadratic increase on average daily gain, final weight, ME intake, hot carcass weight, and dressing percent, suggesting diminishing improvement as co-product inclusion increases. Neutral detergent fiber concentrations from forage is a more accurate predictor of effects on performance than total NDF in finishing feedlot diets. Fermentation rate of grain should be an additional consideration when evaluating forage sources for inclusion in high-concentrate diets. Interactions of dietary forage concentration, forage source, and fermentation rate of grain and impacts on rumen parameters, microbial efficiency, and digestive health to optimize performance in feedlot cattle warrant further research.

Table 2.1. Effect of NDF on dry matter intake

NDF Model	Intercept	NDF Effect		Forage ID			Grain fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF	9.0798	NS	NS	0.6954 *P* = 0.003	0.6403 *P* = 0.001	NS	-1.1758 *P* = 0.017
Forage NDF	8.478	0.0525 *P* = 0.07	-0.0016 *P* = 0.10	0.5824 *P* = 0.013	0.4456 *P* = 0.021	NS	-1.1391 *P* = 0.019
Co-Prod NDF	15.5707	NS	-0.0041 *P* = 0.027				-2.8331 *P* < 0.0001
Grain NDF	10.066	NS	NS				-1.1993 *P* = 0.018

[1]Rate of fermentation in the rumen

Table 2.2. Effect of NDF on average daily gain

NDF Model	Intercept	NDF Effect		Roughage ID			Grain Fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF	2.4903	-0.0057 $P = 0.002$		0.0939 $P = 0.013$	0.0966 $P = 0.001$	NS	-0.2644 $P < 0.0001$
Forage NDF	2.5118	-0.006 $P = 0.025$	NS	0.0985 $P = 0.01$	0.1133 $P = 0.001$	NS	-0.2654 $P < 0.0001$
Co-Prod NDF	1.8141	0.011 $P = 0.07$	-0.0006 $P = 0.09$				-0.1981 $P = 0.001$
Grain NDF	2.6139	NS	NS				-0.2258 $P < 0.0001$

[1]Rate of fermentation in the rumen

Table 2.3. Effect of NDF on out body weight

NDF Model	Intercept	NDF Effect		Forage ID			Grain fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF **Forage NDF** **Grain NDF**	619.99	NS	NS	NS	NS	NS	-46.18 $P < 0.0001$
Co-Prod NDF	614.47	2.2898 $P = 0.032$	-0.1365 $P = 0.018$	NS	NS	NS	-45.51 $P < 0.0001$

[1]Rate of fermentation in the rumen

Table 2.4. Effect of NDF on gain:feed

NDF Model	Intercept	NDF Effect		Forage ID			Grain fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF	0.1843	-0.0004 *P* = 0.08	NS	NS	NS	NS	0.011 *P* = 0.054
Forage NDF	0.1757	-0.0008 *P* = 0.011	NS	NS	NS	NS	0.0097 *P* = 0.09
Co-Prod NDF Grain NDF	0.1831	NS	NS	NS	NS	NS	0.0124 *P* = 0.037

[1]Rate of fermentation in the rumen

Table 2.5. Effect of NDF on metabolizable energy intake

NDF Model	Intercept	NDF Effect		Forage ID			Grain fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF	36.6864	-0.06075 $P = 0.007$	NS	1.5575 $P = 0.001$	1.6542 $P < 0.0001$	NS	-4.9403 $P < 0.0001$
Forage NDF	35.0576	NS	NS	1.4925 $P = 0.001$	1.5334 $P < 0.0001$	NS	-4.5099 $P < 0.0001$
Co-Prod NDF	36.3771	0.1321 $P = 0.06$	-0.0089 $P = 0.034$				-4.6015 $P < 0.0001$
Grain NDF	36.3142	NS	NS				-4.4987 $P < 0.0001$

[1]Rate of fermentation in the rumen

Table 2.6. Effect of NDF on hot carcass weight

NDF Model	Intercept	NDF Effect		Forage ID			Grain
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	fermentation[1]
Total NDF	349.86	-0.5095 $P = 0.016$	NS	NS	NS	NS	-11.51 $P = 0.0016$
Forage NDF **Grain NDF**	379.41	NS	NS	NS	NS	NS	-24.17 $P = 0.001$
Co-Prod NDF	370.17	2.5972 $P = 0.001$	-0.1389 $P = 0.001$	NS	NS	NS	-18.28 $P < 0.0001$

[1]Rate of fermentation in the rumen

Table 2.7. Effect of NDF on dressing percent

NDF Model	Intercept	NDF Effect		Forage ID			Grain fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF	68.08	-0.0345 *P* = 0.029	NS	NS	NS	NS	NS
Forage NDF **Grain NDF**	67.32	NS	NS	NS	NS	NS	NS
Co-Prod NDF	66.95	0.139 *P* = 0.006	-0.0064 *P* = 0.037				NS

[1]Rate of fermentation in the rumen

Table 2.8. Effect of NDF on quality grade

NDF Model	Intercept	NDF Effect		Forage ID		Co-Product ID		Grain fermentation[1]
		Linear	Quadratic	High	Low	Oil	None	
Total NDF	-11.8587	0.1755 *P* < 0.0001	-0.0047 *P* < 0.0001	NS	0.2601 *P* = 0.001			NS
Forage NDF	-12.0782	0.061 *P* < 0.0001	-0.0035 *P* < 0.0001	NS	.1348 *P* = 0.07			0.1090 *P* = 0.10
Co-Prod NDF	-9.842	-0.0633 *P* = 0.006	0.0016 *P* = 0.07			-0.2984 *P* = 0.038	-0.4247 *P* = 0.004	NS
Grain NDF	-11.034	0.1060 *P* < 0.0001						NS

[1]Rate of fermentation in the rumen

Table 2.9. Effect of NDF on longissimus muscle area

NDF Model	Intercept	NDF Effect		Forage ID			Grain fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF **Forage NDF** **Grain NDF**	42.2451	NS	NS	NS	NS	NS	NS
Co-Prod NDF	42.2667	0..4665 *P* = 0.011	-0.0196 *P* = 0.042	NS	NS	NS	NS

[1]Rate of fermentation in the rumen

Table 2.10. Effect of NDF on marbling score

NDF Model	Intercept	NDF Effect		Roughage ID			Grain Fermentation[1]
		Linear	Quadratic	High vs. None	Low vs. None	High vs. Low	
Total NDF	-2.3932	-1.6947 *P* = 0.028	NS	NS	NS	-17.4511 *P* = 0.038	NS
Forage NDF	93.1699	-1.7682 *P* = 0.8		NS	NS	-18.3524 *P* = 0.031	NS
Co-Prod NDF	63.6975	-1.7207 *P* = 0.041	NS				-18.0791 *P* = 0.044
Grain NDF	273.8	NS	NS				NS

[1]Rate of fermentation in the rumen

Table 2.11. Effect of NDF on liver abscesses

NDF Model	Intercept	NDF Effect		Forage ID		Co-Product ID		Grain fermentation[1]
		Linear	Quadratic	High	Low	Oil	None	
Total NDF	3.1698	0.4234 *P* < 0.0001	-0.01 *P* < 0.0001	NS	-0.3979 *P* = 0.004			NS
Forage NDF	-1.2414	-0.0674 *P* = 0.001	NS	NS	NS			0.7654 *P* = 0.002
Co-Prod NDF	-1.6235	-1.7207 *P* = 0.041	NS			NS	-0.2146 *P* = 0.07	0.8642 *P* = 0.001
Grain NDF	0.3205	-0.3228 *P* < 0.0001	0.0095 *P* = 0.003					0.7454 *P* = 0.003

[1]Rate of fermentation in the rumen

REFERENCES

Allen, M. S. 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. J. Dairy Sci. 80:1447-1462.

Anderson, V. L. and B. R. Ilse. 2012. Effect of reciprocal levels of hull-less barley and corn in finishing diets on feedlot performance and carcass characteristics. In: North Dakota Beef Report. Fargo, ND.

Armentano, L. and M. Pereira. 1997. Measuring the effectiveness of fiber by animal response trials. J. Dairy Sci. 80:1416-1425.

Bartle, S. J., R. L. Preston, and M. F. Miller. 1994. Dietary energy source and density: effects of roughage source, roughage equivalent, tallow level, and steer type on feedlot performance and carcass characteristics. J. Anim. Sci. 72:1943-1953.

Beliveau, R. M., and J. J. McKinnon. 2008. Effect of graded levels of wheat-based dried distillers' grains with solubles on performance and carcass characteristics of feedlot steers. Can. J. Anim. Sci. 88:677-684.

Benton, J. R., G. E. Erickson, T. J. Klopfenstein, K. J. Vander Pol, and M. A. Greenquist. 2007. Effects of roughage source and level with the inclusion of wet distillers grains on finishing cattle performance and economics. Beef report, Lincoln: University of Nebraska.

Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrot. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. J. Anim. Sci. 68:1201-1207.

Brown, M. S., C. R. Krehbiel, M. L. Galyean, M. D. Remmenga, J. P. Peters, B. Hibbard, J. Robinson, and W. M. Moseley. 2000. Evaluation of models of acute and subacute acidosis on dry matter intake, ruminal fermentation, blood chemistry, and endocrine profiles of beef steers. J. Anim. Sci. 78:3155-3168.

Brown, M. S., C. H. Ponce, and R. Pulikanti. 2006. Adaptation of beef cattle to high-cocentrate diets: Performance and ruminal metabolism. J. Anim. Sci. 84:(E. Suppl.):E25-E33.

Burken, D. B., B. L. Nuttelman, C. J. Bittner, T. J. Klopfenstein, and G. E. Erickson. 2015. Feeding elevated levels of corn silage and MDGS in finishing diets. Beef report, Lincoln: Univeristy of Nebraska.

Burken, D. B., B. L. Nuttelman, T. J. Klopfenstein, and G. E. Erickson. 2013. Feeding elevated levels of corn silage in finishing diets containing MDGS. Beef report, Lincoln: University of Nebraska.

Burken, D. B., B. L. Nuttelman, T. J. Klopfenstein, and G. E. Erickson. 2014. Feeding elevated levels of corn silage and MDGS in finishing diets. Beef report, Lincoln: University of Nebraska.

Burrin, D. G., and R. A. Britton. 1986. Response to monensin in cattle during subacute acidosis. J. Anim. Sci. 63:888-893.

Carlson, Z. E., T. C. Gilvery, A. Islas, M. L. Bauer, and K. C. Swanson. 2014. Influence of forage source on growth performance, feeding behavior and carcass characteristics in finishing steers. Beef report, Fargo: North Dakota State University.

Chail, A., J. F. Legako, L. R. Pitcher, T. C. Griggs, R. E. Ward, S. Martini, and J. W. MacAdam. 2016. Legume finishing provides beef with positive human dietary fatty acid ratios and consumer preference comparable with grain-finished beef. J. Anim. Sci. 94:2184-2197.

Cheng, K. -J., T. A. McAllister, J. D. Popp, A. N. Hristov, Z. Mir, and H. T. Shin. 1998. A review of bloat in feedlot cattle. J. Anim. Sci. 76:299-308.

Cole, N. A., R. R. Johnson, and F. N. Owens. 1976. Influence of roughage level on the site and extend of digestion of whole shelled corn by beef steers. J. Anim. Sci. 43:483-489.

Cole, N. A., R. R. Johnson, F. N. Owens, and J. R. Males. 1976. Influence of roughage level and corn processing method on microbial protein synthesis by beef steers. J. Anim. Sci. 43:497-503.

Cooper, R., and T. Klopfenstein. 1996 Effect of Rumensin and feed intake variation on ruminal pH. In; Scientific Update on Rumensin/Tylan/Mycotil for the Professional Feedlot Consultant. pp A1-A14. Elanco Animal Health, Indianapolis, IN.

Cranston, J. J., C. R. Krehbiel, L. J. McBeth, and R. A. Ball. 2004. Effects of roughage level and fibrozyme supplementation on performance and carcass characteristics of finishing beef steers. Beef report, Stillwater: Oklahoma State University.

Cranston, J. J., J. D. Rivera, M. L. Galyean, M. M. Brashears, J. C. Brooks, C. E. Markham, L. J. McBeth, and C. R. Krehbiel. 2006. Effects of feeding whole cottonseed products on performance and carcass characteristics of finishing beef cattle. J. Anim. Sci. 84:2186-2199.

Crawford, G. I., C. D. Keeler, J. J. Wagner, C. R. Krehbiel, G. E. Erickson, M. B. Crombie, and G. A. Nunnery. 2008. Effects of calcium magnesium carbonate and roughage level on feedlot performance, ruminal metabolism, and site and extent of digestion in steers fed high-grain diets. J. Anim. Sci. 86:2998-3013.

Daniels, L. B., J. R. Campbell, F. A. Martz, and H. B. Hendrick. 1970. An evaluation of newspaper as feed for ruminants. J. Anim. Sci. 30:593-596.

Defoor, P. J., M. L. Galyean, G. B. Salyer, G. A. Nunnery, and C. H. Parsons. 2002. Effects of roughage source and concentration on intake and performance by finishing heifers. J. Anim. Sci. 80:1395-1404.

DeHaan, K. A., M. T. Van Koevering, and M. L. Gibson. 1995. The effect of age, background, and gender on feed intake by feedlot cattle. Research Report P. Farmland Industries, Inc. 9-22

Depenbusch, B. E., J. S. Drouillard, E. R. Loe, J. J. Higgins, M. E. Corrigan, and M. J. Quinn. 2008. Efficacy of monensin and tylosin in finishing diets based on steam-flaked corn with and without corn wet distillers grains with solubles. J. Anim. Sci. 86:2270-2276.

Depenbusch, B. E., E. R. Loe, J. J. Sindt, N. A. Cole, J. J. Higgins, and J. S. Drouillard. 2009. Optimizing use of distillers grains in finishing diets containing steam-flaked corn. J. Anim. Sci. 87:2644-2652.

Duffield, T. F., J. K. Merrill, and R. N. Bagg. 2012. Meta-analysis of the effects of monensin in beef cattle on feed efficiency, body weight gain, and dry matter intake. J. Anim. Sci. 90:4583-4592.

Edwards, W. 2013. Historic Iowa farm custom rate survey. Ag Decision Maker. A3-12:1-3.

Edwards, W., and Johanns, A. 2010. Iowa farm custom rate survey. Ag Decision Maker. A3-10:1-2.

Edwards, W., Johanns, A., and Chamra, A. 2012. Iowa farm custom survey. Ag Decision Maker. A3-10:1-2.

Edwards, W., Johanns, A., and Neighbor, J. 2014. Iowa farm custom survey. Ag Decision Maker. A3-10b:1-4.

Edwards, W., and Smith, D. 2007. Iowa farm custom survey. Ag Decision Maker. A3-10:1-2.

Edwards, W., and Smith, D. 2008. Iowa farm custom survey. Ag Decision Maker. A3-10:1-2.

Edwards, W., Smith, D., and Johanns, A. 2009. Iowa farm custom survey. Ag Decision Maker. A3-10:1-2.

Elanco. 2003-2017 Sept. An analysis of Elanco's Benchmark database from 2003-2017 Sept. Data filtered to steers and heifers fed in Central Plains, High Plains, and Midwest regions only.

Ensminger, M. E., J. E. Oldfield, and W. W. Heinemann. 1990. Feeds and Nutrition 2nd ed. Ensinger Publishing Company. Clovis, CA.

Farran, T. B., G. E. Erickson, T. J. Klopfenstein, C. N. Macken, and R. U. Lindquist. 2006. Wet corn gluten and alfalfa hay levels in dry-rolled corn finishing diets: Effects on finishing performance and feedlot nitrogen mass balance. J. Anim. Sci. 84:1205-1214.

Felix, T. L., and S. C. Loerch. 2011. Effects of haylage and monensin supplementation on performance, carcass characteristics, and ruminal metabolism of feedlot cattle fed diets containing 60% dried distillers grains. J. Anim. Sci. 89:2614-2623.

Firkins, J. L. 1997. Effects of feeding nonforage fiber sources on site of fiber digestion. J. Dairy Sci. 80:1426-1437.

Galyean, M. L., and C. S. Abney. 2006. Assessing roughage value in diets of high-producing cattle. Pages 127-144 in Proc. Southwest Nutr. Manage Conf. Univ. Arizona, Tucson.

Galyean, M. L., N. DiLorenzo, J. P. McMeniman, and P. J. Defoor. 2011. Alparma beef cattle nutrition symposium: Predictability of feedlot cattle growth performance. J. Anim. Sci. 89:1865-1872.

Galyean, M. L. and J. F. Gleghorn. 2001. Summary of the 2000 Texas Tech University Consulting Nutritionist Survey. Burnett Center Progress Report, Lubbock : Texas Tech.

Galyean, M. L. and M. E. Hubbert. 2014. Review: Traditional and alternative sources of fiber- Roughage values, effectiveness, and levels in starting and finishing diets. Prof. Anim. Sci, 30:571-584.

Galyean, M. L. and L. O. Tedeschi. 2014. Predicting microbial protein synthesis in beef cattle: Relationship to intakes of total digestible nutrients and crude proteins. J. Anim. Sci. 92:5099-5111.

Gibb, D. J., F. N. Owens, P. S. Mir, Z. Mir, M. Ivan, and T. A. McAllister. 2004. Value of sunflower seed in finishing diets of feedlot cattle. J. Anim. Sci. 82:2679-2692.

Gibb, D. J., M. A. Shah, P. S. Mir, and T. A. McAllister. 2005. Effect of full-fat hemp seed on performance and tissue fatty acids of feedlot cattle. Can. J. Anim. Sci. 85:223-230.

Goad, D. W., C. L. Goad, and T. G. Nagaraja. 1998. Ruminal microbial and fermentative changes associated with experimentally induced subacute acidosis in steers. J. Anim. Sci. 76:234-241.

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.

Hales, K. E., T. M. Brown-Brandl, and H. C. Freetly. 2014. Effects of decreased roughage concentrations on energy metabolism and nutrient balance in finishing beef cattle. J. Anim. Sci. 92: 264-271.

Hales, K. E., H. C. Freetly, S. D. Shackelford, and D. A. King. 2013. Effects of roughage concentration in dry-rolled corn-based diets containing wet distillers grains with solubles on performance and carcass characteristics of finishing beef steers. J. Anim. Sci. 91:3315-3321.

Hales, K. E., J. P. McMeniman, J. Leibovich, J. T. Vasconcelos, M. J. Quinn, M. L. May, N. DiLorenzo, D. R. Smith, and M. L. Galyean. 2010. Effects of varying bulk densities of steam-flaked corn and dietary roughage concentration on *in vitro* fermentation, performance, carcass quality, and acid-base balance measurements in finishing steers. J. Anim. Sci. 88:1135-1147.

Hales, K. E., J. E. Wells, E. D. Berry, N. Kalchayanand, J. L. Bono, and M. Kim. 2017. The effect of monensin in diets fed to finishing beef steers and heifers on growth performance and fecal shedding of *Escherichia coli* O157:H7. J. Anim. Sci. 95:3738-3744.

Harding, J. L., C. J. Bittner, D. B. Burken, G. E. Erickson, and J. C. MacDonald. 2015. Effects of replacing corn with a pelleted treated corn stover and distillers grains on performance of finishing cattle. Beef report, Lincoln: University of Nebraska.

Harmon, D. L., R. A. Britton, R. L. Prior, and R. A. Stock. 1985. Net portal absorption of lactate and volatile fatty acids in steers experiencing glucose-induced acidosis or fed a 70% concentrate diet *ad libitum*. J. Anim. Sci. 60:560-569.

Harner, J. P., J. F. Smith, M. J. Brouk, and B. J. Bradford. 2011. Feed Center Design. Western Dairy Management Conference. Reno. 91-102.

Heslop, L. C. and W. K. Bilanski. 1986. Economic benefits of weather protection for large round bales. Can. Agric. Eng. 28:131-135.

Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, H. G. Dolezal, F. K. Ray, V. S. Hays, and C. A. Strasia. 1987. The effect of slaughter date on carcass gain and carcass characteristics of feedlot steers. Oklahoma Agric. Exp. Sta. Res. Rep. MP-119:351.

Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, and C. A. Strasia. 1990. Effects of controlled intake on performance and carcass characteristics of feedlot steers and heifers. J. Anim. Sci. 68:233-244.

Hoover, W. H. 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci. 69:2755-2766.

Horiguchi, K. and T. Takahashi. 2002. Effect of ruminal dosing of mechanical stimulating brusk on rumination time, ruminal passage rate and rumen fermentation status in holstein steers fed a concentrate diet. Anim. Sci. Jour. 73:41-46.

Horn, G. W., J. L. Gordon, E. C. Prigge, and F. N. Owens. 1979. Dietary buffers and ruminal blood parameters of subclinical lactic acidosis in steers. J. Anim. Sci. 48:683-691.

Howarth, R. E., R. K. Chaplin, K.-J. Cheng, B. P. Goplen, J. W. Hall, R. Hironaka, W. Majak, and O. M. Radostits. 1991. Bloat in cattle. Agriculture Canada Publication 1858/E. (Agriculture Canada Publication) 1-32.

Hubbs, P. D. 2010. The origins and consequences of the american feedlot system. Master Thesis, Waco: Baylor University.

Huber, G. M., A. DiCostanzo, and G. I. Crawford. 2012. Interaction of dietary roughage and sulfur concentration on performance of beef feedlot cattle. University of Minnesota Beef Report, Saint Paul: BR-1206.

Huck, G. L., K. K. Kreikemeier, G. L. Kuhl, T. P. Eck, and K. K. Bolsen. 1998. Effects of feeding combinations of steam-flaked grain sorghum and steam-flaked, high-moisture, or dry-rolled corn on growth performance and carcass characteristics in feedlot cattle. J. Anim. Sci. 76:2984-2990.

Huntington, G. B. 1997. Starch Utililzation by Ruminants: From the Basics to the Bunk. J. Anim. Sci. 75:852-867.

Jensen, R., H. M. Deane, L. J. Copper, V. A. Miller, and W. R. Graham. 1954b. The rumenitis-liver abscess complex in beef cattle. Am. J. Vet. Res. 15:202-216.

Johnson, J. M., D. B. Burken, W. A. Griffin, B. L. Nuttelman, G. E. Erickson, T. J. Klopfenstein, M. J. Cecava, and M. J. Rincker. 2013. Effect of feeding greater amounts of calcium oxide treated corn stover and Micro-Aid on performance and nutrient mass balance. Beef report, Lincoln: University of Nebraska.

Kertz, A. F. 1998. Variability in delivery of nutrients to lactating dairy cows. J. Dairy Sci. 81:3075-3084.

Krehbiel, C. R., J. J. Cranston, and M. P. McCurdy. 2006. An upper limit for caloric density of finishing diets. J. Anim. Sci. 84(E. Suppl.):E34-E49.

Krehbiel, C. R., R. A. Stock, D. H. Shain, C. J. Richards, G. A. Ham, R. A. McCoy, T. J. Klopfenstein, R. A. Britton, and R. P. Huffman. 1995. Effect of level and type of fat on subacute acidosis in cattle fed dry-rolled corn finishing diets. J. Anim. Sci. 73:2438-2446.

Kreikemeier, K. K., D. L. Harmon, R. T. Brandt, Jr. 1990. Steam-rolled wheat diets for finishing cattle: Effects of dietary roughage and feed intake on finishing steer performance and ruminal metabolism. J. Anim. Sci. 68:2130-2141.

LaBrune, H. J., C. D. Reinhardt, M. E. Dikeman, and J. S. Drouillard. 2008. Effects of grain processing and dietary lipid source on performance, carcass characteristics, plasma fatty acids, and sensory properties of steaks from finishing cattle. J. Anim. Sci. 86:167-172.

Ladely, S., R. Huffman, F. Goedeken, and R. Stock. 1991. Corn hybrids for finishing cattle. Nebraska Beef Cattle Report, Lincoln: University of Nebraska.

Leedle, J. A. Z., M. L. Coe, and R. A. Frey. 1995. Evaluation of health and ruminal variables during adaptation to grain-based diets in beef cattle. Am. J. Vet. Res. 56:885-892.

Leibovich, J., J. T. Vasconcelos, and M. L. Galyean. 2009. Effects of corn processing method in diets containing sorghum wet distillers grain plus solubles on performance and carcass characteristics of finishing beef cattle and on in vitro fermentation of diets. 2009. J. Anim. Sci. 87:2124-2132.

Loerch, S.C. 1991. Efficacy of plastic pot scrubbers as a replacement for roughage in high-concentrate cattle diets. J. Anim. Sci. 69:2321-2328.

Loerch, S. C. and F. L. Fluharty. 1998. Effects of corn processing, dietary roughage level, and timing of roughage inclusion on performance of feedlot steers. J. Anim. Sci. 76:681-685.

Loy, D. 2010. Feed management- Bunker to bunk. Feedlot Forum Proceedings. Lincoln. 21-25.

Loza, P. L., C. D. Buckner, K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein, and R. A. Stock. Effect of feeding combinations of wet distillers grains and wet corn gluten feed to feedlot cattle. 2010. J. Anim. Sci. 88:1061-1072.

Loza, P. L., K. J. Vanderpohl, G. E. Erickson, T. J. Klopfenstein, and R. A. Stock. 2005. Effect of different corn processing methods and roughage levels in feedlot diets containing wet corn gluten feed. Beef report, Lincoln: University of Nebraska.

Luebbe, M. K., G. E. Erickson, T. J. Klopfenstein, and M. A. Greenquist. 2012. Nutrient mass balance and performance of feedlot cattle fed corn wet distillers grains plus solubles. J. Anim. Sci. 90:296-306.

Mader, T. L., J. M. Dahlquist, and L. D. Schmidt. 1991. Roughage sources in beef cattle finishing diets. J. Anim. Sci. 69:462-471.

Markham, C. E., C. R. Krehbiel, L. O. Burciaga, D. R. Gill, R. E. Peterson, H. A. DePra, and L. J. McBeth. 2002. Effects of roughage and particle size on performance and carcass characteristics of finishing heifers. Beef report, Stillwater: Oklahoma State University.

Maxwell, C. L., B. C. Bernhard, C. F. O'Neill, B. K. Wilson, C. G. Hixon, C. L. Haviland, A. N. Grimes, M. S. Calvo-Lorenzo, D. L. VanOverbeke, G. G. Mafi, C. J. Richards, D. L. Step, B. P. Holland, and C. R. Krehbiel. 2015. The effects of technology use in feedlot production systems on feedlot performance and carcass characteristics. J. Anim. Sci. 93:1340-1349.

May, M. L. 2008. The effects of grain processing method, wet and dry distillers grain's with solubles, and roughage level on performance and carcass characteristics of finishing cattle. Master Thesis, Manhattan: Kansas State University.

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. Dried distillers grains with solubles with reduced corn silage levels in beef finishing diets. J. Anim. Sci. 88:2456-2463.

May, M. L., M. J. Quinn, N. DiLorenzo, D. R. Smith, and M. L. Galyean. 2011. Effects of roughage concentration in steam-flaked corn-based diets containing wet distillers grains with solubles on feedlot cattle performance, carcass characteristics, and in vitro fermentation. J. Anim. Sci. 89:549-559.

McEwen, P. L., I. B. Mandell, G. Brien, and C. P. Campbell. 2007. Effects of grain source, silage level, and slaugher weight endpoint on growth performance, carcass characteristics, and mean quality in Angus and Charolais steers. Can. J. Anim. Sci. 87:167-180.

Mertens, D. R. 1977. Dietary Fiber Components; Relationship to the rate and extent of ruminal digestion. Fed. Proc. 36:187-192.

Moore, J. A., M. H. Poore, and R. S. Swingle. 1990. Influence of roughage source on kinetics of digestion and passage, and on calculated extents of ruminal digestion in beef steers fed 65% concentrate diets. J. Anim. Sci. 68:3412-3420.

Morine, S. J., M. E. Drewnoski and S. L. Hansen. 2014. Increasing dietary neutral detergent fiber concentration decreases ruminal hydrogen suflide concentrations in steers fed high-sulfur diets based on ethanol coproducts. J. Anim. Sci. 92:3035-3041.

Morrow, L. A., T. L. Feliz, F. L. Fluharty, K. M. Daniels, and S. C. Loerch. 2013. Effects of hay supplementation in corn-based and dried distillers grains with solubles-based diets on performance and ruminal metabolism in feedlot cattle. Prof. Anim. Sci. 29:124-132.

Nagaraja, T. G. and M. M. Chengappa. 1998. Liver abscesses in feedlot cattle: A review. J. Anim. Sci. 76:287-298.

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

Owens, F. N. and B. A. Gardner. 2000. A review of the impact of feedlot management and nutrition on carcass measurements of feedlot cattle. J. Anim. Sci. 77(E-Suppl), 1-18.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: A review. J. Anim. Sci. 75:868-879.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: A review. J. Anim. Sci. 76:275-286.

Parsons, C. H., J. T. Vasconcelos, R. S. Swingle, P. J. Defoor, G. A. Nunnery, G. B. Salyer, and M. L. Galyean. 2007. Effects of wet corn gluten and roughage levels on performance, carcass characteristics, and feeding behavior of feedlot cattle. J. Anim. Sci. 85:3079-3089.

Peterson, S. J., B. L. Nuttelman, C. J. Schneider, D. B. Burken, J. C. MacDonald, G. E. Erickson. 2014. Optimum inclusion of alkaline-treated cornstalks and distillers grains fed to calf-fed steers. Beef report, Lincoln: University of Nebraska.

Plastina, A., Johanns, A., and Erwin, J. 2016. Iowa farm custom survey. Ag Decision Maker. A3-10:1-5.

Plastina, A., Johanns, A., and Weets, S. 2015. Iowa farm custom survey. Ag Decision Maker. A3-10:1-2.

Plastina, A., Johanns, A., and Wood, M. 2017. Iowa farm custom survey. Ag Decision Maker. A3-10:1-5.

Poore, M. H., J. A. Moore, and R. S. Swingle. 1990. Differential passage rates and digestion of neutral detergent fiber from grain and forages in 30, 60, 90% concentrate diets fed to steers. J. Anim. Sci. 68:2965-2973.

Pyatt, N. A., L. L. Berger, D. B. Faulkner, P. M. Walker, and S. L. Rodriquez-Zas. 2005. Factors affecting carcass value and profitability in early-weaned Simmental steers: II. Days on feed endpoints and sorting strategies.

Quinn, M. J., M. L. May, N. DiLorenzo, C. H. Ponce, D. R. Smith, S. L. Parr, and M. L. Galyean. 2011. Effects of roughage source and distillers grain concentration on beef cattle finishing performance, carcass characteristics, and *in vitro* fermentation. J. Anim. Sci. 89:2631-2642.

Ray, D. E., W. H. Hale, and J. A. Marchello. 1969. Influence of season, sex, and hormonal growth stimulants on feedlot performance of beef cattle. J. Anim. Sci. 29:490-495

Rivera, J. D., M. 0D. Abney, N. A. Elam, J. F. Gleghorn, J. T. Richeson, J. J. Cranston, and M. L. Galyean. 2003. Effects of supplemental amylase and roughage source on performance and carcass characteristics of finishing beef cattle. Internet Progress Report, Lubbock: Texas Tech University.

Salinas-Chavira, J., E. Alvarez, M. F. Montano, and R. A. Zinn. 2013. Influence of forage NDF level, source and pelletizing on growth performance, dietary energetics, and characteristics of digestive function for feedlot cattle. Anim. Feed Sci. and Tech. 183:106-115.

Samuelson, K. L., M. E. Hubbert, M. L. Galyean, and C. A. LÖest. 2016. Nutritional recommendations of feedlot consulting nutritionists: The 2015 New Mexico State and Texas Tech survey. J. Anim. Sci. 94:2648-2663.

Schoonmaker, J., Trenkle, A. H, and Beitz, D. C. 2009. Effect of feeding ethanol by-products on performance and marbling deposition in steers fed high-concentrate or high-forage diets. Animal Industry Report, Ames: Iowa State University.

Shain, D. H., R. A. Stock, T. J. Klopfenstein, and D. W. Herold. 1999. The effect of forage source and particle size on finishing yearling steer performance and ruminal metabolism. J. Anim. Sci. 77:1082-1092.

Shreck, A. L., B. L. Nuttelman, J. L. Harding, W. A. Griffin, G. E. Erickson, T. J. Klopfenstein, and M. J. Cecava. 2015. Digestibility and performance of steers fed low-quality crop residues treated with calcium oxide to partially replace corn in distillers grains finishing diets. J. Anim. Sci. 93:661-671.

Shreck, A. L., C. J. Schneider, B. L. Nuttelman, D. B. Burken, G. E. Erickson, T. J. Klopfenstein, and M. J. Cecava. 2013. Varying proportions and amounts of distillers grains and alkaline-treated forage as substitutes for corn grain in finishing cattle diets. Beef report, Lincoln: University of Nebraska.

Sindt, J. J., J. S. Drouillard, E. C. Titgemeyer, S. P. Montgomery, C. M. Coetzer, T. B. Farran, J. N. Pike, J. J. Higgins, and R. T. Ethington. 2003. Wet corn gluten feed and alfalfa hay combinations in steam-flaked corn finishing cattle diets. J. Anim. Sci. 81:3121-3129.

Slater, A. L., M. L. Eastridge, J. L. Firkins, and L. J. Bidinger. 2000. Effects of starch source and level of forage neutral detergent fiber on performance of dairy cows. J. Dairy Sci. 83:313-321.

Sorensen, K. S., V. L. Anderson, K. R. Madock-Carlin, C. L. Engel, C. S. Schauer, K. Olsen, and R. J. Maddock. 2013. Effects of dietary forage concentration in finishing diets on growth and carcass characteristics of steers. Beef report, Fargo: North Dakota State University.

Stock, R., and R. Britton. 1993. Acidosis in feedlot cattle. In: C. Parrot. 1993. Secondary benefits from feeding Rumensin. In: Scientific Update on Rumensin/Tylan for the Professional Feedlot Consultant. pp A1-A-13. Elanco Animal Health, Indianapolis, IN.

Stock, R. A., M. H. Sindt, J. C. Parrot, and F. K. Goedeken. 1990. Effect of grain type, roughage level and monensin level on finishing cattle performance. J. Anim. Sci. 68:3441-3455.

Texas A&M. 2017. Extension agricultural economics. Accessed October 11, 2017. https://agecoext.tamu.edu/resources/crop-livestock-budgets/by-commodity/forages/.

Texas A&M. 2001. Texas A&M ranch to rail - north/south summary report. Accessed February 19, 2018. http://aglifesciences.tamu.edu/animalscience/wp-content/uploads/sites/14/2012/04/beef-r2r-20002001.pdf

Theurer, C. B., R. S. Swingle, R. C. Wanderley, R. M. Kattnig, A. Urias, G. Ghenniwa. 1999. Sorghum grain flake density and source of roughage in feedlot cattle diets. J. Anim. Sci. 77:1066-1073.

Turgeon, O. A., J. I. Szasz, W. C. Koers, M. S. Davis, and K. J. Vander Pol. 2010. Manipulating grain processing method and roughage level to improve feed efficiency in feedlot cattle. J. Anim. Sci. 88:284-295.

Tyson, J. T and R. E. Graves. 2012. Bulk Storage- eXtension. Accessed January 6, 2017. articles.extension.org/pages/62758/bulk-storage.

University of Minnesota, 2017. FinBin. Accessed October 10, 2017. https://finbin.umn.edu/CpSummOpts/CpSummIndex.

USDA. 2017. Market news. United States Department of Agriculture Marketing Service. Accessed August 10, 2017. https://marketnews.usda.gov/mnp/ls-report-config.

Uwituze, S., G. L. Parsons, M. K. Shelor, B. E. Depenbusch, K. K. Karges, M. L. Gibson, C. D. Reinhardt, J. J. Higgins, and J. S. Drouillard. 2010. Evalutation of dried distillers grains and roughage source in steam-flaked corn finishing diets. J. Anim. Sci. 88:258-274.

Vance, R. D., R. L. Preston, E. W. Klosterman, and V. R. Cahill. 1972. Utilization of whole shelled and crimped corn grain with varying proportions of corn silage by growing-finishing steers. J. Anim. Sci. 35:598-605.

Vander Pol, K. J., M. K. Luebbe, G. I. Crawford, G. E. Erickson, and T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. 87:639-652.

Van Koevering, M. T., D. R. Gill, F. N. Owens, H. G. Dolexal, and C. A. Strasin. 1995. Effect of time on feed on performance of feedlot steers, carcass characteristics, and tenderness and composition of longissimus muscles. J. Anim. Sci. 73:21-28.

Van Soest, P. J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Assoc. Offic. Anal. Chem. 46:829-835.

Van Soest, P. J. 1964. Symposium on nutrition and forage and pastures: new chemical procedures for evaluating forages. J. Anim. Sci. 23:838-845.

Van Soest, P. J. 1966a. Forage intake in relation to chemical composition and digestibility: Some new concepts. Proc. South. Past. Forage Improvement Conf., Blacksburg, VA.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant 2nd ed. Ithaca: Cornell University Press.

Van Soest, P. J. and J. B. Robertson. 1979. Systems of analysis for evaluating fibrous feeds. Standardazation of analytical methodology for feeds. Ottawa: International Development Research Centre. 49-60.

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.

Van Soest, P. J. and R. H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. J. Assn. Official Anal. Chem. 50:50-55.

Vasconcelos, J. T. and M. L. Galyean. 2007. Nutritional recommendations of feedlot consulting nutritionists: The 2007 Texas Tech University Survey. J. Anim. Sci. 85:2772-2781.

Vogel, G. J., and S. B. Laudert. 1994. The influence of Tylan on liver abscess control and animal performance- A 40 trial summary. J. Anim. Sci. 72(Suppl. 1):293 (Abstr.).

Walter, L. J., T. A. McAllister, W. Z. Yang, K. A. Beauchemin, M. He, and J. J. McKinnon. 2012. Comparison of wheat or corn dried distillers grains with solubles on rumen fermentation and nutrient digestibility by feedlot heifers. J. Anim. Sci. 90:1291-1300.

Walter, L.-A. J., T. J. McEvers, N. D. May, J. A. Reed, J. P. Hutcheson, T. E. Lawrence. 2016. The effect of days on feed and zilpaterol hydrochloride supplementation on feeding behavior and live growth performance of Holstein steers. J. Anim. Sci. 94:2139-2150.

Ware, R. A., and R. A. Zinn. 2005. Effect of pelletizing on the feeding value of rice straw in steam-flaked corn growing-finishing diets for feedlot cattle. Animal Feed Science and Technology. 631-642.

Wise, M. B., R. W. Harvey, B. R. Haskins, and E. R. Barrick. 1968. Finishing beef cattle on all concentrate rations. J. Anim. Sci. 25:1449-1461.

Yang, W. Z., Y. L. Li, T. A. McAllister, J. J. McKinnon, and K. A. Beauchemin. 2012. Wheat distillers grains in feedlot cattle diets; feeding behavior, growth performance, carcass characteristics, and blood metabolites. J. Anim. Sci. 90:1301-1310.

Zebeli, Q., J. R. Aschenbach, M. Tafaj, J. Boguhn, B. N. Ametaj, and W. Drochner. 2012. Invited review: Role of physically effective fiber and estimation of dietary fiber adequancy in high-producing dairy cattle. J. Dairy Sci. 95:1041-1056.

Zinn, R. A., A. Barreras, F. N. Owens, and A. Plascencia. 2008. Performance by feedlot steers and heifers: Daily gain, mature body weight, dry matter intake, and dietary energetics. J. Anim. Sci. 86:2680-2689.

Zinn, R. A., and A. Plascencia. 2002. Influence of level and method of supplementation on the utilization of supplemental tallow fatty acids by feedlot steers. J. Anim. Sci. 80(Suppl. 1):270. (Abstr.)

Zinn, R. A., A. Plascencia, and R. Barajas. 1994. Interaction of forage level and monensin in diets for feedlot cattle on growth performance and digestive function. J. Anim. Sci. 72:2209-2215.