

8-2010

# Interaction Between Roughages and Corn Milling Byproducts in Finishing Cattle Diets

Joshua R. Benton

University of Nebraska at Lincoln, [jbenton2@unl.edu](mailto:jbenton2@unl.edu)

Follow this and additional works at: <http://digitalcommons.unl.edu/animalscidiss>

 Part of the [Other Animal Sciences Commons](#), and the [Other Nutrition Commons](#)

---

Benton, Joshua R., "Interaction Between Roughages and Corn Milling Byproducts in Finishing Cattle Diets" (2010). *Theses and Dissertations in Animal Science*. 16.

<http://digitalcommons.unl.edu/animalscidiss/16>

This Article is brought to you for free and open access by the Animal Science Department at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Theses and Dissertations in Animal Science by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

INTERACTION BETWEEN ROUGHAGES AND CORN MILLING BYPRODUCTS  
IN FINISHING CATTLE DIETS

by

Joshua R. Benton

A DISSERTATION

Presented to the Faculty of  
The Graduate College at the University of Nebraska  
In Partial Fulfillment of Requirements  
For the Degree of Doctor of Philosophy

Major: Animal Science

Under the Supervision of Professors Galen E. Erickson and Terry J. Klopfenstein

Lincoln, Nebraska

August, 2010

INTERACTION BETWEEN ROUGHAGES AND CORN MILLING BYPRODUCTS  
IN FINISHING CATTLE DIETS

Joshua Rowlette Benton

University of Nebraska, 2010

Advisors: Galen E. Erickson and Terry J. Klopfenstein

During ethanol production, starch is the primary nutrient fermented and the remaining byproducts are excellent sources of fiber and protein. In addition, inclusion of byproducts in finishing diets may reduce the incidence of acidosis. As a result, roughage level and quality could potentially be reduced in finishing diets containing byproducts. Three experiments were conducted to examine the effects of roughage and wet corn gluten feed (WCGF) in finishing cattle diets containing corn distillers grains plus solubles. Cattle fed finishing diets containing wet distillers grains plus solubles (WDGS) with no roughage had decreased DMI and ADG compared to cattle fed roughage. Within roughage level, ADG was similar for cattle fed alfalfa hay, corn silage or corn stalks when included on an equal NDF basis. Apparent total tract digestibility of OM, NDF, and CP linearly decreased and ruminal pH variables increased linearly due to increasing roughage levels. Roughage sources can be exchanged on an equal NDF basis in beef finishing diets containing 30% WDGS (DM basis). In finishing diets containing modified distillers grains plus solubles (MDGS), DMI linearly increased due to increasing roughage levels but ADG responded quadratically and was lowest for cattle fed diets without roughage. There was also a quadratic response for DMI and ADG due to WCGF

inclusion level. Gain:feed decreased linearly with increasing roughage and WCGF inclusion levels. Feeding 15% WCGF resulted in similar cattle performance and carcass traits to cattle fed no WCGF in diets containing 30% MDGS, but cattle fed diets with 60% total byproduct inclusion made up of 30% WCGF and 30% MDGS had reduced performance (DM basis). Additionally, reducing corn silage inclusion level to 7.5% resulted in similar finishing cattle performance and carcass traits to cattle fed 15% corn silage in diets containing 30% MDGS with or without inclusion of WCGF. Elimination of roughage in diets containing either WDGS or MDGS resulted in negative impacts on finishing cattle performance, ruminal metabolism, and carcass traits.

## ACKNOWLEDGMENTS

First, I thank God for all the great blessing and opportunities he has provided for me. Often I rely on the strength he has provided me to get through all things and the determination and focus he has provided me which gives me the opportunity to achieve anything I set as a goal for myself.

My time at the University of Nebraska has been a wonderful experience that has taught me many valuable lessons and has allowed me to gain important professional experience. It also enabled me to meet my wonderful wife Jenny.

I want to thank Drs. Galen Erickson and Terry Klopfenstein for not only being a good advisor and boss but also lifelong friends. Thanks for the opportunities that you have provided over the last few years and for trusting in me to make decisions and learn from my mistakes. It does not seem like that long ago that I was calling Terry to ask about opportunities in the feedlot internship program which opened my eyes to the many opportunities in the feedlot and cattle industry. I wish both of you continued success and hope to have opportunities to continue to work with you in the future.

I want to thank Drs. Rick Stock and Paul Kononoff for serving on both my M.S. and Ph.D. graduate and reading committee. I greatly appreciate their ideas and comments in developing and conducting research along with their dedication to our ruminant nutrition group. I also want to thank Dr. Dave Smith for serving on my graduate committee and for providing insight into other ways of analyzing data that may be overlooked.

To all the many graduate students that have helped me through a successful graduate program and technician career at UNL, I thank you for all the help through the fun and not so fun projects that we get to experience.

Last, but most important, I want to thank my parents because all I have done in my life would not have been possible without the lessons I learned from them. My parents have always supported me while I set high goals and work toward making my dreams come true. I just hope that I can do half as good a job raising my children.

## **DEDICATION**

I dedicate all the work reported here to my bride and best friend, Jenny Benton. Without her support and dedication, I would not have been able to accomplish this goal and be at such a great point in my life. I thank God each day for the blessings and opportunities he has provided me to be able to spend my life with such a loving and encouraging person. I look forward to spending our lives together and can't wait for the next chapter in our life as we move forward.

## TABLE OF CONTENTS

<b>CHAPTER I. REVIEW OF LITERATURE .....</b>	<b>1</b>
Feed Intake of Cattle.....	1
Introduction.....	1
Acidosis.....	4
Feeding Management.....	10
Effects of Starch Digestion .....	18
Roughage in Traditional Finishing Cattle Diets .....	22
Introduction.....	22
Effects of NDF on Intake and Performance.....	23
Effects of NDF on Metabolism and Digestion .....	32
Corn Milling Processes for Ethanol Production .....	42
Introduction.....	42
Dry-Milling Process.....	43
Wet-Milling Process .....	47
Nutrient Composition and Variation of Corn-Milling Byproducts.....	51
Introduction.....	51
Dry-Milling Byproducts.....	52
Wet-Milling Byproducts .....	63
Corn-Milling Byproducts in Finishing Cattle Diets .....	65
Introduction.....	65
Effects of Corn-Milling Byproducts on Intake and Performance .....	66
Effects of Corn-Milling Byproducts on Metabolism and Digestion.....	75



Roughage in Finishing Cattle Diets Containing Corn-Milling Byproducts.....	85
Literature Cited .....	92

**CHAPTER II.** Effects of roughage source and inclusion level in beef finishing diets

containing corn wet distillers grains plus solubles .....	111
Abstract .....	112
Introduction.....	113
Materials and Methods.....	114
Results and Discussion .....	122
Literature Cited .....	131

**CHAPTER III.** Effects of wet corn gluten feed and roughage inclusion level in beef

finishing diets containing corn modified distillers grains plus solubles .....	146
Abstract .....	147
Introduction.....	148
Materials and Methods.....	149
Results and Discussion .....	152
Literature Cited .....	156

## LIST OF TABLES

### CHAPTER II

<b>Table 1.</b> Composition of finishing diets and formulated nutrient analysis fed to steers in Exp. 1 .....	134
<b>Table 2.</b> Composition of finishing diets and formulated nutrient analysis fed to steers in Exp. 2 .....	136
<b>Table 3.</b> Simple effects of roughage source and inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 1).....	138
<b>Table 4.</b> Main effects of roughage source and inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 1) .....	140
<b>Table 5.</b> Effects of roughage source and inclusion level on intake and apparent total tract digestibility in steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2) .....	142
<b>Table 6.</b> Effects of roughage source and inclusion level on intake patterns in steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2) .....	143
<b>Table 7.</b> Effects of roughage source and inclusion level on ruminal pH variables of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2) .....	144
<b>Table 8.</b> Effects of roughage source and inclusion level on ruminal VFA profiles of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2) ....	145

**CHAPTER III**

<b>Table 1.</b> Composition of finishing diets and formulated nutrient analysis fed to steers .....	
.....	157
<b>Table 2.</b> Effects of wet corn gluten feed (WCGF) inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% modified distillers grains plus solubles .....	159
<b>Table 3.</b> Effects of roughage inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% modified distillers grains plus solubles .....	160

**LIST OF FIGURES****CHAPTER I**

<b>Figure 1. Dry Milling Process</b> .....	109
<b>Figure 2. Wet Milling Process</b> .....	110

## CHAPTER I

### REVIEW OF LITERATURE

#### *Feed Intake of Cattle*

**Introduction.** Overall performance of any animal is directly related to their ability to extract usable nutrients from consumption of food. Ruminants are unique in that they have the ability to ferment feedstuffs in the rumen before gastric and intestinal digestion and have evolved to utilize forage much more efficiently than non-ruminants. However, the feedlot industry relies heavily on concentrated grain-based diets for finishing cattle primarily due to lower costs of gain by utilizing grains in relation to forage on an energy basis.

The feeding behavior of cattle consuming slowly degraded, energetically dilute forage-based diets is characterized by large meals consumed infrequently during the day and there is a positive relationship between digestibility and DMI, which is principally controlled by rumen kinetics, distention (i.e., gut fill), and osmolarity (Balch and Campling, 1962; Van Soest, 1965; Waldo, 1986; Forbes, 2000). However, DMI is negatively related to digestibility for cattle consuming concentrated grain-based finishing diets which are highly digestible and energetically dense, primarily because gut fill is generally not an issue and other physiological factors regulate DMI (Conrad et al., 1964; Van Soest, 1965; Waldo, 1986; Forbes, 2000). Furthermore, it appears that level of feed intake (% of BW) markedly affects ruminal digestion and microbial crude protein (MCP) efficiency possibly due to changes in retention time and rate of digestion (Zinn and Owens, 1983).

During adaptation to grain-based diets, feed intake patterns are changed, generally resulting in reduced eating rate and meal size and increased meal frequency compared to grazing animals. This change is primarily due to cattle adapting to changes in short-term and long-term metabolic control of intake instead of gut fill. However, the magnitude of the change is influenced by individual animal variation and bunk management strategies. Short-term control of intake is associated with factors linked to initiation and termination of individual meals. Long-term control of intake is associated primarily with energy balance during longer periods of time and is related to metabolic status of the animal (Carter and Grovum, 1990).

Based on recent research investigating the hepatic oxidation theory (HOT), it appears short-term control of intake in ruminants may primarily be regulated by fuel-specific mechanisms initiated by the liver. In a review of HOT, Allen et al. (2009) concluded that DMI of ruminants is likely regulated mainly by hypophagic effects of propionate. The authors developed a conceptual model of how DMI is possibly regulated in ruminants according to HOT. Briefly, propionate is taken up swiftly by the liver during a meal and oxidized in the tricarboxylic acid (TCA) cycle which also stimulates oxidation of acetyl CoA. This increase in hepatic oxidation leads to an increase in the energy status of the liver and causes a decrease in the firing rate of hepatic vagal afferents. These signals from the liver are integrated within the hind-brain and then relayed to the hypothalamus which results in satiety. After a meal, hepatic oxidation is reduced and hepatic ATP pools are depleted by gluconeogenesis. This reduces the energy status of hepatocytes and leads to an increased firing rate of the hepatic vagus which results in hunger. Hepatic oxidation of fatty acids (FA) and carbon oxidation from AA catabolism

during urea synthesis in the liver also appear to have a hypophagic effect. However, during meals, propionate inhibits  $\beta$ -oxidation and urea synthesis indicating that FA oxidation and urea synthesis more likely control intake through long-term effects.

Allen et al. (2009) concluded that because DMI is regulated by multiple mechanisms integrated in the feeding centers of the brain, the hepatic oxidative theory is very intriguing due to its simplicity and extensive explanatory power. The authors noted that the short-term oxidation pattern of fuels is the important factor in the regulation of DMI because the pattern of oxidation over long periods is fairly constant and principally based on the energy needs of the liver. It is clear that HOT can provide an overview for the mechanisms associated with many behavioral responses due to changes in digestion and metabolism but more research is needed to further understand specific animal responses to specific dietary changes.

Increased ruminal osmolarity has also been shown to lead termination of meals. Carter and Grovum (1990) suggested that direct stimulation of osmoreceptors by hypertonicity of ruminal fluid results in satiety. Elevated ruminal osmolarity ( $> 400$  mOsm/kg) due to administration of Na acetate or NaCl has been shown to clearly decrease feed intake in sheep (Bergen, 1972). However, this study did not look at total DMI. Allen (2000) pointed out that this is a critical observation that has generally been ignored by evaluating feed intake of individual meals. In a study by Choi and Allen (1999, as cited by Allen, 2000), infusion of equimolar amounts of either Na acetate or NaCl into the rumen of dairy cows resulted in smaller meal size, but meal frequency was increased with infusion of NaCl compared to Na acetate. Although infusion of NaCl reduced meal size, meal frequency was increased so there was no effect on DMI during

the 12-h infusion period compared with no infusion. In addition, infusion of Na propionate reduced meal size and meal frequency resulting in decreased DMI to a greater extent than Na acetate. The authors concluded that hypertonicity due to Na infusion does reduce meal size but does not affect total daily intake since the intermeal interval was decreased. Overall, when compared to no infusion, reduced meal size due to infusion of Na acetate with no effect on DMI as well as decreased meal size, meal frequency, and total DMI due to propionate infusion further indicates the hypophagic effects of VFA, more specifically propionate, which is in agreement with HOT.

The transition period from forage-based to grain-based diets is commonly referred to as a critical time in order to promote maximal production and health during the finishing period. Nutritional management during this time is very important because rapid transition can lead to multiple metabolic disorders with varying consequences (Brown et al., 2006). Therefore, the primary goal during adaptation is to manage intake in order to avoid consumption of greater than normal quantities of highly fermentable carbohydrates, such as starch, which can result in ruminal acidosis with a range in severity from mild to lethal.

***Acidosis.*** To define ruminal acidosis, an understanding of rumen pH and metabolism are necessary. A decline in pH is based on reduced alkali (base) in relation to acid (hydrogen ion) content of bodily fluids (Owens et al., 1998). Acidosis in finishing cattle has been defined as biochemical and physiological stressors caused by rapid production and absorption of ruminal organic acids and endotoxins resulting from over consumption of readily fermentable carbohydrates primarily resulting in reduced ruminal



pH below 5.6. All organic acid production in the rumen, not just lactic acid, can lead to acidosis (Stock and Britton, 1993).

Though acidosis is generally referred to as one disease, it is better characterized at two different levels based on the extent of pH reduction. Subacute acidosis is generally defined as ruminal pH between 5.0 and 5.5 without accumulation of lactic acid and erratic intakes (Owens et al., 1998). More recently, Schwartzkopf-Genswein et al. (2003) defined subacute acidosis as ruminal pH below 5.8 for more than 12 h/d. Decreased performance, rumenitis, and liver abscesses have also been suggested to be linked with subacute acidosis. However, despite considerable research about the possible negative effects of subacute acidosis, a clear well defined standard is yet to be developed (Vasconcelos and Galvayan, 2008).

On the other hand, acute acidosis has been well characterized and is generally defined as ruminal pH < 5.0 and accumulation of lactic acid possibly exceeding 40mM. For diagnosis of clinical acidosis, a decrease in blood pH below 7.35 is necessary; however, other symptoms of acidosis in finishing cattle include erratic feed intakes, anorexia, lethargy, rumen stasis, and diarrhea. Acute acidosis can impair some physiological functions and systemic acidosis may be so severe as to cause the animal to be sick to the point of death with cardiovascular and respiratory failure.

Elevated concentrations of acids and glucose during acidosis increase rumen osmolarity. High ruminal osmolarity causes water to be rapidly drawn into the rumen from blood leading to abscesses on the wall of the rumen and small intestine due to damage. When damage occurs to ruminal epithelium, microbes can freely flow into the blood stream resulting in liver abscesses (Owens et al., 1998). When damaged

gastrointestinal epithelium are repaired, they are generally thicker and this ultimately lead to reduced absorption (Krehbiel et al., 1995a). Several other ailments directly and indirectly associated with acidosis in the feedlot include bovine laminitis, polyoencephalomalacia, sudden death syndrome, clostridial infections, and grain bloat (Brent, 1976; Stock and Britton, 1993; Nocek, 1997; Glock and DeGroot, 1998).

Most feedlot managers generally only associate acidosis with acute acidosis because signs are easily observable while the only sign for subacute acidosis is generally reduced intake (Fulton et al., 1979). From a practical standpoint in the feedlot, acidosis problems are usually encountered: (1) during step-up period when starting cattle on feed, (2) when cattle are on high energy finishing diets for long time periods, (3) after weather changes, and (4) after some problem in the feeding system, such as a mill breakdown, when cattle are hungry and out of feed (Cooper, 1997). Weather changes are associated with acidosis because there is an interference with feed consumption patterns. However, personnel problems in the feedlot are probably the most common cause.

In a study conducted by Goad et al. (1998), changes in ruminal fermentation and microbial population due to induced subacute acidosis were evaluated. Six ruminally cannulated steers were adapted to either a 20% grain (hay) or 80% grain (grain) diet with alfalfa hay as the roughage. To induce acidosis, feed was withheld for 24 h and then a 100% all grain diet was fed at 3.5 times  $NE_m$  for 3 d. After 48 and 60h, DMI was reduced 19 and 42% for the hay cattle, respectively, compared to 57 and 59% for the grain cattle, respectively. Ruminal pH declined to between 5.0 and 5.6 after 36 h and remained there. For the grain cattle, ruminal pH tended to be lower throughout the 3 d period compared to the hay cattle. Ruminal lactic acid levels increased over time for both the hay and grain

cattle but never exceeded 5 mM. Total VFA production increased through 48 h for both groups. Blood pH and bicarbonate concentration both decreased over time in the hay and grain cattle but total blood lactate was unaffected. These results are very standard in subacute acidosis and are in agreement with several previous studies (Mackie et al., 1978; Horn et al., 1979; Harmon et al., 1985; Burrin and Britton, 1986; Krehbiel et al., 1995c)

In the study by Goad et al. (1998), the concentration of acetate decreased over time while the concentration of propionate increased for both groups. Initially, the acetate to propionate ratio (A:P ratio) was greater for the hay cattle (5.4:1) compared to the grain cattle (3.3:1) but declined for both groups over time to approximately a 1:1 ratio.

Butyrate concentration increased over time for the hay cattle but not for the grain cattle and at 72 h, butyrate concentration was greater for the hay cattle. Total viable anaerobic and amylolytic bacteria counts increased for both groups over time. Anaerobic *Lactobacillus* counts were increased 10-fold for grain steers initially. Both *Lactobacillus* and lactate-utilizing bacteria increased for the hay and grain cattle over time while protozoal populations declined significantly to near zero. These observations made by Goad et al. (1998) are common results seen during grain adaptation and subacute acidosis (Mackie et al., 1978; Fulton et al., 1979; Horn et al., 1979; Harmon et al., 1985; Burrin and Britton, 1986). Goad et al. (1998) concluded that in theory, cattle previously adapted to high grain-based diets should demonstrate a greater resistance to subacute acidosis resulting from overconsumption of high starch diets. Nevertheless, the changes observed for ruminal fermentation during subacute acidosis were the same regardless of adaptation.

Brown et al. (2000) conducted a study to evaluate short and long term effects of both acute and subacute acidosis in steers. They applied four treatments equally across 20

ruminally cannulated steers and treatments consisted of subacute acidosis (SA), subacute acidosis control (SC), acute acidosis (AA) and acute acidosis control (AC). Steers in the subacute groups were adapted to a 50% grain-based diet, fed twice daily at 0700 and 1500, from d -31 to -3 with DMI restricted to 1.7% of BW. Feed was fed at 0900 and 2300 on d -2 and was withheld on d -1. A challenge diet containing a 50:50 blend of rolled wheat and rolled corn was intraruminally feed at 1.5% of BW for the SA steers and feed was withheld from the SC steers on day 0. For steers in the acute groups, coarsely chopped grass hay was fed ad libitum from d -31 to -4. Grass hay was feed at 0.5% BW on d -3 both at 0700 and 1500. On d -2, grass hay was fed once at 0.5% of BW and no feed was offered on d -1. On d 0, the AA steers were intraruminally dosed four times at hourly intervals with a challenge diet containing 100% steam-flaked corn. The total dose was equal to 3.0% of BW and feed was withheld from the AC steers on d 0. From d 1 to 14, all steers were allowed ad libitum access to a 50% grain-based diet fed twice daily.

Two of the five AA steers had to be removed on d 7 due to lack of appetite. There was a quadratic response for DMI in the AA steers which declined sharply through d 3 and then gradually increased to similar level compared to the other treatments. However, the authors noted that this increase in DMI after d 7 was partly due to the removal of two steers. The AC steers had a linear increase in DMI, while DMI responded quadratically in a positive manner for the SA steers. For the SC steers, DMI was unchanged over the 14 d period. Ruminal pH decreased quadratically for AA and AC steers through d 7. Ruminal pH of SA steers increased linearly while the pH for SC steers was not different through d 7. On d 10 and 14, SA steers had the highest pH while AC steers had the lowest pH. Ruminal D-lactate, L-lactate, and total lactate responded quadratically for both AA and

AC steers through day 7. Lactate measurements peaked on d 0 for steers on the AC treatment and then declined compared to d 3 for steers on the AA treatment. Ruminal total lactate for SA and SC steers was not different during the 14-d period. Blood chemistry and endocrine profiles were also evaluated and subsets of individual summary variables within day were subjected to regression analysis to identify any variables between the groups of cattle that could be used to identify acute or subacute acidosis. There was a high correlation ( $r^2 = 0.83$ ) observed between feed intake and average ruminal pH from the previous day which indicates that cattle may adjust their feed intake due to low pH. However, due to inconsistent responses across time for all the measured variables, no single variable was useful in identifying an animal experiencing acute or subacute acidosis. The authors concluded that substantial variation was apparent in the ability of individual animals to handle a carbohydrate challenge (Brown et al., 2000).

A great example of the variation among individual animals to manage a carbohydrate overload is the study conducted by Dougherty et al. (1975) as cited by Brown et al. (2006). In this study, three steers were dosed with finely ground grain at a rate of 70 g/kg of BW. This resulted in one steer being euthanized, one steer endured acute acidosis, and based on the sampling schedule, pH was never observed below 5.5 for the third steer although severe diarrhea was observed.

While our knowledge of the causation of acidosis is fairly extensive, the economic impact of digestive disorders can be significant. According to the National Animal Health Monitoring System (USDA, 2000), 1.90% of all cattle placed in feed yards developed digestive disorders with an average treatment cost of \$6.19 per animal. The prevalence of digestive disorders in larger feed yards is about 2-fold higher

compared to smaller ones (less than 8,000 head). Smith (1998) reported that mortality of beef and Holstein cattle in larger feed yards ranged from 0.17 to 0.42% of inventory per month and approximately 25% were due to digestive disorders.

***Feeding Management.*** The relationships between feeding management, feed intake, and subsequent performance of finishing cattle are complex and further complicated by adaptation strategy, dietary ingredients, bunk management, and individual animal variation. In order to minimize acidosis and long term effects on rumen metabolism and animal performance, cattle are gradually adapted to grain-based diets. During the transition period from forage-based to grain-based diets, the rumen ecology undergoes important changes. The introduction of starch into the rumen raises the availability of free glucose which stimulates growth by most ruminal bacteria. This leads to VFA production progressively increasing thereby progressively decreasing ruminal pH. Lactate concentrations typically remain unchanged although small peaks have been observed within the first two h after feeding (Owens et al., 1998; Brown et al., 2006).

In general, cellulolytic bacteria numbers decline while amylolytic bacteria concentrations gradually increase with higher grain levels (Mackie et al., 1978; Tajima et al., 2001). Lactate-utilizing bacterial concentrations also gradually increase when grain levels are increased up to 60% and then there is a dramatic increase (Mackie et al., 1978). Once cattle are adapted to a concentrated grain-based diet, the size of most carbohydrate-utilizing bacterial populations appear to remain reasonably stable (Schwartzkopf-Genswein et al., 2003). Protozoa numbers, primarily *Entodinium* spp., also rise with increasing dietary grain concentrations and peak at about 60% grain levels (Grubb and

Dehority, 1975). However, protozoa populations are highly variable within cattle. At a given time, 10% of cattle may be defaunated while over 25% of cattle can have protozoa counts over  $10^5$  cells/mL and there does not appear to be a relationship between pH and protozoa counts (Towne et al., 1990).

As mentioned previously, individual animals have highly variable responses to dietary changes and the different effects in relation to HOT must be evaluated. One specific area that may provide more insight into HOT and how it relates to the overall picture is the relationship between microbial populations and variation among animals in response to such things as feeding management, diet composition, and environmental changes.

Rumen bacteria are capable of producing different metabolites at a given time as influenced by intra and extracellular conditions because most species of ruminal bacteria can produce multiple end products. Early research reported that ruminal protozoa were dramatically reduced in cattle consuming grain based diets. As mentioned, large variation in protozoa population counts has been observed (Towne et al., 1990) and the role of ciliated protozoa may be more important than previously thought. It appears that protozoa have an essential function in regulation of the rate of starch digestion in the rumen. They engulf starch and the associated amylolytic bacteria, degrade and ferment ingested starch at a slower rate compared to bacteria, and therefore slow the rate of starch digestion in the rumen. Furthermore, defaunation of cattle consuming an 85% grain-based diet caused a decrease in ruminal pH (5.97 vs. 6.45), an increase in VFA concentration (92.3 vs. 64.8 mM), a reduction in the A:P ratio (approximately 2:1 vs. 3.5:1), and a trend for increased amylolytic bacteria counts (Nagaraja et al., 1992). The ability of protozoa to

influence the rate and amount of VFA production, more specifically propionate, has a large impact on HOT and may help explain changes between individual animals.

Brown et al. (2006) conducted an excellent review of the literature evaluating the influence grain adaptation strategies on ruminal metabolism, microbial populations, and performance of finishing cattle. They described two basic strategies of adapting cattle to grain-based diets commonly used for research trials which involve 1) decreasing the inclusion of roughage from about 45 to 7.50% (DM basis) over a period of 7 to 24 d, or 2) restricting intake of 92 to 95% grain-based diet at approximately 1.50% of BW with incremental increases of diet until ad libitum intake is achieved. The authors commented that in a commercial feed yard with large pens of cattle, more research is needed for intake restriction to be easily applied. The authors concluded that performance of finishing cattle was normally decreased when cattle were allowed ad libitum access to the adaptation diets before the final diet and when the adaptation period was shorter than about 14 d. Based on a survey of 29 consulting feedlot nutritionist conducted by Vasconcelos and Galvayan (2007), 75.9% recommend multiple step-up diets for adapting cattle to concentrated grain-based diets by gradually increasing the grain to roughage ratio over a period of 21 d. On average, three diets were fed for seven days each before the finishing diet. The roughage inclusion for step one ranged from 27.5 to 46.0% with an average of 39.9% (DM basis). The average dietary inclusion of roughage in the finishing diet was 8.30% during the summer and 9.00% during the winter.

In the study by Brown et al. (2000), an interesting observation was made. The acute acidosis control cattle were fed in a manner to imitate a common experience for newly received calves entering a commercial feed yard whereby they were removed from



grazing situation and had either limited or no access to feed until they were placed in their home pen at which time they had ad libitum access to a diet containing 45-50% roughage. This period of restricted feed access can range from 2 h to more than 24 h. Out of the 5 steers fed forage followed by restricted feed and then ad libitum access to a 50% grain-based diet, two were considered to have experienced subacute acidosis (Brown et al., 2006).

Currently, the extent by which feeding management may be modified for maximum DMI while minimizing digestive problems is largely unidentified (Schwartzkopf-Genswein et al., 2003). Once cattle are adapted to high grain-based diets, as with grain adaptation, there are two primary methods used in bunk management. They are characterized by either 1) daily adjustments in order to minimize residual feed to a relatively small percentage of what was delivered or 2) a clean-bunk system so that all delivered feed is consumed before the subsequent feeding (Galyean, 1999; Pritchard and Bruns, 2003). The first method is typically referred to as ad libitum feeding which gives cattle constant access to feed in an effort to maximize feed intake on a daily basis. Pritchard and Bruns (2003) implied that ample feed offering would reduce aggressive eating; however, having ample feed may increase the risk of sorting and increase the deviation from the formulated diet. The clean-bunk management system, also referred to as restricted feeding, is one possible solution to sorting and attempts to maximize feed intake over the entire feeding period. Furthermore, restricted feeding and increased competition at the bunk may define an upper limit for individual DMI and a set period of feed availability thus reducing excess feed that could lead to overconsumption and increased risk of acidosis.

Restricting feed may actually lead to increased subacute acidosis and an overall reduction in DMI because this method tends to create meal eaters which have feed patterns similar to grazing animals. Even though variation in feed intake may be reduced across days, variability within a day in the ruminal environment is possibly greater (Zinn et al., 1995). Research evaluating these two methods of bunk management has produced inconsistent results. Restricted intake has been shown to result in larger meals and faster rates of consumption with a lower and more variable ruminal pH (Fanning et al., 1999). Other research has also shown the restricted intake can lead to increased ADG and efficiency. Furthermore, there appears to be a negative relationship between ADG and time spent at the bunk which implies that cattle with increased eating rates may also have increased growth rates (Schwartzkopf-Genswein et al., 2003). This may help explain variation among individual animals due to dietary changes in relation to HOT. The negative relationship between ADG and time spent at the bunk observed by Schwartzkopf-Genswein et al. (2003) implies that individual animals which have a greater tolerance to carbohydrate overload may have increased growth rates. This may be due to the fact that the faster rate of consumption allows animals to consume larger meals before meal termination is initiated due to hepatic oxidation of propionate. It would be interesting to know if there is a relationship between protozoa populations and cattle with increased growth rates and/or faster rates of consumption as this may help explain variation among individual animals to manage carbohydrate overloads.

Many of the observations that have been made regarding the relationship between adaptation strategies and bunk management in relation to feed intake are based on intakes of a pen of cattle. As previously mentioned, significant variation exists in the ability of

individual animals to deal with a carbohydrate overload and the primary reasons for this are certainly not obvious. Some of the factors that may be involved include 1) stability of the microbial population, 2) metabolic state due to stress, 3) selectivity or feed preference during sorting at the bunk, 4) dominance, temperament, and motivational characteristics, and 5) learning ability (Zinn et al., 1994; Schwartzkopf-Genswein et al., 2003; Brown et al., 2006; Allen et al., 2009). Therefore, general assumptions that positive animal responses such as decreased incidence of subacute acidosis and improved performance are a direct result of reduced intake variation and improved bunk management may not hold true.

In a study conducted by Bevens et al. (2005), heifers were adapted to a 90% grain-based diet by either feeding five diets with increasing grain over 15 d or by feeding a 65% grain-based diet for only 3 d before switching to the 90% concentrate diet. From d 1 to 3, when heifers were fed 65% concentrate, time below ruminal pH 5.6 was greater and more variable for the heifers placed directly on this diet. Adaptation method had no effects on average DMI or variation in DMI, however, average intake across all heifers was reduced 8 and 17% on the second day of feeding the 65 and 90% concentrate diet. There was a large range in DMI across both treatments on the second day of feeding the 90% concentrate diet which may have affected the variation across treatments. The main point of this study is that they categorized heifers as either coping well or poorly with the grain adaptation and graphically showed DMI and ruminal pH. The data show a classical observation of the repeating cycle of DMI during grain adaptation that is commonly seen in feedlot cattle where after overconsumption of starch, ruminal pH declines and some cattle reduce their intake probably in an attempt to decrease production of VFA so that

ruminal pH can be restored. However, once pH is restored, cattle may again over consume starch and the cycle of reduced pH and subsequent intake starts over. This is supported by Brown et al (2000), as previously discussed, who observed a strong relationship ( $r^2 = 0.83$ ) between DMI and average daily pH the preceding day.

Whether daily variation in DMI of cattle consuming concentrated grain-based diets ad libitum ultimately changes maintenance of ruminal pH is not clear (Schwartzkopf-Genswein et al., 2003). As stated, the primary purpose of roughage inclusion is to optimize DMI to maximize animal performance. However, it appears that relatively small variation in daily intake patterns may not affect performance at all.

In a study by Galyean et al. (1992), cattle were fed according to one of three treatments consisting of 1) constant daily feed delivery during a 28-d period, 2) 10% daily fluctuations in feed delivery, or 3) 10% weekly fluctuations in feed delivery compared to the constant feed cattle. Because cattle were programmed-fed, DMI over the 84 d feeding period was the same for all groups and weekly fluctuations had no effect on ADF or G:F. However, daily fluctuations of 10% relative to the constant feed group decreased ADG and G:F by 6.5%.

In contrast, a series of trials conducted by Cooper et al. (1999) evaluated the effects of imposed intake variation between 0.7 kg/d up to 1.8 kg/d in feedlot cattle. In four metabolism studies, the only significant effect observed was that as variation increased, average ruminal pH increased and the area of ruminal pH below 5.6 was decreased. In the two performance trials, increased DMI was observed in one study but no treatment differences were observed for ADG or gain/feed in either trial. The authors concluded that intake variation of cattle fed high-concentrate diets at ad libitum levels

does not increase incidence of acidosis or reduce feedlot performance. Additionally, because intake may have varied in a consistent manner, cattle on all treatments could have been experiencing acidosis to the same degree or may have adjusted their feeding behavior to counter the acid insult.

To evaluate the effects of feeding frequency and feed intake fluctuations on ruminal fermentation and total tract digestibility, Soto-Navarro et al. (2000) used nine ruminally cannulated steers being limit-fed a 90% grain-based diet at 90% of previously determined ad libitum intake. Treatments consisted of 1) feed offered once daily at 0800 at constant daily intake, 2) feed offered once daily at 0800 with 10% daily variation in intake, 3) feed offered twice daily at 0800 and 1700 at constant daily intake, and 4) feed offered twice daily at 0800 and 1700 with 10% daily variation in intake. In summary, digestibility was decreased by feeding twice daily with a 10% variation in feed intake. Increasing frequency of feeding appeared to stabilize the ruminal environment but decreased total VFA production and increased the A:P ratio. The authors implied that feeding twice daily may lead to decreased performance from reduced efficiency of energy utilization in limit-fed steers (Soto-Navarro et al., 2000).

The effects of fluctuating 1) the amount of feed delivered and 2) feeding time of finishing cattle being fed ad libitum access of a grain-based diet were evaluated by Schwartzkopf-Genswein et al. (2004). There were no observed effects on DMI during a metabolism trial or on performance of finishing cattle in a feedlot trial due to variation in feed delivered or feeding time. It was noted, however, that increased fluctuations in feed delivery appear to elevate the risk of subacute acidosis based on a trend for ruminal pH to be lower.

In a study conducted by Hickman et al. (2002), the relationship between eating patterns and feedlot performance was evaluated by electronically following individual animals based on bunk attendance and feed consumption. Variation in daily DMI was analyzed for individual animals classified as having low, average, or high DMI, ADG, and gain/feed. Daily variation for intake was 0.36 kg greater for high ADG steers (n = 9) which consumed 2.1 kg/d more feed and spent 3.7 min/d less time at the feed bunk compared to low ADG steers (n = 13). Likewise, steers with the greatest gain/feed had increased daily variation in intake (0.38 kg/d) and consumed 1.1 kg/d less feed compared to cattle with low gain/feed. The authors concluded that the best performing cattle, based on ADG and gain/feed, have the most variable intake patterns.

Based on the observation made in this review, it appears acidosis may actually be the cause of variable intake in finishing cattle rather than the result. Slight variation in the amount of feed delivered and delivery time, be it deliberate or accidental, tend not to have major impacts on performance of finishing steers. This may primarily be a result of cattle's ability to adapt in many different situations such that variation in day-to-day feeding management only has minimal impacts on production. Additional information about how feeding management may influence the microbial populations and subsequent metabolite production may greatly improve our understanding of variation among animals and how the hepatic oxidation theory fits into this production system.

***Effects of Starch Digestion.*** Cattle may be finished on all-grain diets but in order to optimize the balance between intake, digestion, and absorption for maximum energy intake and animal performance while avoiding digestive problems, roughage is generally

included at 5 - 15% (DM basis) in finishing diets. The relationship between intake, digestion, and absorption is multifaceted and relates to various dietary factors. Based on H<sub>2</sub>O, changes in diet formulation to manipulate the rate of production and absorption of propionate may be the best way to influence DMI in cattle (Allen et al., 2009).

In order to discuss the effects of diet changes on DMI in relation to H<sub>2</sub>O, a brief discussion of starch digestion is necessary. Most starch digestion occurs in the rumen and ruminal degradation of starch across several grains and processing methods ranges from 50 to 94% of starch intake. Starch digestion postruminally ranges from 5 to 20% of starch intake or 38 to 93% of that entering and most occurs in the small intestine. Ruminal degradation and small intestinal digestion of starch are not completely independent because ruminal degradation influences both the quantity and composition of starch entering the small intestine. Total tract starch digestion generally ranges from 86 to 99% of starch intake (Owens et al., 1986; Huntington, 1997). Because total tract starch digestion is quite high across grain sources and processing methods, it implies that postruminal starch digestion can make up for lower ruminal degradation so that overall starch digestion is not affected. Nevertheless, starch fermentation in the rumen is associated with inevitable losses from heat production and production of methane (Hungate, 1966).

In theory, starch digestion postruminally with the absorption and metabolism of glucose should be more energetically efficient than ruminal degradation of starch with the production, absorption, and metabolism of VFA along with energetic losses due to heat and methane production. This is supported by Owens et al. (1986) who reported that starch digested in the small intestine is used 42% more efficiently than if it had been

ruminally degraded. However, several studies suggest there are limitations to starch digestion in the small intestine (Orskov, 1986; Owens et al., 1986; Harmon et al., 2004). Some of the factors which may affect postruminal starch digestion include limited enzyme activity, limited exposure time, and limited access of enzymes to starch granules. In the rumen, starch is rapidly degraded but non-starch components like the protein matrix and seed coat can limit ruminal degradation. Thus, only larger, more resistant particles pass out of the rumen. The combination of large particles in the small intestine (Owens et al., 1986) and a short duration of exposure time (Zinn and Owens, 1980) may combine to decrease the available amylolytic potential. Grain processing helps to increase the access to starch granules and Zinn et al. (2002) concluded that post-ruminal starch digestion appears to be limited by accessibility of the amylolytic enzymes and not the abundance or activity of enzymes.

There is evidence that increased supply of N to the small intestine may increase pancreatic  $\alpha$ -amylase secretion and result in greater starch digestion (Taniguchi et al., 1995; Richards et al., 2003). Additionally, ruminal starch degradation is improved by maximizing microbial efficiency (Milton et al., 1997) and this increases the supply of MCP flowing to the small intestine (Zinn and Shen, 1998; Krehbiel and Ferrell, 1999). This suggests that maximizing microbial efficiency increases the supply of protein to the small intestine and should increase pancreatic  $\alpha$ -amylase secretion which would enhance total tract starch digestion. This is supported by Huntington (1997), who reported that data indicate there may be a double benefit from ruminal digestion of starch, the increased production of microbial protein and the increased duodenal digestion of starch due to the pancreatic response to more protein present in the small intestine.



Although starch appears to be used most efficiently when ruminally fermented (Huntington, 1997), increased ruminal starch degradation due to changes in grain source or processing can depress DMI which may lower energy intake. While lower DMI is commonly explained as a result of reduced pH and greater incidence of acidosis, it may be primarily due to the amount and rate of propionate production. In general, DMI is inversely related to starch availability (Huntington, 1997). Wheat decreases DMI compared to corn and corn generally reduces DMI compared to milo (Stock et al., 1990). Extensive processing methods (Cooper et al., 2002) and increased moisture (Owens et al., 1997) can also reduce DMI. Propionate is a primary product of starch degradation in the rumen. Increased ruminal starch degradation results not only in more total VFA production per kilogram of OM but also in an increased proportion of propionate absorbed which appears to have hypophagic effects in ruminants for short-term control of intake (Allen et al., 2009).

Ultimately, the goal of optimal DMI to maximize energy intake and MCP production depends on the most advantageous rate of production and absorption of propionate which is influenced by the balance between ruminal degradation and postruminal digestion, particularly starch. In finishing diets containing various grain sources and processing methods, slight additions of NDF from roughage inclusion may be the best way to achieve this balance. This is because roughage NDF will likely promote salivary secretion and ruminal kinetics which promote increased ruminal pH and DMI (Arelovich et al., 2008). The effects of roughage in finishing diets are discussed in the following sections.

## *Roughage in Traditional Finishing Cattle Diets*

**Introduction.** Cattle are distinctive given that they are capable of utilizing diets containing grain levels from 0 to 100%; however, based on the survey by Vasconcelos and Galyean (2007), traditional roughages make up approximately 8.3 to 9.0% of finishing diets in the feedlot industry. The reported range was 0 to 13.5% which can result in large changes in cattle performance. The most common source was corn silage (CS; 41.4%), followed by alfalfa hay (31.0%) but also included sorghum silage (SS), cottonseed hulls (CSH), sudangrass hay, and cotton burrs. Of the respondents who generally test forages, 41.4% test for crude fiber (CF), 34.5% test for NDF, and 10.3% test for ADF.

Much time and effort has been devoted to understanding the value of roughages in finishing diets with most of it focusing on the effects on intake. This is likely because 1) changes in DMI are easily measured, 2) feed intake is necessary for all functions, 3) changes in dietary roughage source and level are typically related with changes in DMI, 4) many believe that variation in intake lead to acidosis and reduced performance, and 5) roughages can be expensive on an energy basis compared to corn. However, the biology behind the effects of roughage is still not completely clear.

Most previous research evaluating roughage in finishing diets has focused on the effects of one roughage versus another roughage or the effects of varying levels of roughage. However, focusing on how a specific roughage source or level affects DMI, ADG, digestibility, or ruminal kinetics is probably not the best way to evaluate the implications of roughage in finishing diets. It is clear that roughage sources have different

chemical and physical characteristics that directly and indirectly affect DMI and ruminal fermentation as well as total tract digestion which ultimately influence overall animal performance (White and Reynolds, 1969; White et al., 1971; Rust and Owens, 1981; Moore et al., 1990). Van Soest (1965) reported that voluntary DMI of forage by sheep was more highly correlated to NDF than to any other chemical measurement. In support of this, Waldo (1986) suggested that for ruminants, NDF is the best single chemical predictor of DMI. In addition, when using NDF as the only dietary factor to predict the energy content and filling effect of diets, DMI is positively correlated with dietary NDF when energy limits intake but when gut fill limits intake, DMI is negatively correlated with dietary NDF (Mertens, 1994). Defoor et al. (2002) conducted a study evaluating the effects of roughage source and level and reported that most variation in net energy intake of finishing cattle is explained by differences in the NDF content of the roughage. They observed a moderately strong positive relationship ( $r^2 = 0.68$ ) when  $NE_g$  intake/kg of  $BW^{0.75}$  was regressed against roughage NDF across 5, 10, and 15% roughage levels. Additionally, when roughage sources were exchanged on an equal NDF basis, there were minimal effects on DMI, ADG, and gain efficiency of finishing cattle (Theurer et al., 1999; Defoor et al., 2002; Markham et al., 2004). Therefore, when gut fill does not limit intake, it appears the more appropriate method is to evaluate the amount of NDF supplied by different sources or levels of roughage. For that reason, the following sections in this review will focus primarily on how NDF affects cattle fed finishing diets.

***Effects of NDF on Intake and Performance.*** The primary goal of roughage inclusion is to optimize DMI for maximal animal performance while avoiding health

problems such as acidosis. Because NDF levels are highly variable between roughage sources, ranging from 45% for alfalfa hay to 90% for cottonseed hulls, the actual NDF range commonly fed in the feedlot industry is likely to be much wider than the range in roughage inclusion as reported by Vasconcelos and Galvayan (2007).

Roughage is not absolutely necessary in high-grain finishing diets but addition of low levels of roughage will almost always promote greater DMI. With roughage additions to all-grain diets, ADG generally will either increase or not change (Stock et al., 1990; Huffman et al., 1992; Shain et al., 1999; Turgeon et al., 2010). Changes in feed efficiency appear to be dependent on the grain source and processing method and level of roughage.

Stock et al (1990) conducted several trials evaluating the effects roughage addition on performance of cattle fed finishing diets containing different grain types. In Trial 2, cattle were feed dry-rolled corn, milo, or wheat (DRC, DRM, DRW, respectively) with either 0 or 7.5% roughage that consisted of a 50:50 blend of alfalfa hay and corn silage. This trial was designed to evaluate the rate of starch fermentation with DRM being the slowest and DRW being the fastest. Addition of 7.5% roughage increased total DMI for all three grains. There was a tendency for total DMI to increase more for cattle fed DRM and DRC diets compared to cattle fed DRW diets. Concentrate intake increased 0.48, 0.88, and 0.04 kg/d for cattle fed DRM, DRC, and DRW diets, respectively. Cattle fed DRW diets had increased ( $P < 0.02$ ) ADG with roughage addition while there was a trend for increased ( $P = 0.11$ ) ADG for cattle fed DRC diets with addition of roughage. Addition of roughage in DRM diets numerically decreased ( $P > 0.15$ ) ADG. Addition of 7.5% roughage decreased ( $P < 0.01$ ) feed efficiency for cattle fed

diets containing DRM or DRC but had no effect ( $P > 0.15$ ) on cattle fed DRW. In trial 3, cattle were fed DRC or DRW with 0 or 7.5% roughage as well as 0 or 27.5 mg monensin. Regardless of monensin level fed, the addition of roughage tended to increase DMI more for cattle fed DRC compared to DRW. With monensin addition, cattle fed DRC with 0 or 7.5% roughage had similar ADG (1.23 vs. 1.28) but ADG was increased for cattle fed 7.5% roughage with DRW. Feed efficiency was reduced for cattle fed DRC with the addition of roughage in contrast to improved feed efficiency for cattle fed DRW with addition of 7.5% roughage. Results from these two trials suggest that benefits from roughage may depend on the rate of starch digestion of the grain because cattle fed DRW responded more positively to roughage addition compared to cattle fed DRM or DRC. This implies that cattle fed DRW without roughage were likely experiencing more acidosis. Additionally, it appears that roughage addition to slowly fermented grains such as DRM may lead to increased passage rate and decreased total tract digestion which would decrease energy density of the diet and subsequent animal performance.

A finishing trial was conducted by Shain et al. (1999) to evaluate the effects of forage addition, forage source, and particle size in finishing diets. Cattle were either fed an all-concentrate diet containing 90% DRC or diets containing 10% alfalfa hay or 5.2% wheat straw. Diets were formulated to contain equal amounts of NDF provided from roughage. Additionally, alfalfa hay and wheat straw were ground through a 0.95, 7.62, or 12.70 cm screen. There were no forage source x particle size interactions ( $P > 0.10$ ) and particle size had no effect ( $P > 0.10$ ) on DMI, starch intake, ADG, or G:F. Cattle fed alfalfa hay or straw had increased ( $P < 0.05$ ) DMI and starch intake compared to steers fed no roughage and cattle fed straw had increased ( $P < 0.05$ ) starch intake compared to

cattle fed alfalfa hay. Steers fed alfalfa hay had greater ( $P < 0.05$ ) ADG compared to cattle fed straw or no roughage and G:F compared to cattle fed straw. Steers fed straw had numerically greater ADG but numerically lower G:F compared to steers fed no roughage since DMI was increased for steers fed straw. A metabolism study was also conducted by Shain et al. (1999) with similar dietary treatments which will be discussed in the following section.

In a study by Turgeon et al. (2010), they took the opposite approach and conducted six finishing trials to evaluate the effects of removing all roughage replaced by whole corn (WC) on cattle performance. Treatment diets consisted of various grain source and processing mixtures which included dry-rolled and high-moisture corn, and steam-flaked wheat or milo. The roughage levels ranged from 6.6 to 10.1% (DM basis) and included alfalfa hay, alfalfa pellets, sorghum silage, and cottonseed hulls (CSH). The no roughage diets contained between 7.5 to 22.8% WC which replaced all the roughage and some of the other grains. The results showed that including WC and no roughage in finishing diets lead to lower final BW, DMI, and ADG but feed efficiency was improved with only few noted differences in USDA quality and yield grades. The authors concluded that feeding WC and no roughage tended to increase dietary  $NE_g$  which should reduce feed cost because  $NE_g$  is generally less from grain compared to roughage and this would also lower the dependence on bulky, expensive roughages. However, final live weight and HCW were decreased for cattle fed no roughage in a majority of the trials so it is likely that profitability may also be decreased if no roughage is fed.

In a review of the literature, Galyean and Defoor (2003) performed a meta-analysis to evaluate the function of NDF supplied by roughage in relation to changes in

DMI. Using a mixed-model regression procedure, the random effects of trial on DMI (% BW) and the effects of dietary roughage level (% DM), roughage NDF level (% from roughage), roughage effective NDF level (eNDF; % of eNDF from roughage), and roughage  $NE_g$  (% from roughage) were evaluated. The database was developed based on changes in forage to concentrate ratio without contributions of NDF from byproducts and included 48 observations for treatment means from 11 trials with an average of 148 head per trial and dietary NDF ranged from 7.50 to 35.3%. The results from the regression analysis of trial-adjusted DMI in relation to roughage level, roughage NDF, and roughage eNDF all had significant ( $P < 0.01$ ) intercepts and slopes. The slope for roughage  $NE_g$  was not significant ( $P > 0.28$ ). The authors commented because dietary  $NE_g$  supplied by roughage was not related to DMI, accounting for the relatively small changes in energy intake from roughage do not explain the changes in DMI that are commonly observed due to changes in roughage source and level. Roughage level was moderately related ( $r^2 = 0.699$ ) to DMI but NDF ( $r^2 = 0.920$ ) and eNDF ( $r^2 = 0.931$ ) supplied by the roughage were highly related to DMI. The authors interpreted these results to imply that a majority of the changes observed in DMI due to changes in roughage source and level can be attributed to changes for dietary NDF supplied from roughage.

In a related article, Arelovich et al. (2008) performed a meta-analysis to evaluate relationships between DMI or  $NE_g$  with total dietary NDF for both beef and dairy cattle. For beef cattle, the database was the same as reported by Galyean and Defoor (2003) as discussed previously. Regression equations were developed for DMI, both as % of BW and as kg/d per animal, and for  $NE_g$ , as kcal/kg of  $BW^{0.75}$  or per unit of DMI (Mcal/kg of DMI). Dry matter intake in beef cattle was positively correlated with increasing dietary

NDF content both as % of BW or kg/d. Both correlations appeared to be equally important in relation to dietary NDF with  $r^2$  values of 0.954 and 0.965 for DMI as % of BW or kg/d, respectively. This is in agreement with observations made by Galvayan and Defoor (2003) based on NDF from roughage although the relationship between dietary NDF content and DMI ( $r^2 = 0.954$ ) was slightly stronger compared to the relationship between roughage NDF and DMI ( $r^2 = 0.920$ ). Overall, it appeared that either dietary NDF or roughage NDF would be useful to 1) predict DMI of finishing cattle and 2) formulate diets to utilize different roughage sources (Galvayan and Defoor, 2003; Arelovich et al., 2008).

In the meta-analysis of Arelovich et al. (2008), increasing dietary NDF was also highly correlated ( $r^2 = 0.859$ ) with  $NE_g$  (kcal/kg of  $BW^{0.75}$ ). However,  $NE_g$  per unit of DMI was not related to dietary NDF content at all with an  $r^2$  of 0.001. This is in contrast to results observed in the dairy cattle database whereby increasing dietary NDF was highly correlated to decreasing  $NE_l$  (kcal/kg of  $BW^{0.75}$  or Mcal/kg of DMI) with observed  $r^2$  values of 0.815 or 0.846, respectively. The authors noted that the different response in DMI to increasing dietary NDF between beef and dairy cattle is likely because dietary NDF was only 16.0% for beef cattle compared to 32.7% for dairy cattle. Intake of dairy cattle is probably limited due to gut fill so an increase in NDF would further limit intake. This is in agreement with a study conducted by Yang and Beauchemin (2009) which evaluated the effect of forage to concentrate ratio in dairy cows. The forage to concentrate ratio was increased from 35:65 to 60:40 by increasing the amount of alfalfa silage and decreasing the amount of DRC which caused the dietary NDF level to increase from approximately 28.1 to 31.8%, respectively, and DMI decreased from approximately



25.1 to 22.9 kg/d, respectively. On the other hand, DMI of feedlot cattle is probably regulated by metabolic factors rather than gut fill. Furthermore, the typical observed increase in DMI due to increased roughage (i.e. NDF) level is likely caused by one of two reasons: 1) large changes in roughage NDF typically explained as an energy dilution effect whereby the animal eats more feed to maintain energy intake or 2) slight increases in roughage NDF levels which promote increased DMI due to changes in digestion kinetics.

Increased DMI to maintain energy intake may be possible until roughage limits intake. It is not clear, though, whether cattle actually modify their DMI to match their energy needs. Allen et al. (2009) indicated that it is doubtful that cattle actually consume meals to meet an energy requirement but it is more likely that feeding behavior is regulated by fuel-specific mechanisms as previously describe with the HOT. This will be discussed in more detail in the next section.

When gut fill does not impact intake, slight additions of roughage NDF will likely stimulate ruminal kinetics and promote DMI which may actually lead to greater total energy intake (Galyean and Defoor, 2003). Increased DMI due to additional roughage NDF is supported by the relatively high correlation ( $r^2 = 0.859$ ) between dietary NDF and  $NE_g$  intake (kcal/kg of  $BW^{0.75}$ ) as observed by Arelovich et al. (2008). Arelovich et al. (2008) suggested that increased DMI due to slight increases in NDF content may lead to possible benefits related to ruminal function and lower occurrence of acidosis while negative effects on G:F should be limited. Consequently, increasing roughage level up to or beyond the point where gut fill limits intake results in a quadratic effect on energy intake, daily gain, and feed efficiency. Furthermore, the response to additional roughage

may be dependent on 1) the rate of starch digestion of the grain, 2) the actual increase in roughage NDF level, and 3) feeding management.

Milton et al. (1994) conducted a finishing study evaluating 0, 4, or 8% roughage in WC diets. As roughage level increased, total DMI increased linearly ( $P < 0.05$ ) but concentrate intake was not different. There was a trend ( $P = 0.20$ ) for increased ADG for cattle fed 8% roughage (1.49 kg) compared to cattle fed 0 or 4% roughage (1.42 kg). As roughage level increased, HCW, 12<sup>th</sup> rib fat depth, and marbling score linearly increased ( $P < 0.10$ ). Gain efficiency linearly decreased ( $P < 0.10$ ) and cost of gain slightly increased with increased roughage but concentrate gain efficiency was not different and slightly increased for cattle fed 8% roughage. Compared to cattle fed 0% roughage, more weight was sold and liver abscesses were decreased almost 4-fold for cattle fed 8% roughage. The inverse relationship between roughage level and incidence of liver abscess has been clearly shown in other studies as well (Brent, 1976; Brink et al., 1990). The results of the study conducted by Milton et al. (1994) suggest that feeding 8% roughage in WC diets was optimal because of increased profitability and decreased metabolic problems.

Xiong et al. (1991) conducted a trial to evaluate the effect of roughage level and feeding management in steam-flaked milo (SFM) diets. Cottonseed hulls (CSH) were fed at 9 or 18% of the dietary DM and cattle were either fed ad libitum (AD) or at 2.9 times maintenance (MM) in an attempt to reduce daily variation in feed intake. There was an interaction between feeding management and CSH level for DMI and ADG. Cattle fed 9% CSH had similar DMI and ADG when fed either AD or MM but cattle fed 18% CSH tended ( $P = 0.10$ ) to have increased DMI and ADG when fed AD compared to MM.

Across feeding management, cattle fed 18% CSH had increased DMI, decreased gain efficiency, and tended ( $P < 0.15$ ) to have increased ADG and concentrate gain efficiency compare to cattle fed 9% CSH. The results suggest that feeding 18% CSH is optimal when feeding SFM diets ad libitum but it is beneficial to fed 9% CSH when daily feed intake variation is reduced.

In a study by Bartle et al. (1994), cattle were fed SFM finishing diets containing either alfalfa hay (ALF) or CSH at 10, 20, or 30% of dietary DM. For cattle fed 10 or 20% ALF, ADG was similar but decreased for 30% ALF. However, ADG was decreased for cattle fed 20 or 30% CSH compared to cattle fed 10% CSH. Because CSH have greater NDF content compared to alfalfa hay, DMI increased and gain efficiency decreased more for cattle fed CSH compared to alfalfa hay as roughage level increased. This suggests that cattle fed SFM diets containing 30% ALF and 20 or 30% CSH were not able to increase DMI enough to maintain ADG, probably due to gut fill.

Gill et al. (1981) evaluated five roughage levels (8, 12, 16, 20, and 24% corn silage-alfalfa hay mixture) in high-moisture corn (HMC), steam-flaked corn (SFC), and a mixture of HMC and SFC in a finishing study with 240 steers. Across corn types, DMI increased and gain efficiency decreased as roughage level increased but concentrate intake and concentrate gain efficiency were not different. There was no effect of roughage level on ADG but the optimum roughage levels for the highest ADG when feeding HMC, a mix of HMC and SFC, and SFC were 16, 12, and 8% roughage, respectively.

In summary, it appears that addition of roughage NDF in concentrated grain-based diets is generally beneficial, especially for ADG, although the response to

increasing roughage levels is inconsistent and can be influenced by the rate of starch digestion of the grain and feeding management. There is clearly a complex interaction of many factors to work through to ultimately understand the complete effect of dietary NDF changes on subsequent animal responses. Most animal studies discussed to this point have shown a change in feed efficiency, good or bad, which indicate that changes in nutrient digestion and ruminal kinetics have occurred. The following section in this review will focus on how NDF affects metabolism and digestibility in cattle fed finishing diets.

***Effects of NDF on Metabolism and Digestion.*** Based on studies reviewed in the previous section, addition of NDF from roughage in grain-based finishing diets typically results in increased DMI and ADG although G:F is reduced. Roughage is normally included with the primary goal of optimizing DMI for the most favorable balance between energy intake, digestion, and absorption. This is a primary method used in finishing diets to manipulate the rate of ruminal production and absorption of propionate.

As previously mentioned, large increases in roughage NDF generally result in greater DMI which has typically been explained as an energy dilution effect whereby the animal eats more to maintain energy intake. However, Allen et al. (2009) commented that it is unlikely that cattle actually modify their intake to match a specific energy requirement. It is clear ruminal pH declines as cattle are fed increasing levels of grain. Therefore, lower dietary NDF leads to lower ruminal pH which favors production of propionate compared to acetate resulting in lower A:P ratios (Latham et al., 1974; Sudweeks, 1977; Lana et al., 1998; Coe et al., 1999). Allen et al. (2009) reported that

propionate was more hypophagic than both acetate and butyrate in sheep when infused directly into the portal vein. Additionally, propionate, but not acetate, reduced DMI in steers when infused into the mesenteric vein which is in agreement with HOT. Therefore, it may be expected for propionate to decrease DMI more than acetate due the fact that propionate has a greater energy concentration if cattle modify their intake to match their energy needs. However, in a study by Oba and Allen (2003), propionate and acetate were intraruminally infused as iso-osmotic mixtures into lactating dairy cows and propionate infusion resulted in a linear reduction in ME intake compared to acetate. Additionally, when the propionate proportion was increased, the decrease in dietary ME intake surpassed what was supplied by the infusate. When propionate was increased from 0 to 100% of the infusate, DMI decreased mainly from a linear decrease in meal size (2.5 to 1.5 kg of DM) which signifies greater satiety. Allen et al. (2009) commented that the depression in DMI due to propionate cannot just be explained as propionate supplying additional energy. They concluded that the feeding behavior of cattle is more likely regulated by fuel-specific mechanisms as previously describe with the HOT.

Furthermore, ruminally fermented starch may be used more efficiently but DMI is inversely related to starch availability (Huntington, 1997). Consequently, increased ruminal starch degradability can decrease DMI resulting in lower energy intake. In an all-concentrate diet, high starch intake and degradability lead to increased total VFA production which may result in a greater incidence of acidosis. The rate and amount of VFA production, specifically propionate, can be reduced by decreasing the dietary starch concentration and by improving MCP efficiency (Allen et al., 2006). Inclusion of low roughage levels is a common method used to decrease the dietary starch concentration

which also generally reduces ruminal starch digestion and propionate production while MCP efficiency is increased (Cole et al., 1976a, b). Since NDF generally stimulates rumen motility which would lead to increased VFA absorption, the effects of NDF supplied from roughage are likely due to greater salivary secretion and rate of passage which shifts the site of digestion from the rumen.

Ultimately, by slightly reducing ruminally degraded starch, the acid load in the rumen and the incidence of acidosis are lowered while ruminal pH and DMI are increased. Furthermore, increased DMI leads to increased energy consumption and MCP efficiency which in turn may stimulate postruminal starch digestion which is more energetically efficient so the overall result is much greater energy available to the animal for growth.

In a study conducted by Shuey et al. (1994), four ruminally cannulated steers were used in a 4 x 4 Latin square with a 2 x 2 treatment structure to evaluate the effects of corn processing (WC or DRC) and roughage addition (0 or 8% alfalfa hay) on incidence of subacute acidosis. Periods were 15 d long. On d 1 to 10, cattle were fed 1% of BW at 0800 and 2000 and on d 11, feed was withheld at 2000. On d 12, cattle were fed 1.5% of BW in the bunk at 0800 and then ruminally dosed with feed at 1% of BW at 0930. On d 13 to 15, cattle were fed twice daily at 1% of BW during an intake recovery period. There was no effect on total VFA production or molar percentage of acetate. For cattle fed WC and 8% alfalfa hay, propionate production was decreased and the A:P ratio was increased compared to cattle fed WC without roughage. For cattle fed DRC, there were no effects on propionate production or A:P ratio due to roughage addition. For cattle fed WC or 8% alfalfa hay, time below pH 5.6 was decreased compared to cattle for DRC

or no roughage. Ruminant pH was decreased for cattle fed DRC or no roughage at 3 and 6 h post feeding on the challenge day compared to cattle for WC or 8% alfalfa hay. Intake during the recovery period was increased for cattle fed 8% alfalfa hay compared to cattle fed no roughage. The authors concluded that either feeding WC or 8% alfalfa hay decreased the incidence of acidosis. This is agreement with results from a similar finishing study conducted by Milton et al. (1994) as discussed previously.

In a study conducted by Cole et al. (1976a, b), four ruminally and abomasally cannulated steers were used in a metabolism study to evaluate the effects of roughage level in WC finishing diets. Cottonseed hulls were fed at 0, 7, 14, or 21% of the dietary DM and steers were fed at 90% of maximum intake. Rumen samples were collected and analyzed for pH at time of sampling and for VFA. Feed, abomasal and fecal samples were collected and analyzed for DM, nitrogen, cellulose, starch, and lignin. Microbial N was calculated based on abomasal RNA with the assumption that 10% of total microbial N was represented by RNA-N. Total tract digestion, in grams per day (g/d), was calculated for DM, cellulose and starch by total feed and fecal collection and ruminal digestion, in g/d, was calculated using lignin in a marker ratio technique. Intestinal digestion, also g/d, was calculated by difference. Rumen degradation and total tract digestibility (TTD) coefficients were also calculated as a percentage of total intake and intestine digestibility coefficients were calculated as a percentage entering the intestine. Overall intakes in this trial were very low and only averaged 5.33 kg/d or 1.37% of BW.

Dry matter, N, and cellulose intake were increased with addition of CSH to WC diets and with increasing CSH levels. Starch intake was similar for cattle fed 0, 7, or 14% CSH but was reduced for cattle fed 21% CSH. Addition of CSH had no effect on the

grams of DM ruminally or intestinally digested although the intestinal digestion numerically increased for cattle fed CSH. Grams of starch ruminally digested tended to decrease but grams of starch intestinally digested tended to increase with addition of CSH. Total tract DM and starch digestion were similar between cattle fed 0, 7, and 14% CSH but cattle fed 21% CSH had increased total tract DM digestion and reduced total tract starch digestion, likely due to reduced starch intake. Grams of ruminally digested cellulose was increased for cattle fed CSH and with increasing CSH levels but intestinal cellulose digestion was only increased for cattle fed 21% CSH. Total tract cellulose digestion was increased for cattle fed CSH and for cattle fed 21%. Microbial protein efficiency was increased due to addition of CSH and tended to increase with increasing CSH levels (Cole et al., 1976b).

Addition of CSH to WC diets reduced ( $P < 0.10$ ) the percentage DM, cellulose, and starch ruminally degraded but increasing levels had no effect on ruminally degraded DM, cellulose, and starch. The percentage of N ruminally degraded was similar between 0 and 7% CSH but was decreased for 14 or 21% CSH. Roughage had no effect on the percentage of DM or cellulose intestinally digested but the percentage of starch and N intestinally digested was decreased for cattle fed 14% CSH. Addition of CSH reduced TTD of DM, cellulose, and N and cattle fed 14% CSH had the lowest TTD for DM, cellulose, and starch. Roughage had no effect on ruminal pH, total VFA concentrations, or molar percentage of acetate. Compared to cattle fed no roughage, total VFA production was numerically increased for cattle fed 21% CSH and acetate production was numerically increased in cattle fed CSH. Propionate production was decreased for cattle fed 7 or 14% CSH but was not different between cattle fed 0 or 21% CSH. The A:P ratio



was increased for cattle fed 7% but not different for cattle fed 0, 14, or 21% CSH (Cole et al., 1976a, b).

In a study conducted by Crawford et al. (2008), two metabolism trials were conducted to evaluate the effects of roughage level in finishing diets. In trial 1, ruminally and duodenally cannulated steers were used to evaluate 3.8, 7.6, or 11.4% CS in SFC finishing diets. Intake of DM, OM, and N numerically increased with increased roughage levels. Intake of NDF and starch were numerically lower for cattle fed 3.8% CS. Ruminal digestion and microbial efficiency were not affected but as roughage level increased, ruminal N and NDF digestion numerically increased linearly. Postruminal digestion as a percent of total intake numerically decreased for OM, NDF, and N. Postruminal digestion as a percent leaving the abomasum decreased for OM and starch and numerically decreased for NDF and N. There were linear decreases for TTD of OM and starch and TTD of NDF numerically increased. Average ruminal pH increased linearly with increasing roughage levels. Cattle fed 3.8% CS had numerically lower molar proportion of acetate, and A:P ratio and a numerically greater molar proportion of propionate. There were no effects on total VFA production, fluid dilution rate, retention time, or fluid flow rate.

In trial 2, ruminally and duodenally cannulated steers were used to evaluate 4.5, 9.0, or 13.5% alfalfa hay in finishing diets containing a 20:80 blend of DRC and HMC. Dry matter and NDF intake were numerically lower for cattle fed 4.5% alfalfa hay and starch intake was numerically lower for cattle fed 13.5% alfalfa hay. Cattle fed 9.0% alfalfa hay had numerically greater time spent eating per day and per meal. There was no affect on TTD although TTD of OM, NDF, and CP numerically decreased linearly with

higher roughage levels. Average, maximum, and minimum ruminal pH linearly increased and time spent below pH 5.6 and 5.3 linearly decreased with higher roughage levels.

Cattle fed 13.5% alfalfa hay had numerically lower molar proportion of propionate and numerically greater molar proportion of acetate and A:P ratio. There were no effects on fluid or solids dilution rate although cattle fed 13.5% alfalfa hay had numerically greater dilution rates for both fluid and solids.

Other studies have also observed decreased TTD for DM, OM, starch, and ADF. In a study by Goetsch et al. (1984), the effect of roughage addition (0 or 12% CSH and alfalfa hay blend) on digestibility in rolled milo diets was evaluated. Organic matter and N intakes were similar but cattle fed 12% roughage had decreased starch intakes and increased ADF intakes. Total tract digestibility of OM, starch, and ADF were decreased for cattle fed 12% roughage but N digestibility was not affected. Ledoux et al. (1985) evaluated the effects of 4, 8, 16, and 24% fescue hay in WC diets and total tract DM, starch and ADF digestibility was linearly decreased as roughage level increased but total tract NDF and N digestibility was not affected. Rumen pH and buffering capacity were also not affected by roughage level.

Moore et al. (1990) conducted a metabolism trial to evaluate the effects roughage source on digestibility in finishing diets containing SFM. Cattle were fed diets containing approximately 34.5% roughage and roughages included alfalfa hay, a 50:50 blend of alfalfa hay and CSH, or a 50:50 blend of alfalfa hay and wheat straw. Total tract digestion of DM and NDF were reduced in cattle fed the alfalfa hay/CSH blend and rumination time was increased for cattle fed the alfalfa hay/straw blend. Total tract

passage rate was not different for SFM, alfalfa hay, or liquid but was reduced for CSH and straw. Passage rates were increased in diets containing the alfalfa hay/CSH blend.

In a metabolism study conducted by Moore et al. (1987, as cited by Galyean and Defoor, 2003), ruminally cannulated steers were fed a 90% SFM diet containing either alfalfa hay, wheat straw, or CSH to evaluate the effects of roughage source in finishing diets. Cattle fed straw had increased rumination time compared to cattle fed CSH or alfalfa hay but ruminal pH was not different although pH was numerically increased for cattle fed straw (6.2) compared to cattle fed alfalfa hay (5.9) and CSH (5.8). Cattle fed CSH tended to have increased ruminal fill compared to cattle fed alfalfa hay or straw. The percentage of ruminal DM in the fiber mat was highest for cattle fed straw (19.9%) and there was a tendency for cattle fed CSH (2.4%) to have an increased percentage of ruminal DM in the fiber mat compared to cattle fed alfalfa hay (0%).

A metabolism study was conducted by Shain et al. (1999) to evaluate the effects of forage addition, forage source, and particle size in finishing diets. Six ruminally cannulated steers were used in a 6 x 6 Latin square. Cattle were either fed an all-concentrate diet containing 89% DRC or diets containing 10% alfalfa hay, 5.6% wheat straw, or 5.4% corncobs. Diets were formulated to contain equal amounts of NDF provided from roughage. Additionally, alfalfa hay and wheat straw were ground through a 2.54 or 12.70 cm screen. Cattle fed 2.54 cm straw had increased ( $P < 0.10$ ) DMI compared to cattle fed corncobs or no roughage and cattle fed alfalfa hay or straw had numerically greater DMI (10.16 kg/d) compared to cattle fed corncobs (9.21 kg/d) or no roughage (9.38 kg/d). Cattle fed corncobs or no roughage had a greater ( $P < 0.10$ ) percentage of ruminal DM compared to cattle fed alfalfa hay or straw. Ruminal fill was

increased ( $P < 0.10$ ) for cattle fed corncobs and numerically greater for cattle fed no roughage compared to cattle fed alfalfa hay or straw. There was no effect of diet on in situ rate of ruminal starch disappearance although cattle fed no roughage had numerically lower rate (2.85%/h) compared to cattle fed diets containing roughage (3.21%/h).

Cattle fed 12.70 cm straw had increased ( $P < 0.10$ ) ruminal pH compared to cattle fed 12.70 cm alfalfa hay, corncobs, or no roughage and ruminal pH of cattle fed straw (5.90) was numerically increased compared to all other treatments (5.68). Steers fed straw had decreased total VFA production and increased molar proportions of acetate compared to steers fed 12.70 cm alfalfa hay or no roughage. Additionally, steers fed straw had decreased molar proportions of propionate and a greater A:P ratio compared to steers fed no roughage or corncobs. Cattle fed straw spent more time ruminating and more total time chewing compared to cattle fed alfalfa hay, corncobs, or no roughage. No differences were observed in ruminal passage rates of liquid, corn, or forage.

Based on the studies reviewed here, addition of low levels of roughage NDF to all-concentrate diets generally increased daily intake of DM, cellulose, and ADF, and possibly CP. When roughage NDF levels are increased, DM, OM, NDF, cellulose, and N intakes usually increase linearly. Effects of roughage NDF on starch intake are mixed and appear to be dependent on grain processing. Ruminal, intestinal, and total tract digestibility of DM and OM appear to decrease with addition of increased levels of roughage NDF. Ruminal starch degradation was decreased linearly in the study by Cole et al. (1976a) but was not affected in two trials conducted by Crawford et al. (2008). In the trial by Shain et al. (1999), the rate of in situ starch disappearance was increased for cattle fed roughage. Intestinal digestion in g/d appears to be increased due to roughage

but the percentage of intestinal and total tract digestion of starch appears to be reduced with addition or increasing levels of roughage NDF. Ruminant, intestinal and total tract cellulose digestion in g/d was increased linearly in the study by Cole et al. (1976a) but the percentage of cellulose digested ruminally or total tract was decreased. Ruminant digestion of NDF may be increased but intestinal NDF digestion appears to be decreased when roughage NDF levels are increased. Results are mixed for total tract NDF digestion and may be influenced by grain processing. Total tract ADF digestion is reduced with roughage addition and increased levels of roughage NDF. Ruminant digestion of CP may be decreased with higher levels of roughage and intestinal digestion of CP appears to be reduced with addition or increasing levels of roughage NDF. Total tract CP digestion appears to be unaffected by roughage.

Total VFA production was not affected by addition of roughage with one exception. In the trial conducted by Shain et al. (1999), cattle fed straw had reduced total VFA compared to cattle fed no roughage or alfalfa hay on an equal NDF basis. Addition or increasing levels of roughage NDF generally reduce molar proportions of propionate and increase the molar proportion of acetate and the A:P ratio. Addition of roughage NDF or increasing roughage NDF level in grain-based diets appears to increase ruminal pH and time spent ruminating while the time spent below ruminal pH 5.6 and 5.3 is decreased which suggests that the incidence of acidosis is reduced. Increased chewing and rumination leads to increased salivary secretion (Welch, 1982). Diet formulations, such as addition of roughage NDF, that increase time spent chewing and saliva output increase ruminal pH and promote ruminal digestion by diluting fermentable substrate and by decreasing VFA concentrations. As mentioned, greater ruminal pH favors production

of acetate compared to propionate resulting in greater A:P ratios. Based on H<sub>2</sub>O, lower propionate production will promote greater DMI which may lead to increased total energy intake.

In the study by Shain et al. (1999), a positive relationship ( $r = 0.80$ ) was observed between total time chewing and ruminal pH. In dairy cattle, forage NDF was correlated positively with time spent chewing ( $r^2 = 0.66$ ) and ruminal pH ( $r^2 = 0.63$ ), as observed by Allen (1997) who noted that the balance between production of VFA and salivary secretion is a key determinant of ruminal pH. This helps explain the positive relationship observed by Galyean and Defoor (2003) and Arelovich et al. (2008) between DMI of beef cattle and roughage NDF or dietary NDF. This is further supported by the relatively high correlation ( $r^2 = 0.859$ ) between dietary NDF and NE<sub>g</sub> intake (kcal/kg of BW<sup>0.75</sup>) in beef cattle as observed by Arelovich et al. (2008).

### ***Corn-Milling Processes for Ethanol Production***

***Introduction.*** There are two major processes used to produce ethanol from starch in cereal grains: dry milling (Figure 1) and wet milling (Figure 2). In dry milling, the dry grain is cleaned and finely ground to reduce the particle size and the entire kernel is used in the fermentation process. The wet milling process removes the maximum amount of starch from other components in the kernel by first adding water to the grain and allowing it to steep and then the wet kernel is coarsely ground. The starch is then converted to dextrose to be used in the fermentation process to produce ethanol. Currently, wet milling only produces approximately 12% of the ethanol used for fuel in

the U.S. while the dry milling industry produces the rest. These two processes produce substantially different byproducts to be used in the feed industry. These two processes and their respective byproducts are discussed in more detail below.

***Dry-Milling Process.*** The dry-milling process represents approximately 88% of the fuel grade ethanol produced from cereal grain fermentation in the United States (Renewable Fuels Association, 2010). Dry mill plants have one primary purpose and that is to produce fuel grade ethanol but they also produce carbon dioxide and distillers byproducts. In the past, dry mill plants were primarily producer owned due to decreased capital investments compared to wet milling and created direct benefits to rural economies. However, with most of the recent expansion in the ethanol industry attributed to the dry milling industry, several dry mill plants are now corporate owned. One advantage that dry milling plants have compared to wet milling is the flexibility to utilize different types and qualities of grains (Stock et al., 2000). There are multiple resources available describing the dry-milling process for ethanol production (Stock et al., 2000; Bothast and Schlicher, 2005; Rausch et al., 2007; Nichols and Bothast, 2008; ICM Incorporated, 2009). The following information, taken from these references, is intended to provide a general overview of the dry milling process and it should be noted that there are other processes and modifications for converting corn to ethanol.

In the dry milling process, there are four basic steps used to convert corn to ethanol which include milling, liquefaction, simultaneous saccharification and fermentation (SSF), and ethanol recovery. In the first step, grain is cleaned to remove chaff and other debris and then milled into coarse flour. The two types of mills used are

hammer mills and roller mills. The optimum particle size for this process is one that maximizes the availability of starch for fermentation but allows unfermented particles to be separated easily at the end of the process. The flour is mixed with water to create a slurry for the second step and the pH of the mash is adjusted to about 5.8 along with the addition of a thermostable  $\alpha$ -amylase. During the liquefaction process, the slurry is first heated to 85°C for 30-45 min to decrease viscosity. The second phase is to send the slurry through a jet cooker for 5 min at 105°C and then through a flash condenser to cool the slurry down. The final phase of the liquefaction process is to allow the  $\alpha$ -amylase time to hydrolyze the starch into dextrans by holding it at 85°C for 1-2 h. After cooking is complete, the temperature and pH are reduced to 32°C and 5.0, respectively. At the same time, glucoamylase is added and the mixture is sent to fermentation tanks for the third step.

In the third step, simultaneous saccharification and fermentation, the mixture is now referred to as mash. Fermentation yeast, primarily *Saccharomyces cerevisiae*, which is also referred to as brewer's or baker's yeast, is added to the mash along with the glucoamylase. The glucoamylase breaks the dextrans down into glucose and maltose which are quickly converted to ethanol by the yeast. The fermentation process is completed after 50-60 h and the mash now contains about 15% ethanol as well as solids from grains and yeast. The theoretical yield per gram of glucose is 0.51 g of ethanol and 0.49 g of carbon dioxide. However, under production conditions, the actual ethanol yield is about 90-93%. This is primarily due to some glucose being used for production of glycerol and other fermentation products. During the fermentation process, as the yeast ferments the simple sugars into ethanol, they also produce large amounts carbon dioxide



gas. This carbon dioxide can then be captured, purified, and marketed, primarily to the food processing industry for flash-freezing foods and carbonated beverages but can also be used to produce dry ice. In more recent applications, carbon dioxide may be captured and used for production of algae oils that can be converted to oil-based fuels such as biodiesel.

The final step in the dry milling process is referred to as the ethanol recovery. In this step, the mash is first sent through a multi-column distillation system which exploits the differing boiling points of ethanol (78°C) and water (100°C). When the gaseous ethanol leaves the distillation column, it contains about 95% ethanol which is 190 proof. The remaining liquid and solids are sent out for byproduct processing discussed in the next section. The gaseous ethanol leaves the distillation system and is cooled back down into a liquid to be sent through a dehydration process to remove the last 5% water. To do this, the liquid is sent through a molecular sieve and the product is anhydrous ethanol which is 200 proof. To complete the process, the anhydrous ethanol is blended with a denaturant, such as 5% gasoline, to render it unfit for human consumption.

*Dry-Milling Byproducts.* There are multiple resources available describing the processing methods for production of various distillers byproducts for the livestock industry (Stock et al., 2000; Davis, 2001; Bothast and Schlicher, 2005; Rausch et al., 2007; Nichols and Bothast, 2008; Huls et al., 2008; ICM Incorporated, 2009). Some of these byproducts include condensed distillers solubles (CDS), also called syrup, distillers grains (DG), and a mixture of CDS and DG (DGS)

The solid and liquid portion remaining after distillation during ethanol recovery, called whole stillage (WS), includes fiber, protein, oil, unfermented starch, and minerals from the corn as well as yeast cells from the fermentation process. In the initial step of byproduct processing, the WS goes through a centrifugation process to separate it into thin stillage (TS) and wet distiller grains (WDG) but this could also be done with extruders or presses. The WDG may be dried down to produce dried distillers grains (DDG) and both can be marketed as feed ingredients. About one third of the TS is recycled into the system to reduce the amount of clean water needed in the dry milling process. The other two thirds are sent through an evaporation system to produce CDS which is either marketed as a feed ingredient or added to the WDG to produce wet distillers grains plus solubles (WDGS). The WDGS can also be dried down to produce dried distillers grains plus solubles (DDGS) and this extends the shelf life and makes it more economical to ship long distances by truck or rail. A third option may be to partially dry the WDG before adding the CDS which allows for more CDS to be added to the WDG and this produces modified distillers grains plus solubles (MDGS).

Currently, the progression of the dry mill industry is aimed at adding value to byproducts by implementing some of the biorefinery capabilities of wet milling plants. Fractionation processes of the modified dry-milling processes include quick germ (QG), quick germ quick fiber (QGQF), and enzymatic dry milling (E-milling). Only the germ is recovered in the QG process and the germ and pericarp fiber, i.e. bran, are recovered in the QGQF process. The germ, pericarp fiber, and endosperm fiber are recovered in the E-milling process. The major feed byproduct produced from the fractionation processes is a DDGS with reduced fiber and increased protein content referred to as HP-DDGS (Singh

et al., 2005). A similar fractionation process, referred to as BFRAC™ process, is used by POET®. This process also removes the bran and germ before fermentation and the product resulting after fermentation is DDG which is more concentrated in protein. The solubles, which is much lower in fat compared to traditional CDS, can be added back to either the bran to produce distillers bran or to the distillers germ which is then dried to about 90% DM (Dakota Gold Products, 2009). Benefits from these processes include corn oil, purified fiber, improved protein quality of DG, and improved fermentation rates and ethanol concentrations.

***Wet-Milling Process.*** The wet milling process is a more complex process than traditional dry milling and is generally more capital intensive and corporate owned due to the equipment requirements. The primary goal of wet milling is to isolate the starch from the endosperm but wet milling has evolved into an industry trying to find optimum use and maximum value from all parts of the corn kernel. The wet milling process produces many different products such as corn oil, starch, corn syrup, ethanol, and byproducts for the feed industry. These byproducts include condensed corn fermented extractives (steep liquor), germ meal, bran, gluten meal, distillers solubles (DS), and corn gluten feed (CGF). From an average bushel of corn which weighs 56 pounds, the wet milling process produces 31.5 lb of corn starch, 12.5 lb of corn gluten feed, 2.5 lb of corn gluten meal, and 1.6 lb of corn oil (Davis, 2001). Numerous resources are available which outline the wet milling process (Blanchard, 1992; Stock et al., 2000; Davis, 2001; Corn Refiners Association, 2008). Below is a general overview of the wet milling process from information taken from these references.

The process begins with inspection and cleaning of the incoming corn grain. Since several of the products are produced for human consumption, grain quality is essential and #2 grade corn is used in the United States wet milling industry. Cleaning involves screening the corn twice to remove cob, fines, chaff, and foreign material.

The cleaned whole kernels are then steeped in large stainless steel tanks containing a 0.1% sulfurous dioxide solution at approximately 50°C for 30 to 40 h. Clean water is first used to wash the pure starch and then goes backwards in the system to clean various separated corn components until it ends up being used in the steeping process. Mill water is treated with 0.1% sulfurous dioxide which helps breakdown the protein/starch matrix and the waxy outer layer of the seed coat. The corn is fermented by naturally occurring lactic acid producing bacteria which ferment simple sugars to further soften the kernel and lower pH which inhibits growth of yeast and other undesirable organisms so that alcoholic fermentation does not occur. The kernels will absorb the treated process water which causes them to more than double in size. The moisture content of the kernel increases from around 15% to 45%. During the steeping process, the kernels soften and gluten bonds begin to loosen within the corn and release the starch.

After steeping, the soaked kernel is coarsely ground to break the germ loose and then spun using cyclone separators to remove the germ from the slurry. The germ, which contains about 85% of the oil, is then cleaned, dried, and put through a combination of mechanical and solvent processes to extract the oil which is refined into finished corn oil. The remaining germ, called germ meal, is saved and used as animal feed. The corn and water slurry then undergo a second, more intensive, grinding and screening process to separate the starch and gluten from the fiber. The starch and gluten suspension, called the

mill starch, is then put through a series of centrifuges to separate the gluten from the starch. The starch, which only contains one or two percent protein, is washed and centrifuged many times to produce high quality, 99.5% pure starch. The fiber and gluten components are saved and used for animal byproducts.

The starch can then be dried and sold as unmodified starch or processed into several products. This may include specialty starches, corn syrup, high-fructose corn sweetener, dextrose (D-glucose), or ethanol. Conversion of starch into different products is a multi-step process. Initially, the starch is liquefied in an acid and/or enzyme ( $\alpha$ -amylase) solution which produces a low-dextrose solution. Treatment with other enzymes, such as  $\beta$ -amylase or glucoamylase, will continue the conversion process. At any time during the conversion process, the acid or enzyme actions can be stopped to produce different products to meet specific needs. It can be stopped early for low sweetness sugars or it can progress until it is almost completely all dextrose. After the conversion process is stopped, the syrup is refined and excess water is evaporated so that it can be marketed, crystallized into pure dextrose, or further processed to produce high-fructose corn sweetener. One last option in the wet milling industry may be to produce ethanol. Dextrose is a very fermentable sugar and can be converted by traditional yeast processes to produce ethanol, carbon dioxide, and distillers solubles.

*Wet-Milling Byproducts.* During the wet-milling process, soluble nutrients are absorbed into the water. As mentioned, water enters the process converse to the entry of whole kernels, so the flow of starch and liquid is opposite. After steeping, the portion of the liquid not absorbed by the corn is separated as steep liquor and contains 5 to 10%

solids (Blanchard, 1992). Another liquid stream in the wet-milling process is the remaining liquefied solution after production of ethanol referred to as distillers solubles which contains yeast cells and unfermented sugars. The steep liquor and DS then go through an evaporation process separately or together to produce a 40-45% DM product and the combined products are called steep (Stock et al., 2000). Steep can be marketed several ways including as a liquid protein source, as a pellet binder, as a source of B-vitamins and minerals, or combined with other byproducts to produce CGF (Davis, 2001).

The next byproduct produced from wet milling is the germ meal, left over from oil extraction. Because the germ is dried to increase corn oil yield, germ meal is typically 90% DM. Corn germ meal has a good amino acid balance which favors its use in poultry and swine diets (Davis, 2001). In some plants, germ meal may also be used to produce CGF.

The primary fiber component of the corn kernel separated during wet milling is called bran and is the outer coating of the kernel. It is typically pressed after separation to remove water and contains approximately 40% DM (Stock et al., 2000). Bran can be further dried down to 85% DM but bran is seldom marketed as an individual ingredient and is typically incorporated with steep to produce CGF (Blanchard, 1992).

In the last separation step of wet milling, gluten is removed from the starch. This gluten protein, called corn gluten meal (CGM), is concentrated, dried, and marketed as a high protein feed ingredient. Corn gluten meal is a good source of methionine and xanthophylls which makes it appealing for the pet and poultry industry (Herold, 1999).

By mixing some of the byproducts of the wet milling process, CGF is produced. Corn gluten feed generally contains bran and steep liquor (plus DS depending on the plant) but may also include germ meal and corn screenings of broken and small kernels. Corn gluten feed can be marketed in a wet form or dry form. Generally, all the steep cannot be added back to the wet bran. If the bran is first dried, a larger proportion of steep can be added (Stock et al., 2000).

### ***Nutrient Composition and Variation of Corn-Milling Byproducts***

***Introduction.*** On average, corn contains 70.8% starch, 9.39% CP, 4.18% fat, 10.4% NDF, 3.45% ADF, and 1.50% ash. The mineral composition includes 0.32% P, and 0.10% S. The undegradable intake protein (UIP) content of corn is 61.1% of CP (NRC, 1996; Belyea et al., 2004; Dairy One Forage Lab, 2010). This is primarily because zein is the main protein fraction in corn and zein protein is slowly degraded in the rumen because it is associated with the cell wall. Zein makes up an increased proportion of the protein as the CP concentration of corn increases (Sniffen et al., 1992).

Starch is the primary nutrient in corn with a normal range between 65.0 to 75.3%, as reported for 3,075 corn samples analyzed by Dairy One Forage Lab (2010) from May 1, 2000 through Apr. 30, 2009. The observed SD for starch content was 5.03. The normal ranges referenced in this review as reported by Dairy One Forage Lab represent a reference range or prediction interval of values that 68% (or one standard deviation) of analyzed samples fall into. Since starch is the primary nutrient removed during dry-milling ethanol production and it is approximately two-thirds of corn, the remaining

nutrients found in distillers byproducts should be three times more concentrated.

Therefore, Shurson and Alghamdi (2008) stated that normal variation in the composition of corn, based on variety and geographical location, can explain most variation in the composition of distillers byproducts. However, Belyea et al. (2004) tested corn and DDGS from one ethanol plant over five years and showed that variation in DDGS was not correlated with variation in corn composition and concluded that variation in DDGS was most likely due to variation in processing factors of the plant.

Since most dry-milling plants still operate today with the main goal of producing ethanol, this generally results in variation within and among plants due to changes in the ethanol production process. Some of these factors include grain type, fermentation process, and type and amount of acid used for controlling pH and cleaning. Other factors which introduce variation include centrifugation of whole stillage, the proportion of CDS added back to the WDG, and temperature and duration of drying (Shurson and Alghamdi, 2008). As with dry milling, variation in byproducts used by the livestock industry also exists within and among plants due to changes in process and chemicals used between plants. Some of the processing factors include the techniques used for separation or differences in centrifugation. Corn gluten feed is the major byproduct marketed by the wet milling industry that is fed in the feedlot industry. Most variation in the nutrient composition of CGF is primarily due to what byproducts are blended to produce CGF and the proportion of steep added.

***Dry-Milling Byproducts.*** The DM content of CDS, WDG, and DDG is 30.1, 36.1, and 94.6%, respectively. Condensed distillers solubles contain 21.0% CP, 21.7% fat,



4.49% NDF, 2.39% ADF, 5.43% starch, 9.78% ash, 1.58% P, and 0.80% S content. The composition of DG is 33.4% CP, 7.91% fat, 41.7% NDF, 11.9% ADF, 2.58% ash, 0.51% P, and 0.56% S (Holt and Pritchard, 2004; Knott et al., 2004; Erickson et al., 2005; Noll et al., 2006; Cao et al., 2009; Corrigan et al., 2009b; Dairy One Forage Lab, 2010). The UIP content of CDS ranged from 20.8% as reported by Dairy One Forage Lab (2010) to 65.0% of CP as reported by Erickson et al. (2005). The UIP and ADIN content of WDG (49.9 and 17.4% of CP, respectively) is decreased compared to DDG (66.1 and 18.8% of CP), as reported by Cao et al. (2009), possibly due to the effect of drying which agrees with results observed in the current review between WDGS and DDGS, which is discussed below.

In a study by Holt and Pritchard (2004), four dry-milling plants were sampled four times daily over four days and variation of CDS was increased for DM (23.4%; SD = 2.87) and CP (19.8%; SD = 2.54) content compared to fat content (32.1%; SD = 1.90) with CV of 12.3, 12.8, and 5.92%, respectively. However, DM content of CDS was quite low in that study and fat content was increased 50% versus the average fat content observed in this review. Variation in CDS samples analyzed from May 1, 2000 through Apr. 30, 2009 by Dairy One Forage Lab (2010), was quite high with CV ranging from 28.4, 26.6, and 21.2% for DM, CP, and fat content, respectively, to 95.5, 85.6, and 55.7% for NDF, starch, and S content, respectively.

Knott et al. (2004) stated that the DM and nutrient content of WDG is less variable, based on CV, than CDS for samples collected from six Minnesota ethanol plants over a three week period. They also observed that crude fat was the most variable nutrient in both CDS and WDG.

The DM content of WDGS, MDGS, and DDGS is 33.3% (range = 29.5 to 36.5%), 47.2% (range = 45.2 to 49.3%), and 90.6% (range = 85.0 to 95.1%), respectively. The nutrient composition of DGS consists of 31.0% CP, 11.7% fat, 37.9% NDF, 14.1% ADF, 6.71% starch, 4.46% ash, 0.80% P and 0.70% S (Belyea et al., 1989; Nakamura et al., 1994; Stern et al., 1997; Akayezu et al., 1998; Spiels et al., 2002; Holt and Pritchard, 2004; Belyea et al., 2004; Erickson et al., 2005; Kaiser, 2005; Singh et al., 2005; Noll et al., 2006; Kleinschmit et al., 2007; Kelzer et al., 2007; Tedeschi et al., 2009; Kelzer et al., 2009; Cao et al., 2009; Corrigan et al., 2009b; Loza et al., 2010; Buckner et al., 2010; Dairy One Forage Lab, 2010). The UIP content of WDGS (52.9% of CP) appears to be reduced compared to DDGS (59.2% of CP).

The DM content reported by the NRC (1996) is quite low for WDGS (25.0%) but is similar for DDGS (90.3%) compared to values in the literature. A study conducted in Wisconsin evaluated 51 samples collected from three ethanol plants, two that produce WDGS and one that produces MDGS. Variation was similar for DM content between WDGS (SD = 0.9 and 1.2) from two plants and MDGS (SD = 2.3) from one plant with CV of 2.76, 3.80, and 4.67 respectively (Kaiser, 2005). A recent study conducted at the University of Nebraska sampled six dry-milling plants producing either WDGS or MDGS. Samples were collected ten times daily over five consecutive days during four periods. The overall DM content of WDGS and MDGS observed in that study was 32.5 and 45.2%, respectively. For confidentiality reasons, actual DM content by plant was not disclosed and all DM values were expressed on a 100% basis. Variation for average DM content within day was quite low across periods with CV for plants ranging from 1.05 to 2.38% across periods (Buckner et al., 2010). Holt and Pritchard (2004) sampled four dry-

milling plants producing DGS and overall variation was low. However, DM content between plants was more variable for 144 WDGS samples (31.4%; SD = 2.12) compared to 192 DDGS samples (90.0%; SD = 1.08) with CV of 6.75 and 1.20, respectively. Dairy One Forage Lab (2010) also observed increased variation in DM content for 1,923 WDGS (32.9%; SD = 13.3) compared to 4,948 DDGS (88.1%; SD = 7.03) analyzed from May 1, 2000 through Apr. 30, 2009 with CV of 40.4 and 7.98%, respectively. Standard deviations of DM content reported by Dairy One Forage Lab are the highest observed in this review. Based on the normal range for DM content of WDGS, the reported nutrient composition of Dairy One Forage Lab discussed in this review is probably for both WDGS and MDGS. Other studies have reported very low variation for DM content of DDGS both across plants (SD = 0.98 to 1.51) and within plants (SD = 0.05 to 0.94) with CV ranging from 1.06 to 1.70% and 0.56 to 3.69%, respectively (Akayezu et al., 1998; Spiehs et al., 2002; Tedeschi et al., 2009).

The CP content of WDGS (29.7%) and DDGS (30.4%) reported by the NRC (1996) are slightly lower compared to values in the literature. Kaiser (2005) observed an overall CP content of 26.7% (SD = 1.60) for 51 samples from three dry-milling plants producing either WDGS or MDGS with a CV of 6.00%. The CP content of MDGS was about 1 percentage unit lower in that study. In a recent Nebraska study, the variation in CP content (31.0%; SD = 1.13) among plants was very low with a CV of 3.65% for 1200 samples collected from six dry-milling plants producing either WDGS or MDGS. The observed range in CP content was 27.8 and 37.2% for individual samples with CV for daily averages among plants ranging from 0.39 to 4.90%. For individual plants, the average CP content within day was only slightly variable across periods (SD = 0.34 to

0.65) with CV ranging from 1.11 to 1.98% (Buckner et al., 2010). Holt and Pritchard (2004) also found low variation for both WDGS (29.7%; SD = 1.37) and DDGS (29.5%; SD = 2.78) with CV of 3.86 and 8.35%, respectively. The samples were collected from four traditional dry-milling plants. The average CP content reported for two plants producing WDGS (36.2 and 36.6%) and one plant producing DDGS (36.7%) were the highest reported plant averages observed in the current review for traditional DGS. Variation was much greater for average CP content of 1,905 WDGS (30.0%; SD = 9.88) compared to 4,646 DDGS (30.9%; SD = 3.99) samples analyzed by Dairy One Forage Lab (2010) with CV of 32.9 and 12.9%, respectively. However, as mentioned, WDGS reported by Dairy One Forage Lab probably is for WDGS and MDGS which would lead to greater variation if MDGS has lower CP content since the CDS to WDG ratio is greater for MDGS. The normal range reported for CP content of WDGS and DDGS was 20.1 to 39.9% and 26.9 to 34.8%, respectively. For DDGS, variation is fairly low between plants (SD = 1.11 to 1.93) with CV from 3.70 to 6.40% and within plants (SD = 0.57 to 2.10) with CV from 1.85 to 10.2% as reported by other studies (Belyea et al., 1989; Nakamura et al., 1994; Akayezu et al., 1998; Spiels et al., 2002; Belyea et al., 2004; Tedeschi et al., 2009).

The NRC (1996) reports a much greater UIP content (% of CP) for WDGS (66.6%) and 6 DDGS samples (72.8%, SD = 20.0). The variation was increased for DIP of 274 WDGS (SD = 9.28) and 1,151 DDGS (SD = 8.13) samples by Dairy One Forage Lab (2010) with CV of 30.6 and 26.1%, respectively. The corresponding UIP content for WDGS (69.7% of CP) and DDGS (68.9% of CP) is increased compared to the current review.

In a study by Nakamura et al. (1994), UIP contents of DDGS samples from seven dry-milling plants were significantly different ( $P < 0.05$ ) and highly variable. The SD was 21.1 and UIP content ranged from 15.8 to 79.7% of CP which is the largest reported range observed in this review. Stern et al. (1997) reported an average UIP content of five DDGS samples of 56.0% (SD = 8) with a CV of 14.3%. The overall UIP content of 96 DDGS samples from eight dry-milling plants was 53.5% and significantly different ( $P < 0.01$ ) between plants with low variation both between and within plants. Results in that study were reported as DIP (SD = 3.58) and the CV between plants was 7.70% and ranged from 6.72 to 15.1% within plants. The corresponding UIP content ranged from 40.2 to 68.5% (Akayezu et al., 1998). Kleinschmit et al. (2007) evaluated five DDGS sources and one source of WDGS. The UIP content of DDGS ranged from 59.1 to 71.7% and was statistically different ( $P < 0.05$ ) among sources. The WDGS source had significantly ( $P < 0.05$ ) lower UIP content (53.6%) compared to all DDGS sources.

The NRC (1996) reports lower fat content for WDGS (9.90%) and DDGS (10.7%). As mentioned earlier, the standard ether extract procedures used for most feed analysis may not be accurate for evaluation of the fat content of distillers byproducts and values can vary between methods and labs which can lead to greater variation (Thiex, 2009; Cao et al., 2009). Kaiser (2005) observed an overall CV of 9.43% across plants for fat content (10.6%; SD = 1.00) of WDGS and MDGS. In a recent study conducted in Nebraska, WDGS and MDGS were sampled from six ethanol plants over four periods. Variability among plants was fairly low for fat content (11.9%; SD = 0.97) of 1200 samples with a CV of 8.18%. Fat content of individual samples ranged from 7.15 to 15.3% and CV for daily averages among plants ranged from 0.89 to 11.6%. Plant to plant

variation in fat content within day was low across periods (SD = 0.21 to 0.39) with CV ranging from 1.76 to 3.44% across periods (Buckner et al., 2010). Holt and Pritchard (2004) reported slightly less variation in the fat content of WDGS (12.1%; SD = 1.39) compared to DDGS (13.1%; SD = 1.95) across plants with CV of 11.49 and 14.89%, respectively. Akayezu et al. (1998) reported a significant difference ( $P < 0.01$ ) between plants for fat content (10.5%; SD = 1.68) of 96 DDGS samples collected from eight plants during a six month period CV of 16.9%. Variation in fat content within plants ranged from 4.3 to 18.7% and CV ranged from 12.9 to 38.5%. Dairy One Forage Lab (2010) reported greater average fat content for 1,359 WDGS (12.8%; SD = 4.00) and 3,607 DDGS (13.0%; SD = 2.99) samples. This data set also shows much greater variation overall for fat content and that WDGS has greater variation compared to DDGS with CV of 31.3 and 23.1%, respectively. Again, WDGS reported by Dairy One Forage Lab is probably for both WDGS and MDGS. The normal range for fat content of WDGS and DDGS as reported by Dairy One Forage Lab (2010) is 8.80 to 16.8% and 9.97 to 16.0%, respectively. Other studies has reported mixed variation for fat content of DDGS both across plants (SD = 0.85 to 1.75) and within plants (SD = 0.20 to 1.07) with CV ranging from 7.80 to 16.4% and 1.69 to 10.5%, respectively (Belyea et al., 1989; Spiels et al., 2002; Belyea et al., 2004; Tedeschi et al., 2009).

The NRC (1996) reported slightly greater NDF content for WDGS (40.0%) but NDF and ADF content for DDGS (46.0 and 21.3%, respectively) is much greater than the average value observed in the literature. Average NDF and ADF contents were similar for approximately 1,750 WDGS (30.6 and 15.1%, respectively) compared to approximately 4,100 DDGS (33.8 and 16.9%, respectively) analyzed by Dairy One

Forage Lab (2010). Variation was 2-fold higher for both NDF and ADF content of WDGS (SD = 5.27 and 9.01, respectively) with CV of 34.9 and 29.6%, respectively, compared to DDGS (SD = 3.43 and 4.56, respectively) with CV of 20.3 and 13.5%, respectively. Once more, WDGS reported here is probably for both WDGS and MDGS, based on the range of DM content, and because NDF and ADF content are lower for MDGS due to an increased CDS to WDG ratio, greater variation would be expected. One factor that may lead to such high variation in NDF may be the interference of fat in distillers byproducts which may not be totally dissolved in the traditional Van Soest method typically used for feed analysis. Bremer et al. (2010a) recommend that a pre-NDF fat extraction should be completed before evaluation of NDF in high fat feeds. They analyzed five different DGS samples with varying CDS levels using the traditional NDF method and their new proposed method. The average NDF values were decreased 5.45% for the new method (30.6%) compared to the traditional method (32.2%) and filtering was more efficient (Bremer et al., 2010a).

In a study by Kaiser (2005), they observed very low variation for NDF content (30.2%; SD = 2.90) with a CV across plants of 9.60%. In that study, NDF content was similar between WDGS and MDGS. Holt and Pritchard (2004) observed moderate variation of WDGS and DDGS for both NDF (42.3 and 42.7%, respectively) and ADF (12.1 and 13.2%, respectively) content across plants. Variability was similar for NDF and ADF of WDGS (SD = 6.34 and 2.46, respectively) with CV of 15.0 and 20.3%, respectively compared to DDGS (SD = 5.17 and 2.51, respectively) with CV of 12.1 and 19.0%, respectively. For DDGS, other studies report CV for NDF between plants (SD = 1.86 to 6.02) from 6.60 to 14.3% and within plants (SD = 0.98 to 8.48) from 2.40 to

23.1%. For ADF of DDGS, the CV ranges from 16.9 to 28.4% across plants (SD = 2.62 to 4.60) and from 1.60 to 55.8% within plants (SD = 0.20 to 8.93%) as reported by other studies (Belyea et al., 1989; Akayezu et al., 1998; Spiels et al., 2002; Belyea et al., 2004; Tedeschi et al., 2009).

Ethanol fermentation in dry-milling plants is not 100% efficient and some starch is recovered in the distillers byproducts. The normal range of starch content for 1,102 WDGS (5.57%; SD = 9.04) and 2,582 DDGS (5.43%; SD = 4.41) samples was 0 to 14.6% and 1.02 to 9.83%, respectively, analyzed by Dairy One Forage Lab (2010). The CV for starch content of WDGS and DDGS was 164.9 and 81.2%. Within plants, the variation may be much lower. Belyea et al. (1989) reported a CV of 5.50% for starch content (9.7%; SD = 0.53) of 10 DDGS from one plant. Belyea et al. (2004) evaluated 118 DDGS samples from one plant over five years and observed a CV of 3.99% for starch content which averaged 5.1% (SD = 0.20).

As with other nutrients, the mineral composition of distillers byproducts is also increased 3- fold compared to corn which is supported by an average reported ash content of 4.56% for DGS compared to 1.50% for corn. The main minerals of interest in distillers byproducts are generally P and S. As mentioned, corn contains 0.32% P and 0.10% S which suggests that distillers byproducts should contain about 0.96% P and 0.30% S. However, some of the P is used for yeast production during fermentation, and dry-milling plants primarily use sulfuric acid during ethanol production.

Compared to the average P content for DGS observed in this review, the P content of DDGS (0.83%) reported by NRC (1996) is similar, however, the P content of WDGS (1.40%) reported by NRC (1996) is 2-fold higher. In the literature, P content of



traditional DGS ranged from 0.48 to 0.97%. Although there is not a toxic level of P that exists for ruminants, high levels should be accounted for. The primary reason high P content should be recognized is for formulating waste management plans so that enough land is available for spreading manure. Another reason is to prevent urinary calculi (water belly) by accurately balancing diets for Ca with a Ca to P ratio of at least 1.5:1 but not more than 7:1. The recommended requirement for Ca and P for finishing cattle is 0.5 to 0.7% and approximately 0.15%, respectively (NRC, 1996; Geisert et al., 2004). Corn and DGS do not have high levels of Ca (0.03 and 0.10%, respectively); therefore, Ca must be added to properly balance diets, however, when corn or byproducts are fed, especially in finishing diets, supplemental P should not ever be needed.

On the other hand, the increased S content of traditional DGS, compared to corn, can create problems. The average S content observed in this review is about 1.7 times greater compared to the S content of WDGS (0.40%) and DDGS (0.44%) reported by NRC (1996). In the literature, S content of traditional DGS ranged from 0.35 to 1.06%. The NRC (2005) reports that the upper limit for dietary S content is 0.5 and 0.3% for cattle fed forage and concentrate (less than 40% forage) based diets, respectively. A finishing diet with 30% WDGS (DM basis) is approximately 0.30% S if the WDGS has S content of 0.68%, which is similar to the observed value in the current review.

Sulfur is primarily reduced to hydrogen sulfide ( $H_2S$ ) in the rumen by bacteria and then used for MCP production or absorbed. Increased production of  $H_2S$ , due to high levels of S intake, has been associated with an increased risk of polioencephalomalacia (PEM), which is commonly referred to as “brainers” in the feedlot industry (Gould, 1998). In a review of feeding experiments containing byproducts conducted at the

University of Nebraska, 0.46% S was determined to be the safe limit for finishing cattle with low incidence of PEM (0.14%) and only 3 observed cases out of 2147 cattle. At this level, WDGS may safely be fed up to 50% of diet DM if S content of the byproduct remains below 0.75%. However, when dietary S content is 0.47% or greater, the incidence of PEM (1.59%) increases severely with 9 observed cases out of 566 cattle (Vanness et al., 2009).

In the study by Buckner et al. (2010), variation for P and S content was much lower compared to most other publications. Among plants, the average P content was 0.83% (SD = 0.06) with a CV of 6.74%. Individual samples ranged from 0.69 to 0.97% P content with CV of daily averages among plants ranged from 0.92 to 8.63%. Variability of P content within day was very low across periods (SD = 0.01 to 0.02) with CV ranging from 1.55 to 2.53%. The average S content among plants was 0.77% (SD = 0.11) with a CV of 14.3%. The CV for daily averages of S content among plants ranged from 1.92 to 32.1%. Across periods, variation in S content (SD = 0.03 to 0.06) of plants was fairly low with CV ranging from 3.91 to 7.13%.

Kaiser (2005) observed a overall CV of 22.2% for average P content (0.90%; SD = 0.20) across plants producing either WDGS or MDGS and within plants, CV ranged from 11.1 to 25.0%. Reported P values ranged from 0.50 to 1.20%. Holt and Pritchard (2004) reported variation between plants for P content of WDGS and high variation in S content for DDGS. The average S content of WDGS (0.38%) and DDGS (0.48%) observed by Holt and Pritchard (2004) ranged from 0.35 to 0.69% but most plant averages were much lower than any other reported values observed in the current review. The normal range for P content of 1,119 WDGS (0.85%; SD = 0.17) and 3,519 DDGS

(0.88%; SD = 0.16) samples analyzed by Dairy One Forage Lab (2010) is 0.68 to 1.02% and 0.73 and 1.04%, respectively with CV of 20.0 and 17.8%. The normal range for S content of 976 WDGS (0.58%; SD = 0.15) and 2,748 DDGS (0.64%; SD = 0.18) samples analyzed by Dairy One Forage Lab (2010) is 0.43 to 0.73% and 0.46 to 0.82%, respectively, with CV of 25.5 and 27.8%, respectively. Other studies have reported moderate variation in P content of DDGS between plants (SD = 0.10 to 0.15) with CV from 11.7 to 19.4% but variation is mixed within plants (SD = 0.03 to 0.25) with CV from 3.10 to 15.3%. For S content of DDGS, other studies have reported rather high variation both between plants (SD = 0.17 to 0.26) and within plants (SD = 0.02 to 0.16) with CV from 37.1 to 37.7% and 6.40 to 40.8%, respectively (Belyea et al., 1989; Spiels et al., 2002). Overall, it appears that variation in P content is decreased compared to S content for both WDGS and DDGS.

***Wet-Milling Byproducts.*** Steep is 50.0% DM and contains 38.1% CP (14.5% UIP), 0.80% fat, 2.30% NDF, 0.70% ADF, 2.06% P, and 1.26% S (Herold, 1999; DeFrain et al., 2003; Erickson et al., 2005). Compared to CDS from dry milling, steep has 2-fold higher CP content, 30% more P, and 58 % more S content. However, fat, NDF, and UIP content are much lower for steep compared to CDS.

Germ meal has a DM content of 90.4% and the nutrient profile consists of 22.8% CP, 6.94% fat, 56.2% NDF, 16.9% ADF, 20.8% starch, 0.45% P and 0.31% S. Corn bran contains of 11.8% CP, 63.5% NDF, 20.1% starch, 0.11% P, and 0.43% S (Oliveros et al., 1989; Herold et al., 1998; Herold, 1999; Dairy One Forage Lab, 2010).

Wet corn gluten feed (WCGF) is more commonly used by feed yards or dairies that are relatively close to the plant. Based on a review by Stock et al. (2000), there are several types of WCGF. Research at the University of Nebraska-Lincoln has focused on two primary types. The first (WCGF-A) is mainly composed of wet bran and steep which contains approximately 41.0% DM, 17.5% CP, and 48% NDF. The other (WCGF-B) is mostly composed of dry bran, steep, and germ meal which contains about 60.0% DM, 22.5% CP, and 37% NDF. These differences in nutrient composition are primarily due to a greater ratio of steep to bran in WCGF-B.

In the literature, WCGF-A had a DM content of 46.0% and contained 20.4% CP (19.2% UIP), 45.3% NDF, 7.40%, ADF, 23.3% starch, and 0.99% P. WCGF-B was 60.0% DM and consisted of 23.6% CP (14.9% UIP), 3.65% fat, 41.6% NDF, 13.4% ADF, 21.6% starch, 0.94% P, and 0.49% S content (Droppo et al., 1985; Oliveros et al., 1989; Belyea et al., 1989; McCoy et al., 1997; Erickson et al., 2005; Kelzer et al., 2007; Loza et al., 2010). Between the two types of WCGF, WCGF-B has about 15 and 80% more CP and ADF content, respectively, but WCGF-A has about 30% more UIP.

In a study by Droppo et al. (1985), the variation in CP (22.5%; SD = 2.59), ADF (7.4%; SD = 0.81), and P (1.31%; SD = 0.21) content was moderate for 56 samples of WCGF collected from 14 loads out of one plant with CV of 11.5, 10.9, and 16.0%, respectively. In a study by Belyea et al. (1989), 10 WCGF samples were collected from one wet-milling plant daily during a five day workweek over 2 periods. Samples were collected every one to two hours each day and composited. They observed low variation for CP, NDF, and ADF with CV of 5.90, 4.30, and 5.30%, respectively. Variation was

moderate to high for fat, starch, and P content with CV of 28.1, 19.0, and 16.5%, respectively.

In summary, variation is present in the nutrient profile of corn-milling byproducts and changes for each nutrient across different byproducts and different plants due to changes in production methods. Variation in CP content of traditional DGS with CV below 8.50% may not be of any practical importance for most feedlots if they are feeding moderate to high levels of byproducts because they are probably already overfeeding protein and a 2 percentage unit change in CP of byproducts may not even be realized. Fat content is highly variable within byproducts. Variation in NDF content is generally fairly low with CV less than 10% within corn-milling plants. Since the starch content of traditional DGS (5.43%), HP-DDG (9.10%), and CGF (22.4%) is relatively low compared to the corn it replaces in feedlot diets, high variation is probably not a concern. Variation in P content is also not really a concern in finishing diets but should be accounted for, primarily for waste management plans but also to avoid urinary calculi. The high variability of S is most likely due to the fact that corn-milling plants primarily use sulfuric acid during production. Variation in S content is much more of a problem. High variability and content of S are concerns due to effects on DMI and the increased incidence of PEM.

### ***Corn-Milling Byproducts in Finishing Cattle Diets.***

***Introduction.*** Corn-milling byproducts were initially used at low levels in cattle feeding, primarily as a protein source to replace urea or natural sources such as soybean

meal. However, byproduct inclusion levels have increased in recent years and byproducts are currently being used as an energy source to replace corn or other grains (Erickson et al., 2007). This is likely because byproducts have become more economically feasible for use in cattle feeding due to 1) the rapid growth of the ethanol industry and 2) the current progression of the dry mill industry which is aimed at adding value to byproducts by utilizing new fractionation processes which create new byproducts. In addition to higher inclusion levels of individual byproducts, many cattle feeders also have the opportunity to include two or more corn-milling byproducts which may have complementary effects due to their nutritional profiles. Furthermore, utilizing multiple byproducts ensure that cattle feeders have a consistent supply of at least one byproduct all the time although this may create another source of variability. Because the starch has been removed during milling, byproduct inclusion in finishing diets should reduce the incidence of acidosis and roughage levels may possibly be reduced.

*Effects of Corn-Milling Byproducts on Intake and Performance.* In a recent meta-analysis, Bremer et al. (2010b) analyzed means from research trials conducted at the University of Nebraska to evaluate the effects of WDGS inclusion level in finishing cattle diets containing DRC or HMC. In 14 experiments, representing 2,534 steers, a quadratic response ( $P < 0.05$ ) was observed for DMI, ADG, and G:F as WDGS inclusion level increased from 0 to 50% of dietary DM. Intake was slightly increased for cattle fed 10 or 20% WDGS (10.6 kg/d), similar for cattle fed 30% WDGS (10.5 kg/d), and slightly decreased for cattle fed 40 or 50% WDGS (10.0 kg/d) compared to cattle fed a control diet (10.4 kg/d). Cattle fed 10 to 50% WDGS had greater ADG (1.72 kg) and G:F (0.167)

compared to cattle fed a control diet (1.60 kg and 0.153, respectively). The feeding value of WDGS, relative to the corn it replaced and calculated by difference of G:F, was 148, 142, 136, 129, and 123% for diets containing 10, 20, 30, 40, and 50% WDGS, respectively. While G:F values were not decreased with increasing levels of WDGS, the feeding value relative to corn was decreased when the inclusion level was accounted for. One thing that should be noted is that although ADG is decreased for cattle fed 50% WDGS, ADG and G:F are higher compared to a traditional corn based diet.

For MDGS, Bremer (2010, Unpublished) analyzed four trials, representing 680 steers, and a quadratic response ( $P < 0.05$ ) was also observed for DMI, ADG, and G:F with increasing inclusion level of MDGS from 0 to 40% of dietary DM. Cattle fed 10 to 40% MDGS had greater DMI (11.4 kg/d), ADG (1.82 kg), and G:F (0.159) compared to cattle fed a control diet (11.0 kg/d, 1.67 kg, and 0.152, respectively). The feeding value of MDGS was calculated to be 129, 125, 121, and 117% the value of the corn it replaced using the difference in G:F for diets containing 10, 20, 30, and 40% MDGS, respectively. Trenkle (2007) fed cattle DRC-based diets containing 0, 24.9, or 47.0% MDGS (DM basis). Dry matter intake was similar ( $P > 0.05$ ) for cattle fed 0 or 24.9% MDGS (9.30 or 9.57 kg/d) but was decreased ( $P < 0.05$ ) for cattle fed 47.0% MDGS (8.80 kg/d). There was no difference ( $P > 0.05$ ) in ADG (1.65 kg) but cattle fed 24.9% MDGS had lower G:F (0.174) compared to cattle fed 47.0% MDGS (0.184) with cattle fed a control diet (0.180) being intermediate ( $P < 0.05$ ). The feeding value of MDGS relative to the corn it replaced in the study by Trenkle (2007) was calculated to be 86 and 104% for diets containing 24.9 or 47.0% MDGS.

For DDGS, Bremer (2010, Unpublished) analyzed four trials representing 581 steers, and a quadratic response ( $P < 0.05$ ) was observed for DMI. For cattle fed 10 to 40% DDGS, DMI (11.8 kg/d) was greater compared to cattle fed a control diet (11.0 kg/d). Increasing the inclusion level of DDGS from 0 to 40% of dietary DM resulted in a linear increase ( $P < 0.05$ ) observed for ADG (1.57 to 1.80 kg, respectively) and G:F (0.142 to 0.151, respectively). The feeding value of DDGS relative to corn using the difference in G:F was calculated to be 113%. Klopfenstein et al. (2008) also performed a meta-analysis on means from five research trials to evaluate the effects of DDGS inclusion level on finishing cattle performance. There was a quadratic response observed for DMI ( $P = 0.08$ ) and ADG ( $P < 0.01$ ) but a cubic response was observed for G:F ( $P < 0.01$ ) with increasing inclusion level of DDGS. For cattle fed 10 to 40% DDGS, DMI (10.5 kg/d) and ADG (1.68 kg) were greater compared to cattle fed a control diet (10.2 kg/d and 1.56 kg, respectively). Cattle fed 10 to 20% DDGS had the highest G:F (0.160 and 0.159, respectively) and cattle fed 0 or 40% DDGS had the lowest G:F (0.152). The feeding value of DDGS, relative to the corn it replaced and calculated by difference of G:F, was 153, 123, 107, and 100% for diets containing 10, 20, 30, and 40% DDGS as reported by Klopfenstein et al. (2008). One thing that should be mentioned is that although the feeding value of DDGS was calculated to be 100% relative to corn when included at 40% of the dietary DM, ADG for cattle fed 40% DDGS (1.66 kg) was numerically increased compared to cattle fed the corn control (1.56 kg).

It appears that the drying process has a negative effect on  $NE_g$  because performance was optimized at different levels and because the feeding value was reduced with drying. However, there is one problem with making comparisons between distillers



byproducts based on the meta-analysis previously mentioned. None of these trials directly compared the distillers byproducts in the same trial with the same control diet.

In a study conducted by Mateo et al. (2004), two finishing trials were conducted over a two-year period to evaluate the effect of feeding DDGS or WDGS at 0, 20, or 40% in a DRC-based diet. The distillers byproducts replaced corn and SBM. There was a type x level interaction ( $P < 0.01$ ) observed for DMI. Cattle fed DDGS (10.6 kg/d) had the highest DMI and cattle fed 40% WDGS (9.44 kg/d) had the lowest DMI while cattle fed the corn control or 20% WDGS (10.0 kg/d) were intermediate. There was no difference ( $P > 0.05$ ) in ADG (1.67 kg) among treatments. Cattle fed DDGS had decreased G:F ( $P < 0.05$ ) compared to cattle fed WDGS or the corn control and cattle fed 40% WDGS had increased G:F ( $P < 0.05$ ) compared to cattle fed 20% WDGS or corn control. The feeding value relative to corn was calculated to be 77 or 74% for diets containing 20 or 40% DDGS and 100 or 120% for diets containing 20 or 40% WDGS.

Nuttleman et al. (2010) recently conducted a trial to evaluate the effects feeding WDGS, MDGS, or DDGS at 0, 20, 30, or 40% of the dietary DM on finishing cattle performance. There was not a type x level interaction observed ( $P > 0.10$ ). Cattle fed 20, 30, or 40% DGS had increased ( $P < 0.05$ ) DMI (11.9, 11.7, or 11.9 kg/d, respectively), ADG (1.85, 1.84, or 1.90 kg), and G:F (0.156, 0.157, or 0.161, respectively) compared to cattle fed a corn control (11.2 kg/d, 1.62 kg, and 0.146, respectively). The feeding value of DGS, calculated based on the difference in G:F relative to corn, when included at 20, 30, or 40% of dietary DM was calculated to be 134, 125, and 126% relative to the corn it replaced. Cattle fed WDGS (11.3 kg/d) had decreased ( $P < 0.01$ ) DMI compared to cattle fed MDGS and DDGS (12.0 and 12.3 kg/d, respectively) but there was no difference in

ADG ( $P=0.48$ ). Cattle fed WDGS (0.165) had the greatest ( $P < 0.05$ ) G:F compared to cattle fed MDGS and DDGS (0.158 and 0.150, respectively) and cattle fed DDGS had the lowest ( $P < 0.05$ ) G:F compared to cattle fed WDGS or MDGS. The feeding value of WDGS, MDGS, and DDGS across 20, 30, and 40% inclusion was calculated to be 143, 127, and 109%, respectively, relative to corn based on differences in G:F. Based on differences in G:F for the three types of DGS, MDGS and DDGS had 95 and 90% the feeding value compared to WDGS in the study by Nuttleman et al. (2010).

Overall, it appears finishing cattle performance is optimized for WDGS between 30 and 40% dietary inclusion with a feeding value of about 132%. For MDGS, performance is optimized between 20 and 30% dietary inclusion with a feeding value of about 120% relative to corn. For DDGS, it appears that performance is optimized at about 20% dietary inclusion with a feeding value of about 110 to 115% relative to corn.

In a meta-analysis conducted by Bremer et al. (2008), 35 treatment means from 11 feedlot trials conducted at the University of Nebraska were analyzed to evaluate the effects of WCGF inclusion level. For WCGF-A, which primarily consists of wet bran and steep, there was no effect ( $P > 0.35$ ) on DMI (10.2 kg/d) or G:F (0.155) due to increasing inclusion level from 0 to 40% of dietary DM. There was a linear increase ( $P = 0.10$ ) for ADG with increasing inclusion level of WCGF-A from 0 to 40% of dietary DM (1.56 to 1.62 kg, respectively). There was not a difference in G:F with increasing levels of WCGF-A from 0 to 40% dietary DM even though ADG increased linearly because there was also a slight numerical linear increase for DMI (10.1 to 10.4 kg/d, respectively). The feeding value of WCGF-A relative to corn was calculated to be 99% based on the differences in G:F. Increasing the inclusion level of WCGF-B from 0 to 40% of dietary

DM resulted in a linear increase ( $P < 0.05$ ) observed for DMI (9.89 to 10.9 kg/d, respectively), ADG (1.66 to 1.89 kg, respectively), and G:F (0.168 to 0.174, respectively). The feeding value of WCGF-B was calculated to be 112% the value of the corn it replaced using the difference in G:F. Other research evaluating WCGF have shown that finishing cattle performance is optimized between 20 and 50% dietary inclusion (Ham et al., 1995; Hussein and Berger, 1995; Sindt et al., 2002; Macken et al., 2004; Block et al., 2005; Loe et al., 2006). Other research has successfully fed WCGF in finishing diets up to 90% dietary inclusion with finishing cattle performance being similar or better to cattle fed a corn-based control diet (Firkins et al., 1985; Ham et al., 1995; Richards et al., 1996; Loe et al., 2006).

To this point, it appears that performance is optimized when individual corn-milling by-products are included between 20 and 40% of dietary DM. The primary reason that WDGS appears to have a greater feeding value relative to corn compared to MDGS, DDGS, and WCGF is because compared to cattle fed corn control diets, cattle fed WDGS and other byproducts have greater ADG but DMI is generally lower for cattle fed WDGS while cattle fed MDGS, DDGS, or WCGF generally have greater DMI compared to cattle fed corn control diets.

Further, it appears that WCGF can be fed at relatively high levels without any major negative impacts on cattle performance or health. However, the increased fat and S content of DGS may limit the inclusion level and could result in reduced cattle performance or increased health problems when DGS are used to replace corn at more than 50% of dietary DM in finishing diets. On the other hand, as more and more corn-milling byproducts are available, feeding a combination of WCGF and WDGS may

provide an opportunity to take advantage of the complimentary effects of these two byproducts and allow cattle feeders to replace more grain and lower their cost of gain.

In a study by Loza et al. (2010), two trials were conducted to evaluate the effects of feeding combinations of WCGF-B and WDGS in finishing cattle diets. In trial 1, dietary treatments consisted of 1) corn control, 2) 30% WCGF-B, 3) 30% WDGS, 4) 30% 1:1 blend of WCGF and WDGS, and 5) 60% 1:1 blend of WCGF-B and WDGS (DM basis). Cattle fed 30% byproduct had increased ( $P < 0.05$ ) DMI (11.6 kg/d) compared to cattle fed the corn control or the 60% byproduct diet (10.8 kg/d). Cattle fed 30% WDGS had greater ( $P < 0.05$ ) ADG (2.12 kg) compared to cattle fed 30% WCGF-B or 60% byproduct blend (2.03 and 1.94 kg, respectively) and cattle fed 30% byproduct blend had intermediate ADG (2.07 kg). All cattle fed byproducts had increased ( $P < 0.05$ ) ADG compared to cattle fed the corn control diet (1.85kg). Cattle fed 30% WDGS had the highest ( $P < 0.05$ ) G:F (0.187) and cattle fed 30% WCGF-B and the corn control had the lowest G:F (0.171 and 0.172, respectively). Cattle fed either 30 or 60% of a 1:1 blend of WCGF-B and WDGS had intermediate G:F (0.179). In trial 3, the seven dietary treatments consisted of a corn control and six diets containing 30% WCGF-B with the addition of 0, 10, 15, 20, 25, or 30% WDGS (DM basis). Inclusion of 30% WCGF-B increased ( $P < 0.05$ ) DMI, ADG, and G:F compared to the corn control. Inclusion of WDGS in finishing diets containing 30% WCGF-B had no effect ( $P > 0.10$ ) on DMI or G:F although there was a quadratic response ( $P < 0.05$ ) for ADG. In finishing diets containing 30% WCGF, cattle fed 15 or 20% WDGS had the highest ADG (1.81 kg) and cattle fed 30% WDGS had the lowest ADG (1.71 kg). The authors concluded from Trial 1 that there was not a positive associative effect observed by feeding WCGF and WDGS

in combination because feeding a 30% combination resulted in intermediate performance between either 30% WDGS and 30% WCGF. However, in Trial 3, feeding a combination of 30% WCGF and 15 or 20% WDGS resulted in optimal performance but feeding up to 60% of a 1:1 blend of WCGF and WDGS resulted in improved finishing performance compared to the corn control.

In a study by Bremer et al. (2009), a finishing trial was conducted to evaluate the effects of adding WDGS or CDS to diets containing 35% WCGF-B (DM basis). The seven dietary treatments consisted of a control diet with 35% WCGF-B, three diets with the addition of 13.3, 26.7, or 40% WDGS, and three diets with the addition of 6.7, 13.3, or 20% CDS (DM basis). For cattle fed WDGS, there was a linear decrease in DMI ( $P = 0.06$ ) and ADG ( $P < 0.01$ ) but feeding CDS had no effect ( $P > 0.50$ ) on DMI or ADG. There was no effect ( $P > 0.50$ ) of feeding up to 40% WDGS or 20% CDS on G:F in finishing diets containing 35% WCGF-B. The authors concluded that up to 20% CDS can be used in finishing diets containing WCGF-B to replace corn without any impacts on performance but inclusion of WDGS may decrease ADG although G:F may not be affected.

To further evaluate the opportunity to feed high levels of a combination of WCGF and WDGS to replace corn, Nichols et al. (2009) conducted a finishing study to evaluate the effects of feeding WCGF with or without WDGS in a diet without feeding corn. Dietary treatments consisted of 1) a control diet with 20% WCGF, 20% WDGS, and 50% HMC 2) 90% WCGF, 3) 80% WCGF and 10% WDGS, 4) 70% WCGF and 20% WDGS, 5) 60% WCGF and 30% WDGS, and 6) 50% WCGF and 40% WDGS (DM basis). Cattle fed the control diet and 60% WCGF and 30% WDGS had similar DMI and DMI

decreased linearly ( $P < 0.01$ ) as WDGS inclusion level increased from 10 to 40% in diets without corn. Cattle fed the control diet had increased ( $P < 0.05$ ) ADG and G:F compared to cattle fed diets without corn. There was no effect ( $P > 0.10$ ) of WDGS inclusion level on ADG but G:F increased ( $P < 0.05$ ) with increasing inclusion level of WDGS in diets without corn. The authors concluded that corn-milling byproducts may be fed at 90% of dietary DM in finishing diets without corn but ADG may be decreased. Further, performance was optimized without corn when 50% WCGF and 40% WDGS was fed.

It appears that from the studies reviewed, there is something that inhibits finishing cattle performance when DGS are fed alone or in combination with WCGF at more than 50% of the dietary DM. Bremer et al. (2009) commented that it appears the S content of WDGS, rather than the fat content, likely limits the inclusion level of WDGS.

Interestingly, in the study by Bremer et al. (2009), DMI and ADG were slightly decreased for cattle fed 35% WCGF and 13.3% WDGS (48.3% total byproducts) compared to cattle fed 35% WCGF while G:F was the same. This appears to contrast the data by Loza et al. (2010) who found that feeding 30% WCGF and 15 or 20% WDGS (45 or 50% total byproducts) resulted in optimal performance with slightly greater ADG and G:F compared to cattle fed 30% WCGF while DMI was the same. However, the studies reviewed here all agree that ADG will be increased with greater levels of DGS, mainly due to the increased fat content but that the S content likely limits greater inclusion levels and feeding DGS in combination with WCGF gives cattle feeders an opportunity to increase the total byproduct inclusion level while reducing the level of corn necessary to finishing cattle.

*Effects of Corn-Milling Byproducts on Metabolism and Digestion.* As

previously mentioned, the corn-milling industry has one main goal which is to extract starch from the grain. Because starch is approximately two-thirds of the corn kernel, other nutrients are increased 3-fold in the remaining product, especially in byproducts from the dry-milling industry. Therefore, corn-milling byproducts can be excellent sources of fiber, protein, and fat.

Corn-milling byproducts were initially used at low inclusion levels as a source of protein. Since the main protein fraction in corn is zein which is slowly degraded in the rumen, DGS are a good source of UIP. On the other hand, WCGF is generally a good source of DIP, primarily due to the high crude protein and DIP content of steep. Because DGS contains a relatively high UIP content, the NRC (1996) model generally predicts a DIP deficiency even if metabolizable protein (MP) balance is positive. The reason MP may still be positive is because the NRC (1996) model assumes that DIP requirements will be met. Surplus MP is generally assumed to be recycled to meet the DIP requirements but when DGS are included in finishing diets, assumptions of almost 100% recycling may be necessary to make up for the DIP deficiency.

Vander Pol et al. (2005) evaluated the effects of feeding 10 or 20% DDG (DM basis) with or without urea supplementation in DRC-based finishing diets. The NRC (1996) model predicted the diets containing 10 and 20% DDG to have DIP deficiencies of 192 and 111 g/d, respectively and urea was added at 0.80 and 0.63%, respectively, to balance for DIP. There were no effects ( $P > 0.10$ ) on cattle performance due to treatment although there was a slight numerical increase in G:F with the addition of urea in diets containing 10% DDG. Additionally, blood urea nitrogen values appeared to be sufficient

for N recycling to occur. The authors concluded that adequate N was recycled to the rumen to meet DIP requirements in diets containing 10 or 20% DDG.

Similarly, WCGF contains a relatively high DIP content and MP may be limiting in some situations. Krehbiel et al. (1995b) evaluated the effects of feeding 0, 35, 86.5, or 94.5% WCGF (DM basis) with or without escape protein supplementation. The escape protein supplementation consisted of 1.6% CGM and 0.9% blood meal (DM basis). There were no effects ( $P > 0.10$ ) of escape protein supplementation on cattle performance.

Richards et al. (1998) also evaluated the effects of supplemental protein in finishing diets containing WCGF. Dietary treatments consisted of 1) DRC control, 2) 25% WCGF plus urea, 3) 25% WCGF plus protein, and 4) 50% WCGF. The DRC control and 25% WCGF plus protein diets were supplemented with a combination of urea, SBM, feather meal, and blood meal to meet MP requirements. There was no effect ( $P > 0.10$ ) on DMI due to treatment but cattle fed WCGF had increased ( $P < 0.10$ ) ADG compared to cattle fed the DRC control. Cattle fed 25% WCGF plus protein or 50% WCGF had improved ( $P < 0.10$ ) G:F (0.186 or 0.187, respectively) compared to cattle fed DRC control (0.179) while cattle fed 25% WCGF plus urea had intermediate G:F (0.184).

As ethanol production and byproduct availability continue to increase, byproduct inclusion levels may continue to increase as well because byproducts are more and more economically competitive. At higher inclusion levels, byproducts serve primarily as an energy source. Since DGS have 11.7% dietary fat, or about 2.8 times more fat than corn, this may be the primary reason why DGS have a greater feeding value relative to corn. Dietary fat resists ruminal degradation and is primarily absorbed in the small intestines as free fatty acids (Zinn, 1989a; Zinn and Plascencia, 1996; Zinn et al., 2000). The  $NE_g$



value of fat was calculated to be 3.78 Mcal/kg when fed to cattle and this is 2.4 times greater compared to the  $NE_g$  of 1.55 Mcal/kg for corn (Zinn, 1988). Additionally, Brandt and Anderson (1990) found that the average  $NE_g$  value of soybean oil, tallow, and yellow grease was 3.94 Mcal/kg when added to the diet at 3.5% (DM basis) which was 2.9 times greater compared to the  $NE_g$  value of 1.38 Mcal/kg for the control diet.

To better understand the reason for the high feeding value of DGS relative to corn, Lodge et al. (1997) conducted a finishing trial to evaluate the contribution of individual components of DGS in a DRC-based diet. They developed a composite feed which was formulated to be very similar to WDGS and consisted of 65.7% WCGF-A, 26.3% CGM, and 8.0% tallow (COMP2). Dietary treatments consisted of 1) DRC, 2) WCGF, 3) COMP2, 4) COMP2 minus tallow (-FAT), and 5) COMP2 minus CGM (-CGM). Cattle fed COMP2 and -FAT had lower ( $P < 0.10$ ) DMI (9.07 kg/d) compared to cattle fed DRC (9.75 kg/d) while cattle fed WCGF and -CGM had intermediate DMI (9.46 kg/d). There was no difference ( $P > 0.10$ ) in ADG between treatments (1.33 kg). Cattle fed COMP2 had greater G:F (0.149) compared to cattle fed DRC or WCGF (0.136) and cattle fed -FAT and -CGM had intermediate G:F (0.146). The feeding value of COMP2, based on differences in G:F, was 124% relative to corn. The feeding value of -FAT and -CGM were both 118% relative to corn. The feeding value of WCGF was calculated to be 100% relative to corn. The authors attributed the greater feeding value of COMP2 compared to WCGF to be due to the fat content of the composite. This is supported by other research which found that the addition of tallow, yellow grease, or dried full-fat corn germ to diets containing WCGF further improved finishing cattle performance (Richards et al., 1998; Defoor et al., 2003; Montgomery et al., 2005). Since

gain efficiency was reduced equally when either tallow or CGM was removed in the study by Lodge et al. (1997), it is still unclear how the fiber, protein, or fat content of DGS may individually contribute to the improved feeding value relative to corn. Excess protein supplied by feeding DGS can be deaminated and used for energy and this may help explain why G:F was reduced equally when either tallow or CGM was removed.

Vander Pol et al. (2009) hypothesized that the fat in DGS could be protected to some degree from total ruminal biohydrogenation and this may allow for more unsaturated fatty acids to reach the intestine which may help explain the greater feeding value observed for DGS in finishing cattle diets. Zinn et al. (2000) showed that low intestinal digestibility of supplemental fat in finishing diets was due to extensive ruminal biohydrogenation. The authors stated that the formations of micelles are critical for absorption of fatty acids and micelles formed from unsaturated fatty acids have a greater surface area which leads to increased digestibility and more efficient utilization compared to SFA. Therefore, a reduction in biohydrogenation resulting in an increased amount of unsaturated fatty acids reaching the intestine may lead to increased animal performance.

Vander Pol et al. (2009) conducted three trials to further investigate how fat in WDGS may contribute to the increased feeding value. The first two trials were finishing studies utilizing 60 individually fed heifers and 234 steers, respectively. Dietary treatments consisted of a corn control diet with addition of corn oil at 2.5 or 5.0% (Trial 1), addition of tallow at 1.3 or 2.6% (Trial 2), or addition of WDGS (Trial 1) or DDGS (Trial 2) at 20 or 40% (DM basis). In Trial 2, all diets contained 20% WCGF-B. The diets were formulated so that the dietary fat content was similar between the 2.5% corn oil or 1.3% tallow and the 20% DGS and between the 5.0% corn oil or 2.6% tallow and 40%

DGS diets. There was no difference ( $P > 0.10$ ) in DMI due to treatments although cattle fed 5.0% corn oil in Trial 1 had numerically lower DMI (8.2 kg/d) compared to all other treatments (9.0 kg/d). In Trial 1, cattle fed 5.0% corn oil had decreased ADG and G:F compared to other treatments. In Trial 2, there were no effects on ADG or G:F due to treatments. A metabolism study was conducted in Trial 3 utilizing five ruminally and duodenally cannulated steers. The dietary treatments consisted of a DRC control (CON) diet with the addition of 3.4% corn oil (CON + OIL), 40% WDGS (WDGS), 29.6% corn bran plus 11.6% CGM (COMP), or COMP plus 4.1% corn oil (COMP + OIL). The COMP treatment was formulated to contain a similar NDF and CP content compared to WDGS treatment and the COMP + OIL treatment was formulated to contain a similar NDF, CP, and fat content compared to the WDGS treatment. Cattle fed COMP + OIL had greater average ruminal pH and less time spent below pH 5.6 compared to other treatments ( $P < 0.10$ ). Cattle fed WDGS had the lowest numerical average and maximum pH and pH change as well as the highest numerical time spent below pH 5.6 and 5.3. Cattle fed WDGS also had the greatest molar proportion of propionate and lowest molar proportion of acetate as well as lowest A:P ratio compared other treatments ( $P < 0.10$ ). Ruminal OM and NDF digestion were not affected by treatment although ruminal NDF digestibility was numerically increased for cattle fed WDGS compared to cattle fed the corn control (71.0 vs. 56.2%, respectively). Total tract OM, NDF, and fat digestion were lowest for cattle fed COMP and COMP + OIL. Total tract OM, NDF, and starch digestion were not different between cattle fed WDGS or corn control but cattle fed WDGS had the highest total tract fat digestion (81.0%) compared to all other treatments including the control (72.5%). The authors concluded that the fat in WDGS may be

different than corn oil but it appears to be similar to tallow, at least in HMC based diets containing 20% WCGF-B. Furthermore, they concluded that the increased feeding value of WDGS relative to corn could be due to a combination of greater propionate production and greater fat digestion likely because greater levels of unsaturated fatty acids are available for intestinal digestion when WDGS is fed in finishing diets.

The reason for the difference in the response to corn oil or tallow by Vander Pol et al. (2009) may be the composition of the fat. Corn oil is mainly composed of unsaturated fatty acids but tallow consists of a mixture of unsaturated and saturated fatty acids. However, Zinn (1989b) evaluated several sources of fat and found that fat level affected cattle performance but fat source did not. The author also found that changes in fat intake per kg of BW accounted for 95% of the variation in postruminal fat digestion which implies that fat level was the primary factor responsible for the variation observed when supplemental fat was included in finishing diets (Zinn, 1994). Although fat source did not influence the comparative feeding value, fat sources consisting primarily of SFA did increase the ruminal production of propionate compared to fat sources consisting primarily of unsaturated fatty acids (Zinn, 1989a). Corn oil in WDGS should be similar to corn oil supplementation but this was not the case in the study by Vander Pol et al. (2009). The increase in propionate production observed for cattle fed WDGS suggests that the fat content of WDGS is acting similar to a fat source composed primarily of SFA. However, Vander Pol et al. (2009) observed that the proportion of unsaturated fatty acids was increased in the duodenal fat content of cattle fed WDGS compared to cattle fed DRC with or without supplemental corn oil. This implies that the fat content of WDGS is somehow protected from ruminal biohydrogenation which leads to greater intestinal fat

digestibility and is probably the primary reason for the high feeding value of WDGS. The reason the fat is protected is not understood. Vander Pol et al. (2009) commented that the oil may be protected if it is still associated with an intact germ portion. Montgomery et al. (2005) and Sulpizio et al. (2003) observed that cattle fed finishing diets containing WCGF supplemented with either dried full-fat corn germ or tallow had similar performance.

As mentioned previously, diet formulations, such as addition of roughage NDF, that increase ruminal pH favor production of acetate compared to propionate resulting in greater A:P ratios. Conversely, ruminal fermentation of starch leads to increased production of propionate and lower ruminal pH which may lead to an increased incidence of acidosis. Since DGS and WCGF have relatively low starch content and high NDF content compared to corn, it may be expected that pH and A:P ratio would be greater when DGS or WCGF are included in finishing diets. Cattle fed DGS and WCGF have decreased starch intake and increased CP and NDF intake. Cattle fed DGS also have increased fat intake which would favor increased production of propionate.

With greater NDF intakes, feeding WCGF in finishing diets appeared to affect ruminal fermentation as expected. Ham et al. (1994) observed cattle fed 40% WCGF had numerically greater ruminal pH and numerically lower ruminal VFA production but A:P ratio was similar to cattle fed DRC. Furthermore, Montgomery et al. (2004) reported that cattle fed 40% WCGF had greater ruminal pH and A:P ratio while ruminal VFA concentrations were decreased compared to steers fed SFC-based control diet. Additionally, Sindt et al. (2002) reported that ruminal pH and A:P ratio increased linearly as WCGF inclusion level was increased from 0 to 60% in SFC-based diets while total

VFA and propionate production decreased linearly. In the study by Sindt et al. (2002), ruminal acetate production was similar between cattle fed 0 or 30% WCGF but was numerically increased for cattle fed 60% WCGF.

However, feeding DGS seems to have different effects on ruminal fermentation than WCGF. Although cattle fed DGS have greater NDF intakes, Vander Pol et al. (2009) reported that ruminal pH and A:P ratio were decreased compared to cattle fed a corn control diet. The lower ruminal pH is supported by results from other trials feeding WDGS or MDGS as observed by Corrigan et al. (2009a) and Nuttleman et al. (2010). Additionally, cattle fed DDGS had lower ruminal pH compared to cattle fed corn control when alfalfa hay was the roughage source (Uwituze et al., 2010). The reduction in A:P ratio is also in agreement with results observed by Corrigan et al. (2009a) and Uwituze et al. (2010) who reported a decrease in the A:P ratio when 40% WDGS or 25% DDGS were included in a corn based diet. In addition, Leupp et al. (2009) reported a linear decrease in the A:P ratio as DDGS inclusion level was increased from 0 to 60% (DM basis) in a DRC-based finishing diet.

In contrast, May (2008) reported that steers fed 25% DDGS in DRC or SFC-based diets had similar A:P ratios compared to cattle fed diets without DDGS. Furthermore, cattle fed DDGS appear to have increased ruminal pH compared to cattle fed corn control with CS as the roughage source (Uwituze et al., 2010; Nuttleman et al., 2010). Leupp et al. (2009) reported that ruminal pH increased linearly as DDGS inclusion level was increased from 0 to 60% in DRC-based diets. In the study by Leupp et al. (2009), grass hay was included at 30% in all diets and average ruminal pH was above 6.3 for all treatments.

DiLorenzo and Galyean (2010) commented that the composition of the fiber fraction in DGS may be a possible reason for the decrease in A:P ratio observed when DGS are fed since ruminal fermentation of hemicellulose results in a decrease in the A:P ratio compared to cellulose (Murphy et al., 1982). Hemicellulose content can be calculated by subtracting the ADF content from the NDF content (Collins and Fritz, 2003). Using the NDF and ADF content previously reported, the hemicellulose content of DGS, WCGF, and corn are 23.8, 33.1, and 6.95%, respectively. Therefore, feeding DGS or WCGF by replacing corn will lead to an increase in hemicellulose intake. Although this may help explain the decrease in A:P ratio when DGS are fed since DGS has 3.4 times more hemicellulose compared to corn, WCGF has 4.8 times more hemicellulose compared to corn and feeding WCGF usually results in an increase in A:P ratio compared to corn.

DiLorenzo and Galyean (2010) also commented that the CDS fraction of DGS may be another possible reason for the decrease in ruminal pH and A:P ratio observed when DGS are fed. Ham et al. (1994) observed that cattle fed 40% WDG had similar ruminal pH and acetate production compared to cattle fed DRC but propionate production was slightly decreased numerically and A:P ratio was numerically increased for cattle fed 40% WDG. However, cattle fed 20% TS had decreased ruminal pH, acetate production, and A:P ratio while propionate production was increased 40% compared to cattle fed DRC. Scott et al. (1998) also observed that cattle fed 15 or 30% steep had decreased ruminal pH, acetate production, and A:P ratio while propionate production was increased compared to cattle fed DRC. Cattle fed 15% corn bran tended to have increased ruminal pH, propionate production was numerically greater, while acetate production and A:P

ratio were numerically lower compared to cattle fed DRC. Cattle fed corn bran plus steep or DRC had similar ruminal pH and VFA production.

The fiber portion of DGS and WCGF has been shown to be highly digestible (DeHaan, 1983; Firkins et al., 1985; Sayer, 2004) and this may also be another explanation for the increased feeding value of corn-milling byproducts relative to corn. Additionally, the increased NDF content and reduced starch content of byproducts would be expected to reduce the incidence of acidosis. Because ruminal pH is generally similar to or lower than that of cattle fed DRC, it appears feeding DGS does not reduce the incidence of acidosis compared to feeding corn based diets. Further, the effect of feeding DGS on NDF digestion has mixed results. On the other hand, feeding WCGF results in increased ruminal pH and NDF digestibility (Ham et al., 1994; McCoy et al., 1997; Montgomery et al., 2004) and may reduce the incidence of acidosis.

Krehbiel et al. (1995b) evaluated the effects of feeding WCGF on the incidence of acidosis by measuring variation in DMI and ruminal pH. Cattle were fed three diets consisting of 57.8% DRC, 29.3% DRC plus 29.3% WCGF, or 58.8% WCGF (DM basis). The remainder of the diet consisted of 20% alfalfa hay, 20% CS, and dry supplement. The acidosis challenge was done by intraruminally dosing 7.9 kg of the corresponding diet for each steer. Results indicated that feeding WCGF will not eliminate acidosis but the total amount of time that cattle experience acidosis is reduced. This is because cattle fed WCGF had lower ruminal pH and increased ruminal VFA production at 3 and 6 h after the challenge but ruminal pH returned to initial values by 21 h after the challenge. Cattle fed only DRC had decreased ruminal pH 15 to 24 h after the challenge and ruminal VFA production was increased at 15 and 18 h compared to cattle fed WCGF. The authors



commented that the initial drop in pH for cattle fed WCGF was due to the high lactic acid content of the steep fraction of WCGF. This may actually help further reduce the effects of acidosis by predisposing the ruminal microbial population to lactic acid which may encourage growth by lactate-utilizing bacteria.

In summary, it appears the increased feeding value of DGS is primarily due to composition and digestibility of fat, but there may also be additional benefits from the high UIP content and the decreased A:P ratio. In contrast, the increased feeding value of WCGF may be primarily due to the highly digestible fiber content along with a reduction in the incidence of acidosis.

*Roughage in Finishing Cattle Diets Containing Corn-Milling Byproducts.* As noted, addition of roughage NDF generally leads to greater ruminal pH which favors production of acetate compared to propionate. Lower propionate production will promote greater DMI which may lead to increased total energy intake. In contrast, DMI is inversely related to ruminal fermentation of starch which may lead to an increased incidence of acidosis and decreased total energy intake. When corn is replaced with byproducts such as WDGS or WCGF, starch intake is decreased and fiber intake is increased.

Based on the positive relationship between DMI and dietary NDF, as well as the relatively high correlation ( $r^2 = 0.859$ ) between dietary NDF and  $NE_g$  intake (kcal/kg of  $BW^{0.75}$ ) as observed by Arelovich et al. (2008) in beef cattle, it may be expected that DMI would be greater when DGS or WCGF are included in finishing diets. Unsurprisingly, DMI of cattle fed MDGS, DDGS, and WCGF are generally increased

compared to cattle fed a corn control diet and ADG is generally improved. However, DMI of cattle fed WDGS is dependent on level. The increase in DMI could imply that cattle fed byproducts are experiencing less acidosis compared to cattle fed corn control diets when roughage levels are similar. Along with providing NDF and decreasing the starch content, byproducts such as WDGS and WCGF can also supply protein and moisture. As a result, roughage level and quality could potentially be reduced.

*Effects of Roughage in Diets Containing Dry-Milling Byproducts.* To evaluate the effects of roughage level in SFC-based finishing diets containing corn WDG, Godsey et al. (2009) fed diets containing 40% WDG with the addition of 7.5, 11.3, or 15% alfalfa hay (DM basis). As roughage level was increased, DMI tended ( $P = 0.07$ ) to increase linearly and G:F tended ( $P = 0.09$ ) to decrease linearly. There was no effect on ADG. The authors concluded that 7.5% alfalfa hay is sufficient in SFC-based finishing diets containing 40% WDG. Similarly, MacDonald et al. (2009) reported that the inclusion of 7.5% alfalfa hay appeared to be adequate in SFC-based diets containing 25% sorghum WDG.

To evaluate the effects of roughage level in diets containing corn DDGS, May et al. (2010) conducted two finishing trials. In Trial 1, cattle were fed SFC-based diets containing 25% DDGS with addition of 5 or 15% CS. In Trial 2, cattle were fed DRC or SFC-based diets containing 25% DDGS with addition of 5 or 15% CS (DM basis). No difference in finishing cattle performance or carcass characteristics was observed in Trial 1 due to roughage level although cattle fed 15% CS had numerically greater DMI compared to cattle fed 5% CS (8.77 vs. 8.52 kg/d). In Trial 2, DMI was increased ( $P <$

0.01) when CS was increased from 5 to 15% in both DRC and SFC-based diets. There was no effect on ADG so G:F was decreased ( $P = 0.02$ ) when CS was increased from 5 to 15% of dietary DM. The authors concluded that roughage levels can be reduced in finishing diets containing 25% DDGS without effecting finishing cattle performance.

Uwituze et al. (2010) conducted a finishing trial and a metabolism trial to evaluate the effects of roughage source in SFC-based diets containing corn DDGS. Cattle were fed diets containing 25% DDGS with addition of 5.6% alfalfa hay or 11.0% CS. Although diets were formulated to contain equal amounts of dietary NDF, diets containing CS had 13% more dietary NDF compared to alfalfa hay (19.2 vs. 17.0%). In the finishing study, cattle fed CS had increased DMI compared to cattle fed alfalfa hay which is likely due to the slight increase in dietary NDF for diets containing CS. There were no effects on ADG, G:F, or any carcass characteristics due to roughage source. In the metabolism study, cattle fed alfalfa hay had increased DM, OM, starch, and NDF intake compared to cattle fed CS but there were no differences in apparent total tract digestibility (%) for DM, OM, or NDF due to roughage source. Cattle fed alfalfa hay had decreased ruminal pH (5.31) and total VFA concentration (118.4 mM) and increased ruminal propionate concentration (50.7 mM) compared to cattle fed CS (5.72, 105.0, and 42.2 mM, respectively). The decreased ruminal pH and increased propionate production for cattle fed alfalfa hay are likely a function of increased DM and starch intake. The authors concluded that alfalfa hay and CS had similar feeding values in SFC-based finishing diets containing 25% DDGS.

Depenbusch et al. (2009) conducted a finishing study to evaluate the effects of roughage in SFC-based diets containing dried or wet sorghum DGS (SDDGS or

SWDGS). Cattle were fed diets containing 15% SDDGS or 16% SWDGS with the addition of 0 or 6% alfalfa hay (DM basis). Cattle fed 6% alfalfa hay had increased DMI and ADG for both SDDGS and SWDGS compared to cattle fed no roughage. However, the interaction between roughage level and DGS type was not evaluated. Carcass adjusted ADG was numerically similar for cattle fed 0 or 6% alfalfa hay in diets containing SWDGS (1.35 and 1.37 kg, respectively) but carcass adjusted ADG was greater for cattle fed 6% alfalfa hay compared to cattle fed 0% alfalfa hay in diets containing SDDGS (1.41 vs. 1.22 kg). There was no difference ( $P = 0.78$ ) in G:F between treatments although cattle fed 0% alfalfa hay with SWDGS had the highest numerical G:F compared to cattle fed 6% alfalfa hay with SWDGS or cattle fed SDDGS with either 0 or 6% alfalfa hay (155 vs. 147, 142, or 148 g/kg, respectively). Cattle fed 6% alfalfa hay did have increased ( $P < 0.05$ ) HCW and 12<sup>th</sup> rib fat compared to cattle fed 0% alfalfa hay. Hot carcass weight was numerically similar between cattle fed SWDGS diets with 0 or 6% alfalfa hay (327 or 329 kg, respectively). Apparent total tract digestibility of DM and OM were lower ( $P = 0.01$ ) for cattle fed 6% alfalfa hay. The authors concluded that eliminating roughage in SFC-based diets containing sorghum DGS will reduce DMI, ADG, and HCW without affecting G:F. Although the interaction between DGS type and roughage level was not tested, it appears that roughage could possibly be eliminated in SFC-based diets containing 16% SWDGS with minimal effects on finishing cattle performance.

*Effects of Roughage in Diets Containing Wet-Milling Byproducts.* Goedecken et al. (1989) conducted two trials to evaluate the effects of roughage level in diets containing

CGF on finishing cattle performance. In Trial 1, cattle were fed DRC or HMC-based diets containing 40% CGF with or without addition of 5% alfalfa hay and 5% corn silage (DM basis). Treatments had no effect on ADG but cattle fed 40% CGF without roughage had decreased DMI and increased G:F compared to cattle fed 40% CGF with 10% roughage ( $P < 0.05$ ). In trial 2, cattle were fed DRC-based finishing diets containing 20% CGF with addition of 0, 4, 8, or 12% roughage composed of a 1:1 blend of alfalfa hay and CS. Dry matter intake increased linearly ( $P < 0.05$ ) as roughage was increased from 0 to 12%. Treatments had no effect on ADG and there was a quadratic effect ( $P < 0.05$ ) due to roughage level for G:F with cattle fed 0 or 12% alfalfa hay having the highest G:F. The authors concluded that CGF may be used as a roughage source for finishing cattle.

In a similar study, Farran et al. (2006) fed DRC-based finishing diets containing 35% WCGF with addition of 0, 3.75, or 7.5% alfalfa hay (DM basis). Dry matter intake and ADG increased linearly ( $P < 0.05$ ) when alfalfa hay was increased from 0 to 7.5% although ADG was numerically the same between cattle fed 3.75 or 7.5% alfalfa hay. As alfalfa hay increased from 0 to 7.5%, G:F tended ( $P = 0.06$ ) to decrease linearly. The authors concluded that alfalfa hay can be decreased in DRC-based finishing diets containing 35% WCGF.

Parsons et al. (2007) conducted two trials to evaluate the effects of roughage level on finishing cattle performance fed SFC-based diets containing WCGF. In Trial 1, cattle were fed diets containing 40% WCGF with the addition of 0, 4.5, or 9.0% alfalfa hay (DM basis). Dry matter intake and ADG linearly increased ( $P = 0.01$ ) when alfalfa hay was increased from 0 to 9%. Increasing alfalfa hay level did not affect ( $P = 0.92$ ) G:F. In Trial 2, cattle were fed diets containing 40% WCGF with the addition of 4.5 or 9.0%

alfalfa hay (DM basis). Cattle fed 9% alfalfa hay tended ( $P = 0.06$ ) to have greater DMI compared to cattle fed 4.5% alfalfa hay and ADG was similar between treatments. Cattle fed 4.5% alfalfa hay tended ( $P = 0.07$ ) to have increased G:F compared to cattle fed 9.0% alfalfa hay. The authors concluded that alfalfa hay can be decreased in SFC-based finishing diets containing 40% WCGF.

In a similar study, Sindt et al. (2003) conducted a finishing trial and a metabolism trial to evaluate roughage level in SFC-based finishing diets containing WCGF. In the finishing trial, cattle were fed diets containing 2 or 6% alfalfa hay with the addition of 25, 35, or 45% WCGF (DM basis). There was no difference in DMI or ADG ( $P > 0.10$ ) between treatments but G:F decreased linearly ( $P < 0.01$ ) when WCGF was increased from 25 to 45% of dietary DM. In the metabolism trial, cattle were fed diets containing 25 or 45% WCGF with addition of 0, 2, or 6% alfalfa hay (DM basis). Intake of DM and OM was similar between treatments but increasing WCGF or alfalfa hay lead to an increase in NDF intake. Cattle fed 45% WCGF had decreased OM digestibility but NDF digestibility and passage rate (%/h) was not affected by treatments. Ruminal pH tended ( $P = 0.08$ ) to greater for cattle fed 45% WCGF and ruminal pH increased linearly ( $P < 0.05$ ) as alfalfa hay level was increased. There was a WCGF by alfalfa hay level interaction ( $P < 0.05$ ) for A:P ratio. Cattle fed 45% WCGF had a greater A:P ratio when fed with 0 or 2% alfalfa hay compared to cattle fed 25% WCGF with 0 or 2% alfalfa hay but cattle fed 6% alfalfa hay had lower A:P ratio when fed 45% WCGF compared 25% WCGF. The authors concluded that alfalfa hay levels may be lowered in SFC-based diets when at least 25% WCGF is included.

*Effects of Roughage in Diets Containing Corn-Milling Byproduct Combinations.*

Loza et al. (2010) conducted a finishing study to evaluate roughage levels in finishing diets containing a combination of WDGS and WCGF. Dietary treatments consisted of feeding a blend of WDGS and WCGF in a 1:1 ratio at 0, 25, 50 or 75% with addition of 7.5% alfalfa hay (DM basis). Additionally, alfalfa hay was reduced from 7.5% to 5, 2.5, or 0% as the inclusion level of byproducts increased from 25 to 75%, respectively (DM basis). There were no combination x alfalfa hay interactions observed for finishing cattle performance. As the byproduct inclusion level increased from 25 to 75%, DMI, ADG, and G:F responded quadratically ( $P < 0.01$ ) with cattle fed 25 or 50% byproduct having the similar performance which was improved compared to cattle fed 0 or 75% byproduct. Cattle fed 0 or 75% byproduct had similar finishing performance. Cattle fed 7.5% alfalfa hay tended ( $P = 0.06$ ) to have greater DMI compared to cattle fed lower roughage levels but roughage level had no affect on ADG or G:F. The authors commented that 12 steers (30% of cattle fed this dietary treatment) fed 75% byproduct with 0% alfalfa hay were diagnosed with PEM and were removed from the trial. This study along with others previously mentioned (Vanness et al., 2009) implies that forage may interact with dietary S and the incidence of PEM. The authors concluded that roughage should not be eliminated when diets contain more than 0.4% dietary S. However, it appears that roughage levels could be reduced in finishing diets containing a combination of WDGS and WCGF in a 1:1 ratio.

Based on the studies reviewed here, it appears that roughage level may be reduced or even possibly eliminated in feedlot diets containing DGS and/or WCGF without negatively affecting finishing cattle performance.

**LITERATURE CITED**

- Akayezu, J. M., J. G. Linn, S. R. Harty, and J. M. Cassady. 1998. Use of distillers grains and co-products in ruminant diets. Proc. 59th Minnesota Nutr.Conf., Bloomington, MN.
- Allen, M. S., B. J. Bradford, and M. Oba. 2009. BOARD-INVITED REVIEW: The hepatic oxidation theory of the control of feed intake and its application to ruminants. *J. Anim. Sci.* 87:3317-3334.
- Allen, M. S., J. A. Voelker, and M. Oba. 2006. Effective fiber and regulation of ruminal pH: Its more than just chewing. Pages 270-278 in *Production Diseases in Farm Animals*. N. P. Joshi and T. H. Herdt, ed. Wageningen Academic Publishers, Wageningen, the Netherlands.
- 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.
- Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *J. Dairy Sci.* 83:1598-1624.
- Arelovich, H. M., C. S. Abney, J. A. Vizcarra, and M. L. Galyean. 2008. Effects of dietary neutral detergent fiber on intakes of dry matter and net energy by dairy and beef cattle: analysis of published data. *Prof. Anim. Sci.* 24:375-383.
- Balch, C. C. and R. C. Campling. 1962. Regulation of voluntary food intake in ruminants. *Nutrition Abstracts and Reviews, A and B* 32:669-686.
- 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.
- Belyea, R. L., K. D. Rausch, and M. E. Tumbleson. 2004. Composition of corn and distillers dried grains with solubles from dry grind ethanol processing. *Bioresource Technology* 94:293-298.
- Belyea, R. L., B. J. Steevens, R. J. Restrepo, and A. P. Clubb. 1989. Variation in composition of by-product feeds. *J. Dairy Sci.* 72:2339-2345.
- Bergen, W. G. 1972. Rumen osmolality as a factor in feed intake control of sheep. *J. Anim. Sci.* 34:1054-1060.
- Bevans, D. W., K. A. Beauchemin, K. S. Schwartzkopf-Genswein, J. J. McKinnon, and T. A. McAllister. 2005. Effect of rapid or gradual grain adaptation on subacute acidosis and feed intake by feedlot cattle. *J. Anim. Sci.* 83:1116-1132.
- Blanchard, P. H. 1992. *Technology of Corn Wet Milling and Associated Processes*. Industrial chemistry library, Vol. 4. Elsevier, New York.



- Block, H. C., C. N. Macken, T. J. Klopfenstein, G. E. Erickson, and R. A. Stock. 2005. Optimal wet corn gluten and protein levels in steam-flaked corn-based finishing diets for steer calves. *J. Anim. Sci.* 83:2798-2805.
- Bothast, R. J. and M. A. Schlicher. 2005. Biotechnological processes for conversion of corn into ethanol. *Appl. Microbiol. Biotechnol.* 67:19-25.
- Brandt, R. T., Jr. and S. J. Anderson. 1990. Supplemental fat source affects feedlot performance and carcass traits of finishing yearling steers and estimated diet net energy value. *J. Anim. Sci.* 68:2208-2216.
- Bremer, V. R., J. R. Benton, M. K. Luebbe, K. J. Hanford, G. E. Erickson, T. J. Klopfenstein, and R. A. Stock. 2009. Wet distillers grains plus solubles or solubles in feedlot diets containing wet corn gluten feed. *Nebraska Beef Cattle Rep.* MP 92:64-65. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Bremer, V. R., C. D. Buckner, A. W. Brown, T. P. Carr, R. M. Diedrichsen, G. E. Erickson, and T. J. Klopfenstein. 2010a. Lipid and NDF analysis of ethanol byproduct feedstuffs. *Nebraska Beef Cattle Rep.* MP 93:83-86. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Bremer, V. R., G. E. Erickson, and T. J. Klopfenstein. 2008. Meta-analysis of UNL feedlot trials replacing corn with WCGF. *Nebraska Beef Cattle Rep.* MP 91:37-38. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Bremer, V. R., K. J. Hanford, G. E. Erickson, and T. J. Klopfenstein. 2010b. Update: meta-analysis of UNL feedlot trials replacing corn with WDGS. *Nebraska Beef Cattle Rep.* MP 93:67-68. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Brent, B. E. 1976. Relationship of acidosis to other feedlot ailments. *J. Anim. Sci.* 43:930-935.
- Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrott. 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-concentrate diets: Performance and ruminal metabolism. *J. Anim. Sci.* 84:E25.
- Buckner, C. D., M. F. Wilken, J. R. Benton, S. J. Vanness, V. R. Bremer, T. J. Klopfenstein, G. E. Erickson, B. Adkins, and P. J. Kononoff. 2010. Evaluation of

methods to determine dry matter content of ethanol byproducts and nutrient variability for wet distillers grains plus solubles. *Prof. Anim. Sci.* (In press).

- Burrin, D. G. and R. A. Britton. 1986. Response to monensin in cattle during subacute acidosis. *J. Anim. Sci.* 63:888-893.
- Cao, Z. J., J. L. Anderson, and K. F. Kalscheur. 2009. Ruminant degradation and intestinal digestibility of dried or wet distillers grains with increasing concentrations of condensed distillers solubles. *J Anim Sci* 87:3013-3019.
- Carter, R. R. and W. L. Grovum. 1990. A review of the physiological significance of hypertonic body fluids on feed intake and ruminal function: salivation, motility and microbes. *J. Anim. Sci.* 68:2811-2832.
- Choi, B. R. and M. S. Allen. 1999. Intake regulation by volatile fatty acids and physical fill. *S. Afr. J. Anim. Sci.* 29(ISRP):40-41. (Abstr.)
- Coe, M. L., T. G. Nagaraja, Y. D. Sun, N. Wallace, E. G. Towne, K. E. Kemp, and J. P. Hutcheson. 1999. Effect of virginiamycin on ruminal fermentation in cattle during adaptation to a high concentrate diet and during an induced acidosis 1. *J Anim Sci* 77:2259-2268.
- Cole, N. A., R. R. Johnson, and F. N. Owens. 1976a. Influence of roughage level on the site and extent 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. 1976b. Influence of roughage level and corn processing method on microbial protein synthesis by beef steers. *J. Anim. Sci.* 43:497-503.
- Collins, M. and J. O. Fritz. 2003. Forage Quality. Pages 363-390 in *Forages: An Introduction to Grassland Agriculture*. 6th ed. R. F. Barnes, C. J. Nelson, M. Collins, and K. J. Moore, ed. Blackwell Publ., Ames, Iowa.
- Conrad, H. R., A. D. Pratt, and J. W. Hibbs. 1964. Regulation of feed intake in dairy cows. I. Change in importance of physical and physiological factors with increasing digestibility. *J. Dairy Sci.* 47:54-62.
- Cooper, R. J. 1997. Evaluation of feed intake variation and monensin on acidosis in finishing steers. M. S. Thesis. Univ. of Nebraska, Lincoln.
- Cooper, R. J., T. J. Klopfenstein, R. A. Stock, C. T. Milton, D. W. Herold, and J. C. Parrott. 1999. Effects of imposed feed intake variation on acidosis and performance of finishing steers. *J. Anim. Sci.* 77:1093-1099.
- Cooper, R. J., C. T. Milton, T. J. Klopfenstein, and D. J. Jordon. 2002. Effect of corn processing on degradable intake protein requirement of finishing cattle. *J. Anim. Sci.* 80:242-247.

- Corn Refiners Association. 2008. The corn refining process., Washington, D.C.  
<http://www.corn.org/web/processo.pdf> Accessed Aug. 19, 2009.
- Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vanness, and K. J. Hanford. 2009a. Effect of corn processing method and corn wet distillers grains plus solubles inclusion level in finishing steers. *J. Anim. Sci.* 87:3351-3362.
- Corrigan, M. E., T. J. Klopfenstein, G. E. Erickson, N. F. Meyer, K. J. Vander Pol, M. A. Greenquist, M. K. Luebbe, K. K. Karges, and M. L. Gibson. 2009b. Effects of level of condensed distillers solubles in corn dried distiller's grains on intake, daily body weight gain, and digestibility in growing steers fed forage diets. *J. Anim. Sci.* 87:4073-4081.
- 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.
- Dairy One Forage Lab. 2010. Feed Composition Library., Ithaca, NY.  
<http://www.dairyone.com/Forage/FeedComp/mainlibrary>. Accessed Mar. 2, 2010.
- Dakota Gold Products. 2009. POET Nutrition, Sioux Falls, SD.  
<http://www.dakotagold.com/products/index.asp> Accessed Feb. 3, 2010.
- Davis, K. S. 2001. Milling, processing and generation of co-products. Page 1-7 in Proc. 62nd Minnesota Nutr.Conf., St. Paul, MN.
- 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.
- Defoor, P. J., D. A. Walker, K. J. Malcolm-Callis, and J. F. Gleghorn. 2003. Effects of Sweet Bran<sup>®</sup> and added fat level on performance and carcass quality responses by finishing steers. Clayton Livest. Res. Ctr. Prog. Rep. No. 108. New Mexico State Univ., Las Cruces. [http://aces.nmsu.edu/aes/clayton/progress\\_reports/](http://aces.nmsu.edu/aes/clayton/progress_reports/).
- DeFrain, J. M., J. E. Shirley, K. C. Behnke, E. C. Titgemeyer, and R. T. Ethington. 2003. Development and evaluation of a pelleted feedstuff containing condensed corn steep liquor and raw soybean hulls for dairy cattle diets. *Anim. Feed Sci. Technol.* 107:75-86.
- DeHaan, K. A. 1983. Improving the utilization of fiber and energy through the use of corn gluten feed and alkali compounds. Ph. D. Dissertation. Univ. of Nebraska, Lincoln.

- 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.
- DiLorenzo, N. and M. L. Galyean. 2010. Applying technology with newer feed ingredients in feedlot diets: Do the old paradigms apply? *J. Anim. Sci.* 88:E123-E132.
- Droppo, R. E., G. K. Macleod, and D. G. Grieve. 1985. Composition and storage characteristics of wet corn gluten feed. *Can. J. Anim. Sci.* 65:265-268.
- Erickson, G. E., V. R. Bremer, T. J. Klopfenstein, L. A. Stalker, and R. J. Rasby. 2007. Feeding of corn milling co-products to beef cattle. Utilization of corn co-products in the beef industry 2nd ed., Nebraska Corn Board, Lincoln, NE. [http://beef.unl.edu/byprodfeeds/07CORN-048\\_BeefCoProducts.pdf](http://beef.unl.edu/byprodfeeds/07CORN-048_BeefCoProducts.pdf) Accessed Oct. 12, 2009.
- Erickson, G. E., T. J. Klopfenstein, K. J. Vander Pol, V. Bremer, and P. Loza. 2005. Feeding of wet corn milling byproducts to beef cattle. Page 69-79 in Proc. 66th Minnesota Nutr.Conf., St. Paul, MN.
- Fanning, K. C., C. T. Milton, T. J. Klopfenstein, D. J. Jordon, R. J. Cooper, and J. C. Parrott. 1999. Effects of rumensin level and bunk management strategy of finishing steers. *Nebraska Beef Cattle Rep.* MP 71-A:41-44. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Farran, T. B., G. E. Erickson, T. J. Klopfenstein, C. N. Macken, and R. U. Lindquist. 2006. Wet corn gluten feed 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.
- Firkins, J. L., L. L. Berger, and G. C. Fahey, Jr. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. *J. Anim. Sci.* 60:847-860.
- Forbes, J. M. 2000. Physiological and metabolic aspects of feed intake control. Pages 319-334 in *Farm Animal Metabolism and Nutrition*. J. P. F. D'Mello, ed. CAB International, Wallingford, Oxon, UK.
- Fulton, W. R., T. J. Klopfenstein, and R. A. Britton. 1979. Adaptation to high concentrate diets by beef cattle. II. Effect of ruminal pH alteration on rumen fermentation and voluntary intake of wheat diets. *J. Anim. Sci.* 49:785-789.
- Galyean, M. L. 1999. Review: Restricted and programmed feeding of beef cattle-- definitions, application, and research results. *Prof. Anim. Sci.* 15:1-6.
- Galyean, M. L. and P. J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. *J. Anim. Sci.* 81 (E. Suppl. 2):E8-E16.

- Galyean, M. L., K. J. Malcolm-Callis, D. R. Garcia, and G. D. Pulsipher. 1992. Effects of varying the pattern of feed consumption on performance by programmed-fed beef steers. Clayton Livest. Res. Ctr. Prog. Rep. No. 78. New Mexico State Univ., Las Cruces. [http://aces.nmsu.edu/aes/clayton/progress\\_reports/](http://aces.nmsu.edu/aes/clayton/progress_reports/).
- Geisert, B. G., G. E. Erickson, T. J. Klopfenstein, and C. N. Macken. 2004. Phosphorus requirement for finishing heifers. Nebraska Beef Cattle Rep. MP 80-A:49-51. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Gill, D. R., F. N. Owens, J. J. Martin, D. E. Williams, R. A. Zinn, and R. J. Hillier. 1981. Roughage levels in feedlot diets. Anim. Sci. Res. Rep. MP-108:141-146. Oklahoma State Univ., Stillwater. <http://www.beefextension.com/new%20site%202/research.html>.
- Glock, R. D. and B. D. DeGroot. 1998. Sudden death of feedlot cattle. J. Anim. Sci. 76:315-319.
- Goad, D. W., C. L. Goad, and T. G. Nagaraja. 1998. Ruminant microbial and fermentative changes associated with experimentally induced subacute acidosis in steers. J. Anim. Sci. 76:234-241.
- Godsey, C. M., W. A. Griffin, M. K. Luebke, J. R. Benton, G. E. Erickson, and T. J. Klopfenstein. 2009. Cattle performance and economic analysis of diets containing wet distillers grains and dry-rolled or steam-flaked corn. Nebraska Beef Cattle Rep. MP 92:66-69. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Goedeken, F. K., R. A. Stock, T. J. Klopfenstein, and L. Roth. 1989. Corn gluten feed as a source of both energy and roughage. Nebraska Beef Cattle Rep. MP 54:48-50. Univ. of Nebraska, Lincoln.
- Goetsch, A. L., M. A. Funk, F. N. Owens, and K. B. Poling. 1984. Roughage source for beef heifers fed rolled milo diets. Anim. Sci. Res. Rep. MP-116:204-208. Oklahoma State Univ., Stillwater. <http://www.beefextension.com/new%20site%202/research.html>.
- Gould, D. H. 1998. Polioencephalomalacia. J. Anim. Sci. 76:309-314.
- Grubb, J. A. and B. A. Dehority. 1975. Effects of an abrupt change in ration from all roughage to high concentrate upon rumen microbial numbers in sheep. Appl. Environ. Microbiol. 30:404-412.
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, and R. P. Huffman. 1995. Determining the net energy value of wet and dry corn gluten feed in beef growing and finishing diets. J. Anim. Sci. 73:353-359.
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers

grains with solubles as a source of protein and energy for ruminants. *J. Anim. Sci.* 72:3246-3257.

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.

Harmon, D. L., R. M. Yamka, and N. A. Elam. 2004. Factors affecting intestinal starch digestion in ruminants: A review. *Can. J. Anim. Sci.* 84:309-318.

Herold, D. W., M. J. Klemesrud, T. J. Klopfenstein, C. T. Milton, and R. A. Stock. 1998. Solvent-extracted germ meal, corn bran, and steep liquor blends for finishing steers. *Nebraska Beef Cattle Rep.* MP 69-A:50-53. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.

Herold, D. W. 1999. Solvent-extracted germ meal for ruminants. Ph. D. Dissertation. Univ. of Nebraska, Lincoln.

Hickman, D. D., K. S. Schwartzkopf-Genswein, R. Silasi, D. H. Crews, Jr., C. R. Krehbiel, and T. A. McAllister. 2002. Relationship between feeding behavior and performance of feedlot steers. *J. Anim. Sci.* 80(E-Suppl. 1):15. (Abstr.)

Holt, S. M. and R. H. Pritchard. 2004. Composition and nutritive value of corn co-products from dry milling ethanol plants. *South Dakota Beef Rep.* Beef 2004-01. South Dakota State Univ., Brookings. [http://ars.sdstate.edu/extbeef/2004\\_Beef\\_Report.htm](http://ars.sdstate.edu/extbeef/2004_Beef_Report.htm).

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

Huffman, R. P., R. A. Stock, M. H. Sindt, and D. H. Shain. 1992. Effect of fat type and forage level on performance of finishing cattle. *J. Anim. Sci.* 70:3889-3898.

Huls, T. J., M. K. Luebke, G. E. Erickson, and T. J. Klopfenstein. 2008. Effect of inclusion level of modified distillers grains plus solubles in finishing steers. *Nebraska Beef Cattle Rep.* MP 91:41-42. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.

Hungate, R. E. 1966. *The Rumen and Its Microbes*. Academic Press, New York, N.Y.

Huntington, G. B. 1997. Starch utilization by ruminants: from basics to the bunk. *J. Anim. Sci.* 75:852-867.

Hussein, H. S. and L. L. Berger. 1995. Effects of feed intake and dietary level of wet corn gluten feed on feedlot performance, digestibility of nutrients, and carcass characteristics of growing-finishing beef heifers. *J. Anim. Sci.* 73:3246-3252.

- ICM Incorporated. 2009. Ethanol production process.,  
[http://www.icminc.com/ethanol/production\\_process/](http://www.icminc.com/ethanol/production_process/) Accessed July 23, 2009.
- Kaiser, R. M. 2005. Variation in composition of distillers wet grains with solubles. Page 191-197 in Proc. 4-State Dairy Nutr.& Manag.Conf., Dubuque, IA.
- Kelzer, J. M., P. J. Kononoff, A. M. Gehman, L. O. Tedeschi, K. Karges, and M. L. Gibson. 2009. Effects of feeding three types of corn-milling coproducts on milk production and ruminal fermentation of lactating Holstein cattle. *J. Dairy Sci.* 92:5120-5132.
- Kelzer, J. M., P. J. Kononoff, K. Karges, and M. L. Gibson. 2007. Evaluation of protein fractionation and ruminal and intestinal digestibility of corn milling co-products. *J. Dairy Sci.* 90(Suppl. 1):350. (Abstr.)
- Kleinschmit, D. H., J. L. Anderson, D. J. Schingoethe, K. F. Kalscheur, and A. R. Hippen. 2007. Ruminal and intestinal degradability of distillers grains plus solubles varies by source. *J. Dairy Sci.* 90:2909-2918.
- Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. *J. Anim. Sci.* 86:1223-1231.
- Knott, J., G. C. Shurson, and J. Goihl. 2004. Effects of nutrient variability of distiller's solubles and grains within ethanol plants and the amount of distiller's solubles blended with distiller's grains on fat, protein and phosphorus content of DDGS., Univ. of Minnesota, St. Paul. <http://www.ddgs.umn.edu/articles-proc-storage-quality/2004-Knott-%20Nutrient%20variability.pdf> Accessed Feb. 15, 2010.
- Krehbiel, C. R., R. A. Britton, D. L. Harmon, T. J. Wester, and R. A. Stock. 1995a. The effects of ruminal acidosis on volatile fatty acid absorption and plasma activities of pancreatic enzymes in lambs. *J. Anim. Sci.* 73:3111-3121.
- Krehbiel, C. R. and C. L. Ferrell. 1999. Effects of increasing ruminally degraded nitrogen and abomasal casein infusion on net portal flux of nutrients in yearling heifers consuming a high-grain diet. *J. Anim. Sci.* 77:1295-1305.
- Krehbiel, C. R., R. A. Stock, D. W. Herold, D. H. Shain, G. A. Ham, and J. E. Carulla. 1995b. Feeding wet corn gluten feed to reduce subacute acidosis in cattle. *J. Anim. Sci.* 73:2931-2939.
- 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. 1995c. Effect of level and type of fat on subacute acidosis in cattle fed dry-rolled corn finishing diets. *J. Anim. Sci.* 73:2438-2446.
- Lana, R. P., J. B. Russell, and M. E. Van Amburgh. 1998. The role of pH in regulating ruminal methane and ammonia production. *J. Anim. Sci.* 76:2190-2196.

- Latham, M. J., J. D. Sutton, and M. E. Sharpe. 1974. Fermentation and microorganisms in the rumen and the content of fat in the milk of cows given low roughage diets. *J. Dairy Sci.* 57:803-810.
- Ledoux, D. R., J. E. Williams, T. E. Stroud, G. B. Garner, and J. A. Paterson. 1985. Influence of forage level on passage rate, digestibility and performance of cattle. *J. Anim. Sci.* 61:1559-1566.
- Leupp, J. L., G. P. Lardy, K. K. Karges, M. L. Gibson, and J. S. Caton. 2009. Effects of increasing level of corn distillers dried grains with solubles on intake, digestion, and ruminal fermentation in steers fed seventy percent concentrate diets. *J. Anim. Sci.* 87:2906-2912.
- Lodge, S. L., R. A. Stock, T. J. Klopfenstein, D. H. Shain, and D. W. Herold. 1997. Evaluation of wet distillers composite for finishing ruminants. *J. Anim. Sci.* 75:44-50.
- Loe, E. R., M. L. Bauer, and G. P. Lardy. 2006. Grain source and processing in diets containing varying concentrations of wet corn gluten feed for finishing cattle. *J. Anim. Sci.* 84:986-996.
- Loza, P. L., C. D. Buckner, K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein, and R. A. Stock. 2010. Effect of feeding combinations of wet distillers grains and wet corn gluten feed to feedlot cattle. *J. Anim. Sci.* 88:1061-1072.
- MacDonald, J. C., K. J. Jenkins, F. T. McCollum, and N. A. Cole. 2009. Effects of concentration of alfalfa hay on performance of steers fed steam-flaked corn-based finishing diets containing 25% sorghum wet distiller's grains. *J. Anim. Sci.* 87(E-Suppl. 3):121. (Abstr.)
- Macken, C. N., G. E. Erickson, T. J. Klopfenstein, and R. A. Stock. 2004. Effects of concentration and composition of wet corn gluten feed in steam-flaked corn-based finishing diets. *J. Anim. Sci.* 82:2718-2723.
- Mackie, R. I., F. M. Gilchrist, A. M. Roberts, P. E. Hannah, and H. M. Schwartz. 1978. Microbiological and chemical changes in the rumen during the stepwise adaptation of sheep to high concentrate diets. *J. Agric. Sci.* 90:241-254.
- Markham, C. E., C. R. Krehbiel, L. O. Burciaga, D. R. Gill, R. E. Peterson, H. A. DePra, and L. J. McBeth. 2004. Effects of roughage source and particle size on performance and carcass characteristics of finishing heifers. *Anim. Sci. Res. Rep.* MP-1008. Oklahoma State Univ., Stillwater. <http://www.ansi.okstate.edu/Research>.
- Mateo, K. S., K. E. Tjardes, C. L. Wright, T. J. Koger, and B. D. Rops. 2004. Evaluation of feeding varying levels of wet distillers grains with solubles as compared to dry distillers grains with solubles to finishing steers. *South Dakota Beef Rep.* Beef



2004-03. South Dakota State Univ., Brookings.  
[http://ars.sdstate.edu/extbeef/2004\\_Beef\\_Report.htm](http://ars.sdstate.edu/extbeef/2004_Beef_Report.htm).

- May, M. L. 2008. The effects of grain processing method, wet and dry distiller's grains with solubles and roughage level on performance and carcass characteristics of finishing cattle. M. S. Thesis. Kansas State Univ., Manhattan.
- May, M. L., M. J. Quinn, B. E. Deppenbusch, C. D. Reinhardt, M. L. Gibson, K. K. Karges, N. A. Cole, and J. S. Drouillard. 2010. Dried distiller's grains with solubles with reduced corn silage levels in beef finishing diets. *J. Anim. Sci.*, <http://jas.fass.org/cgi/reprint/jas.2009-2637v1> Accessed Mar. 22, 2010.
- McCoy, R. A., C. J. Richards, T. L. Scott, R. A. Stock, T. J. Klopfenstein, and D. W. Herold. 1997. Digestibility of dry-rolled corn, wet corn gluten feed, and alfalfa hay in receiving and finishing diets. *Nebraska Beef Cattle Rep. MP 67-A:61-65*. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Mertens, D. R. 1994. Regulation of forage intake. Pages 450-493 in *Forage Quality, Evaluation, and Utilization*. G. C. Fahey, Jr., M. Collins, D. R. Mertens, and L. E. Moser, ed. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.
- Milton, C. T., R. T. Brandt, and S. A. Shuey. 1994. Roughage levels and comparison of mixed diets vs self-feeders in whole shelled corn finishing programs. *Cattlemen's Day SRP 704:21-23*. Kansas State Univ., Manhattan.  
<http://www.ksre.ksu.edu/library/DesktopDefault.aspx?tabid=45>.
- Milton, C. T., R. T. Brandt, and E. C. Titgemeyer. 1997. Effects of dietary nitrogen source and concentration in high-grain diets on finishing steer performance and nutrient digestion. *J. Anim. Sci.* 75:2813-2823.
- Montgomery, S. P., J. S. Drouillard, J. J. Sindt, M. A. Greenquist, B. E. Deppenbusch, E. J. Good, E. R. Loe, M. J. Sulpizio, T. J. Kessen, and R. T. Ethington. 2005. Effects of dried full-fat corn germ and vitamin E on growth performance and carcass characteristics of finishing cattle  
5. *J Anim Sci* 83:2440-2447.
- Montgomery, S. P., J. S. Drouillard, E. C. Titgemeyer, J. J. Sindt, T. B. Farran, J. N. Pike, C. M. Coetzer, A. M. Trater, and J. J. Higgins. 2004. Effects of wet corn gluten feed and intake level on diet digestibility and ruminal passage rate in steers. *J. Anim. Sci.* 82:3526-3536.
- Moore, J. A., M. H. Poore, and R. S. Swingle. 1987. Influence of roughage source in 65 or 90% concentrate diets on rumination time, rumen pH, and in situ neutral detergent fiber digestion in beef steers. *Proc. West. Sec. Am. Soc. Anim. Sci.* 38:277-280.

- 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.
- Murphy, M. R., R. L. Baldwin, and L. J. Koong. 1982. Estimation of stoichiometric parameters for rumen fermentation of roughage and concentrate diets. *J. Anim. Sci.* 55:411-421.
- Nagaraja, T. G., G. Towne, and A. A. Beharka. 1992. Moderation of ruminal fermentation by ciliated protozoa in cattle fed a high-grain diet. *Appl. Environ. Microbiol.* 58:2410-2414.
- Nakamura, T., T. J. Klopfenstein, and R. A. Britton. 1994. Evaluation of acid detergent insoluble nitrogen as an indicator of protein quality in nonforage proteins. *J. Anim. Sci.* 72:1043-1048.
- Nichols, C. A., M. K. Luebke, G. E. Erickson, R. A. Stock, and T. J. Klopfenstein. 2009. Effects of substituting wet distillers grains with solubles in a wet corn gluten feed-based diet on finishing performance. *Nebraska Beef Cattle Rep.* MP 92:62-63. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Nichols, N. N. and R. J. Bothast. 2008. Production of ethanol from grain. Pages 75-88 in *Genetic Improvement of Bioenergy Crops*. W. Vermerris, ed. Springer, New York, N.Y.
- Nocek, J. E. 1997. Bovine acidosis: implications on laminitis. *J. Dairy Sci.* 80:1005-1028.
- Noll, S., C. Parsons, and B. Walters. 2006. What's new since September 2005 in feeding distillers co-products to poultry. *Proc. 67th Minnesota Nutr.Conf.*, St. Paul, MN.
- NRC. 1996. *Nutrient Requirements of Beef Cattle*. 7th rev. ed. (update 2000) Natl. Acad. Press, Washington, D.C.
- NRC. 2005. *Mineral Tolerance of Animals*. 2nd ed. Natl. Acad. Press, Washington, D.C.
- Nuttleman, B. L., W. A. Griffin, J. R. Benton, K. M. Rolfe, V. R. Bremer, J. O. Sarturi, G. E. Erickson, and T. J. Klopfenstein. 2010. Comparing dry, wet, or modified distillers grains plus solubles on feedlot cattle performance and metabolism characteristics. *Proc. Plains Nutr.Council Spring Conf.*, (In press). San Antonio, TX.
- Oba, M. and M. S. Allen. 2003. Intraruminal infusion of propionate alters feeding behavior and decreases energy intake of lactating dairy cows. *J. Nutr.* 133:1094-1099.
- Oliveros, B. A., T. J. Klopfenstein, F. K. Goedecken, F. K. Nelson, and E. E. Hawkins. 1989. Corn fiber as an energy supplement in high roughage diets fed to steers and lambs. *J. Anim. Sci.* 67:1784-1792.

- Orskov, E. R. 1986. Starch digestion and utilization in ruminants. *J. Anim. Sci.* 63:1624-1633.
- 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.
- Owens, F. N., R. A. Zinn, and Y. K. Kim. 1986. Limits to starch digestion in the ruminant small intestine. *J. Anim. Sci.* 63:1634-1648.
- 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 feed and roughage levels on performance, carcass characteristics, and feeding behavior of feedlot cattle. *J. Anim. Sci.* 85:3079-3089.
- Pritchard, R. H. and K. W. Bruns. 2003. Controlling variation in feed intake through bunk management. *J. Anim. Sci.* 81:E133-E138.
- Rausch, K. D., R. L. Belyea, V. Singh, and M. E. Tumbleson. 2007. Corn processing coproducts from ethanol production. *Proc. Biofuels, Food, and Feed Tradeoffs*, St. Louis, MO.
- Renewable Fuels Association. 2010. *Climate of Opportunity: 2010 Ethanol Industry Outlook.*, Washington, D.C. <http://www.ethanolrfa.org/industry/outlook/> Accessed Feb. 16, 2010.
- Richards, C. J., R. A. Stock, and T. J. Klopfenstein. 1996. Evaluation of levels of wet corn gluten feed and addition of tallow. *Nebraska Beef Cattle Rep.* MP 66-A:61-63. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- Richards, C. J., R. A. Stock, T. J. Klopfenstein, and D. H. Shain. 1998. Effect of wet corn gluten feed, supplemental protein, and tallow on steer finishing performance. *J. Anim. Sci.* 76:421-428.
- Richards, C. J., K. C. Swanson, S. J. Paton, D. L. Harmon, and G. B. Huntington. 2003. Pancreatic exocrine secretion in steers infused postruminally with casein and cornstarch. *J. Anim. Sci.* 81:1051-1056.
- Rust, S. R. and F. N. Owens. 1981. Roughage source in feedlot diets. *Anim. Sci. Res. Rep.* MP-108:150-153. Oklahoma State Univ., Stillwater. <http://www.beefextension.com/new%20site%202/research.html>.
- Sayer, K. M. 2004. Effects of corn bran and steep inclusion in finishing diets on cattle performance, nutrient mass balance, and diet digestibility. M. S. Thesis. Univ. of Nebraska, Lincoln.

- Schwartzkopf-Genswein, K. S., K. A. Beauchemin, D. J. Gibb, D. H. Crews, Jr., D. D. Hickman, M. Streeter, and T. A. McAllister. 2003. Effect of bunk management on feeding behavior, ruminal acidosis and performance of feedlot cattle: A review. *J. Anim. Sci.* 81:E149-E158.
- Schwartzkopf-Genswein, K. S., K. A. Beauchemin, T. A. McAllister, D. J. Gibb, M. Streeter, and A. D. Kennedy. 2004. Effect of feed delivery fluctuations and feeding time on ruminal acidosis, growth performance, and feeding behavior of feedlot cattle. *J. Anim. Sci.* 82:3357-3365.
- Scott, T. L., T. J. Klopfenstein, R. A. Stock, and R. J. Cooper. 1998. Metabolism and digestibility of corn bran and corn steep liquor/distillers solubles. *Nebraska Beef Cattle Rep.* MP 69-A:69-71. Univ. of Nebraska, Lincoln.  
<http://beef.unl.edu/reports.shtml>.
- 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.
- Shuey, S. A., R. T. Brandt, S. M. Gramlich, and C. T. Milton. 1994. Roughage level and corn processing in finishing diets: subacute acidosis. *Cattlemen's Day SRP* 704:21-26. Kansas State Univ., Manhattan.  
<http://www.ksre.ksu.edu/library/DesktopDefault.aspx?tabid=45>.
- Shurson, J. and A. S. Alghamdi. 2008. Quality and New Technologies to Create Corn Co-Products from Ethanol Production. Pages 231-259 in *Using Distillers Grains in the U.S. and International Livestock and Poultry Industries*. B. A. Babcock, D. J. Hayes, and J. D. Lawrence, ed. MATRIC, Iowa State Univ., Ames.
- Sindt, J. J., J. S. Drouillard, H. Thippreddi, R. K. Phebus, D. L. Lambert, S. P. Montgomery, T. B. Farran, H. J. LaBrune, J. J. Higgins, and R. T. Ethington. 2002. Evaluation of finishing performance, carcass characteristics, acid-resistant *E. coli* and total coliforms from steers fed combinations of wet corn gluten feed and steam-flaked corn. *J. Anim. Sci.* 80:3328-3335.
- 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.
- Singh, V., D. B. Johnston, K. Naidu, K. D. Rausch, R. L. Belyea, and M. E. Tumbleson. 2005. Comparison of modified dry-grind corn processes for fermentation characteristics and DDGS composition. *Cereal Chemistry* 82:187-190.
- Smith, R. A. 1998. Impact of disease on feedlot performance: a review. *J. Anim. Sci.* 76:272-274.

- Sniffen, C. J., J. D. O'Connor, P. J. Van Soest, D. G. Fox, and J. B. Russell. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *J. Anim. Sci.* 70:3562-3577.
- Soto-Navarro, S. A., C. R. Krehbiel, G. C. Duff, M. L. Galyean, M. S. Brown, and R. L. Steiner. 2000. Influence of feed intake fluctuation and frequency of feeding on nutrient digestion, digesta kinetics, and ruminal fermentation profiles in limit-fed steers. *J. Anim. Sci.* 78:2215-2222.
- Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. *J. Anim. Sci.* 80:2639-2645.
- Stern, M. D., A. Bach, and S. Calsamiglia. 1997. Alternative techniques for measuring nutrient digestion in ruminants. *J. Anim. Sci.* 75:2256-2276.
- Stock, R. A. and R. A. Britton. 1993. Acidosis in feedlot cattle. Page 1-11 in Proc. Scientific Update on Rumensin/Tylan for the Professional Feedlot Consultant, Elanco Animal Health, Indianapolis, IN.
- Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information of the use of wet and dry milling feed by-products in feedlot diets. *J. Anim. Sci.* 77, <http://www.asas.org/JAS/symposia/proceedings/0924.pdf> Accessed Sept. 17, 2004.
- Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedeken. 1990. Effects of grain type, roughage level and monensin level on finishing cattle performance. *J. Anim. Sci.* 68:3441-3455.
- Sudweeks, E. M. 1977. Chewing time, rumen fermentation and their relationship in steers as affected by diet composition. *J. Anim. Sci.* 44:694-701.
- Sulpizio, M. J., J. S. Drouillard, T. J. Kessen, E. R. Loe, S. P. Montgomery, J. N. Pike, J. J. Sindt, and R. T. Ethington. 2003. Comparison of dried full-fat corn germ and tallow in finishing feedlot diets for heifers. *Cattlemen's Day SRP 908:185-187*. Kansas State Univ., Manhattan. <http://www.ksre.ksu.edu/library/DesktopDefault.aspx?tabid=56>.
- Tajima, K., R. I. Aminov, T. Nagamine, H. Matsui, M. Nakamura, and Y. Benno. 2001. Diet-dependent shifts in the bacterial population of the rumen revealed with real-time PCR. *Appl. Environ. Microbiol.* 67:2766-2774.
- Taniguchi, K., G. B. Huntington, and B. P. Glenn. 1995. Net nutrient flux by visceral tissues of beef steers given abomasal and ruminal infusions of casein and starch. *J. Anim. Sci.* 73:236-249.

- Tedeschi, L. O., P. J. Kononoff, K. Karges, and M. L. Gibson. 2009. Effects of chemical composition variation on the dynamics of ruminal fermentation and biological value of corn milling (co)products. *J. Dairy Sci.* 92:401-413.
- Theurer, C. B., R. S. Swingle, R. C. Wanderley, R. M. Kattnig, A. Urias, and G. Ghenniwa. 1999. Sorghum grain flake density and source of roughage in feedlot cattle diets. *J. Anim. Sci.* 77:1066-1073.
- Thiex, N. 2009. Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles. *J. AOAC Int.* 92:61-73.
- Towne, G., T. G. Nagaraja, R. T. Brandt, Jr., and K. E. Kemp. 1990. Ruminal ciliated protozoa in cattle fed finishing diets with or without supplemental fat. *J. Anim. Sci.* 68:2150-2155.
- Trenkle, A. 2007. Performance of finishing steers fed modified wet distillers grains. Animal Industry Report A.S. Leaflet R2183. Iowa State Univ., Ames.  
[http://www.iowabeefcenter.org/content/research\\_beef%20reports.html](http://www.iowabeefcenter.org/content/research_beef%20reports.html).
- 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.
- USDA. 2000. National Animal Health Monitoring System. Part III. Health management and biosecurity in U.S. feedlots, 1999. USDA, Animal and Plant Health Inspection Service, Veterinarian Services,  
[http://www.aphis.usda.gov/vs/ceah/ncahs/nahms/feedlot/feedlot99/Feedlot99\\_dr\\_PartIII.pdf](http://www.aphis.usda.gov/vs/ceah/ncahs/nahms/feedlot/feedlot99/Feedlot99_dr_PartIII.pdf) Accessed June 3, 2007.
- 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. Evaluation of dried distillers grains and roughage source in steam-flaked corn finishing diets. *J. Anim. Sci.* 88:258-274.
- Van Soest, P. J. 1965. Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. *J. Anim. Sci.* 24:834-843.
- Vander Pol, K. J., G. E. Erickson, and T. J. Klopfenstein. 2005. Degradable intake protein in finishing diets containing dried distillers grains. Nebraska Beef Cattle Rep. MP 83-A:42-44. Univ. of Nebraska, Lincoln.  
<http://beef.unl.edu/reports.shtml>.
- Vander Pol, K. J., M. K. Luebke, 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.

- Vanness, S. J., T. J. Klopfenstein, G. E. Erickson, and K. K. Karges. 2009. Sulfur in distillers grains. Nebraska Beef Cattle Rep. MP 92:79-80. Univ. of Nebraska, Lincoln. <http://beef.unl.edu/reports.shtml>.
- 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.
- Vasconcelos, J. T. and M. L. Galyean. 2008. ASAS Centennial Paper: Contributions in the Journal of Animal Science to understanding cattle metabolic and digestive disorders. *J. Anim. Sci.* 86:1711-1721.
- Waldo, D. R. 1986. Effect of forage quality on intake and forage-concentrate interactions. *J. Dairy Sci.* 69:617-631.
- Welch, J. G. 1982. Rumination, particle size and passage from the rumen. *J. Anim. Sci.* 54:885-894.
- White, T. W. and W. L. Reynolds. 1969. Various sources and levels of roughage in steer diets. *J. Anim. Sci.* 28:705-710.
- White, T. W., W. L. Reynolds, and F. G. Hembry. 1971. Digestibility of finishing diets containing various sources and levels of roughage by steers. *J. Anim. Sci.* 32:544-548.
- Xiong, Y., S. J. Bartle, and R. L. Preston. 1991. Density of steam-flaked sorghum grain, roughage level, and feeding regimen for feedlot steers. *J. Anim. Sci.* 69:1707-1718.
- Yang, W. Z. and K. A. Beauchemin. 2009. Increasing physically effective fiber content of dairy cow diets through forage proportion versus forage chop length: Chewing and ruminal pH. *J. Dairy Sci.* 92:1603-1615.
- Zinn, R. A. 1988. Comparative feeding value of supplemental fat in finishing diets for feedlot steers supplemented with and without monensin. *J Anim Sci* 66:213-227.
- Zinn, R. A. 1989a. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for feedlot steers: metabolism. *J Anim Sci* 67:1038-1049.
- Zinn, R. A. 1989b. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for steers: feedlot cattle growth and performance. *J Anim Sci* 67:1029-1037.
- Zinn, R. A. 1994. Effects of excessive supplemental fat on feedlot cattle growth performance and digestive function. *Prof. Anim. Sci.* 10:66-72.

- Zinn, R. A., C. F. Adam, and M. S. Tamayo. 1995. Interaction of feed intake level on comparative ruminal and total tract digestion of dry-rolled and steam-flaked corn. *J. Anim. Sci.* 73:1239-1245.
- Zinn, R. A., S. K. Gulati, A. Plascencia, and J. Salinas. 2000. Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. *J. Anim. Sci.* 78:1738-1746.
- Zinn, R. A. and F. N. Owens. 1980. Expanding our concept of starch digestion in the ruminant. Page 69 in Proc. 41st Minnesota Nutr.Conf., Bloomington, MN.
- Zinn, R. A. and F. N. Owens. 1983. Influence of feed intake level on site of digestion in steers fed a high concentrate diet. *J. Anim. Sci.* 56:471-475.
- Zinn, R. A., F. N. Owens, and R. A. Ware. 2002. Flaking corn: processing mechanics, quality standards, and impacts on energy availability and performance of feedlot cattle. *J. Anim. Sci.* 80:1145-1156.
- Zinn, R. A. and A. Plascencia. 1996. Effects of forage level on the comparative feeding value of supplemental fat in growing-finishing diets for feedlot cattle. *J. Anim. Sci.* 74:1194-1201.
- 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.
- Zinn, R. A. and Y. Shen. 1998. An evaluation of ruminally degradable intake protein and metabolizable amino acid requirements of feedlot calves. *J. Anim. Sci.* 76:1280-1289.



Figure 1. Dry Milling Process

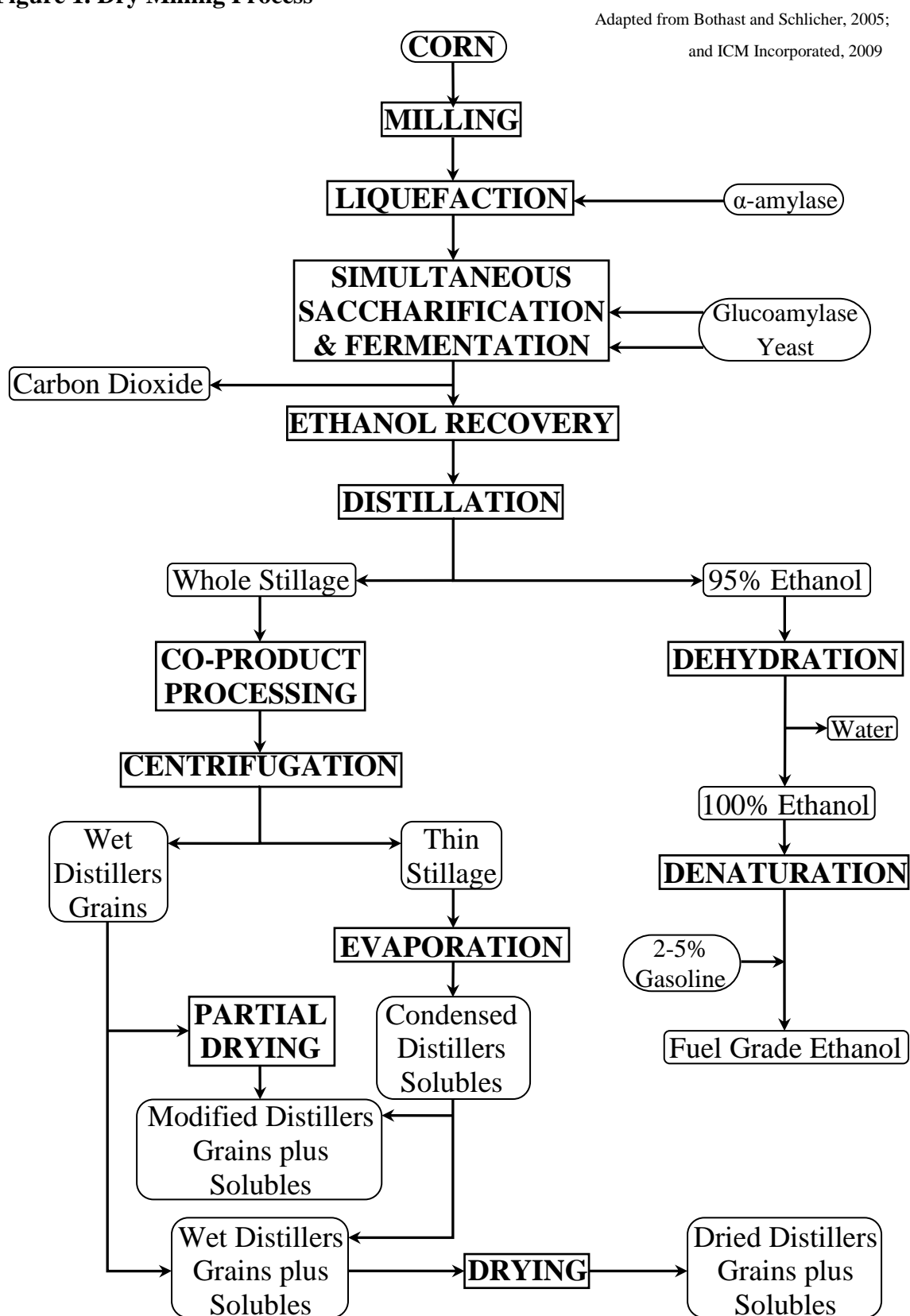
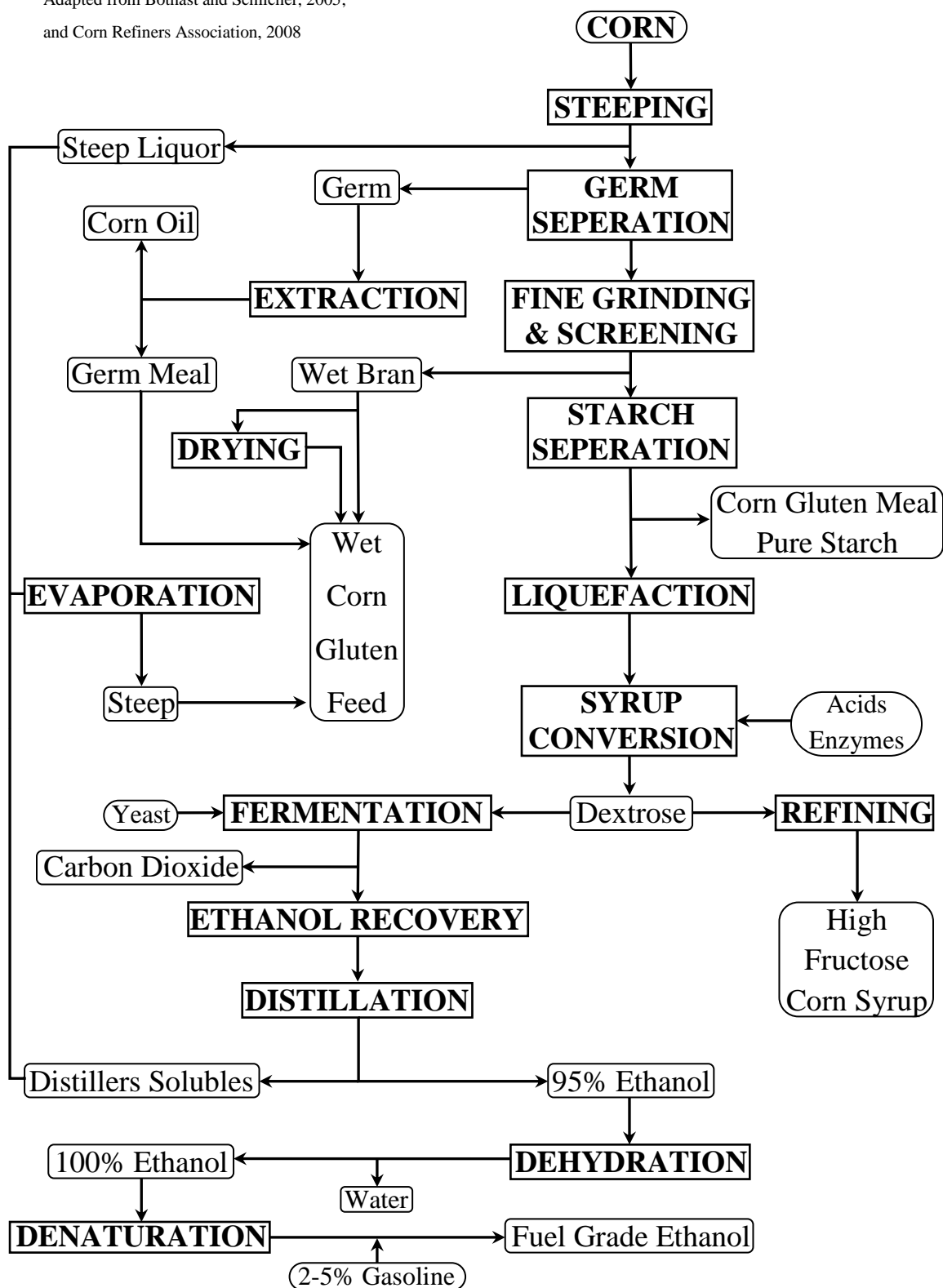


Figure 2. Wet Milling Process

Adapted from Bothast and Schlicher, 2005;  
and Corn Refiners Association, 2008



## CHAPTER II

**Effects of roughage source and inclusion level in beef finishing diets containing corn  
wet distillers grains plus solubles<sup>1</sup>**

J. R. Benton, G. E. Erickson<sup>2</sup>, T. J. Klopfenstein, K. J. Vander Pol, N. F. Meyer, C. D.

Buckner, M. A. Greenquist

Department of Animal Science, University of Nebraska, Lincoln 68583

---

<sup>1</sup> A contribution of the University of Nebraska Agricultural Research Division, supported in part by funds provided through the Hatch Act.

<sup>2</sup> Corresponding author: [geericks@unlnotes.unl.edu](mailto:geericks@unlnotes.unl.edu)

ABSTRACT: Two experiments were conducted to determine the effects of roughage source and level in feedlot diets containing wet distillers grains plus solubles (WDGS) on finishing cattle performance and ruminal metabolism. In Exp. 1, 385 crossbred steer calves ( $346 \pm 29$  kg) were used in a finishing trial. A control diet with no roughage inclusion was compared to six diets containing either alfalfa hay (ALF), corn silage (CSIL), or corn stalks (CSTK) included at two levels as a 3 x 2 factorial. Alfalfa hay was included at 4 or 8% (DM basis) and used as a low and standard inclusion level. Diets containing CSIL or CSTK were formulated on an equal roughage NDF basis compared to the low and standard ALF inclusion level. The final diets contained 6.13 and 12.26% CSIL or 3.04 and 6.08% CSTK (DM basis). All diets contained 30% WDGS and a 1:1 mixture of dry-rolled and high-moisture corn (DM basis). Cattle fed no roughage had reduced ( $P < 0.01$ ) DMI and the lowest numeric final BW and ADG compared to cattle fed roughage. There were no differences ( $P \geq 0.11$ ) in finishing performance due to roughage sources. Cattle fed standard levels of roughage had greater ( $P \leq 0.04$ ) DMI and ADG compared to cattle fed low roughage levels. No differences ( $P = 0.09$ ) in G:F were observed among treatments. In Exp. 2, six ruminally fistulated steers ( $347 \pm 25$  kg) were used in a 6 x 6 Latin square design. Treatments were arranged as a 2 x 3 factorial with ALF or CSTK included at a zero, low, or standard levels similar to Exp. 1. Apparent total tract digestibility (%) of DM, OM, NDF, and CP decreased linearly ( $P \leq 0.07$ ) due to increasing roughage level. Ruminal pH variables increased linearly ( $P \leq 0.09$ ) as roughage inclusion was increased. Molar proportion of acetate decreased ( $P = 0.07$ ) as roughage level increased. There was a roughage source x inclusion level interaction ( $P \leq 0.02$ ) for molar proportion of propionate, which was decreased for cattle fed 6% CSTK,

and for acetate to propionate ratio which was decreased for cattle fed ALF or 6% CSTK. Based on the results of this study, it appears low quality roughages, such as CSTK, have similar feeding values compared to ALF when included on an equal NDF basis and that roughage sources can be exchanged on an equal NDF basis in DRC:HMC-based finishing diets containing 30% WDGS without negatively impacting finishing cattle. It was not beneficial to reduce or eliminate roughages when 30% WDGS was included in finishing diets.

**Key words:** corn, digestibility, distillers grains, finishing cattle, roughage

## INTRODUCTION

With rapid expansion of the ethanol industry, availability and use of corn-milling byproducts are increasing. Since starch is the primary nutrient fermented during ethanol production, inclusion of byproducts in finishing diets may reduce the incidence of acidosis. Traditionally, roughage has been included in feedlot diets with the primary goal of optimizing DMI for maximum ADG and G:F while avoiding digestive problems such as acidosis. Along with providing NDF, byproducts such as wet distillers grain plus solubles (WDGS) and wet corn gluten feed (WCGF) can also supply protein and moisture. As a result, roughage level and quality could potentially be reduced in finishing diets containing byproducts (Klopfenstein et al., 2008). Feeding WCGF in finishing diets has been shown to be beneficial in controlling acidosis (Krehbiel et al., 1995) and roughage levels may be reduced or eliminated (Sindt et al., 2003; Farran et al., 2006; Parsons et al., 2007). In steam-flaked corn (SFC)-based finishing diets containing dried distillers grains plus solubles (DDGS), it appears that roughage levels can be lowered

(May et al., 2010) and that roughage sources can be exchanged on an equal NDF basis (Uwituze et al., 2010). However, complete elimination of roughage in SFC-based diets containing sorghum distillers grains plus solubles negatively affected performance of finishing cattle (Depenbusch et al., 2009). The effect of roughages in dry-rolled or high-moisture corn-based finishing diets containing WDGS has not been evaluated.

Therefore, the objectives of the current study were to 1) determine if roughage sources can be exchanged on an equal NDF basis in finishing cattle diets containing WDGS, and 2) examine the effects of roughage source and level in feedlot diets containing WDGS on finishing cattle performance and ruminal metabolism.

## MATERIALS AND METHODS

All procedures used for these experiments involving animal care were approved by the University of Nebraska Institutional Animal Care and Use Committee.

### *Exp. 1*

A 139-d finishing trial used 385 crossbred steer calves (BW = 346 ± 29 kg) in a randomized complete block design. Steers were received at the University of Nebraska beef research facility located at the Agricultural Research and Development Center (Ithaca, NE) in the fall of 2005. Upon arrival, steers were individually weighed and identified, vaccinated with BoviShield Gold 5 (for prevention against infectious bovine rhinotracheitis virus, bovine viral diarrhea virus types 1 and 2, parainfluenza-3 virus, and bovine respiratory syncytial virus; Pfizer Animal Health, New York, NY), Somubac (for prevention against *Haemophilus somnus*; Pfizer Animal Health), and Dectomax Injectable (for protection against internal and external parasites; Pfizer Animal Health).

Approximately 18 d after arrival, calves were weighed and revaccinated with Somubac/Ultrabac 7 (for prevention against *Clostridium chauvoei*, *Cl. septicum*, *Cl. novyi*, *Cl. sordellii*, *Cl. perfringens* types C and D, and *Haemophilus somnus*; Pfizer Animal Health) and a second dose of BoviShield Gold 5 (Pfizer Animal Health) and injected with Piligaurd Pinkeye Triview (for prevention against *Moraxella bovis*; Intervet/Schering-Plough Animal Health, Union, NJ). Steers were weaned on smooth bromegrass for approximately 4 wk. Steers were then implanted with Synovex-C (containing 100 mg progesterone and 10 mg estradiol benzoate; Fort Dodge/Pfizer Animal Health, Overland Park, KS) and allowed to graze corn stalks for 45 d. While on stalks, steers were supplemented with 2.3 kg/hd daily of WCGF (DM basis). Steers were brought to the feedlot 5 d before initiation of the trial and limit-fed a diet consisting of 50% WCGF and 50% alfalfa hay (DM basis) at 2% of BW. On d 0 and d 1, steers were individually weighed in order to get an accurate initial BW. The weights from d 0 were used to assign steers to pen. Steers were blocked by BW into 3 blocks, stratified by BW within block and assigned randomly to pen (11 steers/pen). There were two light, two medium, and one heavy BW blocks. Pens were assigned randomly to one of 7 finishing diets within block (5 pens/diet). On d 1, all steers were implanted with Revalor-S (containing 120 mg of trenbolone acetate and 24 mg of estradiol; Intervet/Schering-Plough, Millsboro, DE).

The dietary treatments (Table 1) consisted of a control diet with no roughage inclusion (CON) compared to inclusion of alfalfa hay (ALF), corn silage (CSIL), and corn stalks (CSTK) at two levels as a 3 x 2 factorial. Inclusion of ALF at 4 and 8% was used as a low and standard inclusion level (LALF and SALF), respectively. Diets

containing CSIL or CSTK were formulated on an equal roughage NDF basis compared to the low and standard ALF inclusion level. The final diets contained 6.1 and 12.3% CSIL (LCSIL and SCSIL) or 3.0 and 6.1% CSTK (LCSTK and SCSTK). The NDF content of ALF (61.1%), CSIL (43.3%), and CSTK (75.6%) was analyzed according to the method of Van Soest et al. (1991), except that 0.5g of NaSO<sub>3</sub> was added per 100 mL of NDF solution (Midland Scientific, Omaha, NE). All diets contained a mixture of dry-rolled (DRC) and high-moisture corn (HMC) fed at a 1:1 ratio and 30% WDGS (DM basis). Diets were initially formulated to contain 3% dry supplement but on d 42, it was increased to 5%, replacing the corn mixture. The dry supplement inclusion was increased to ensure the supplement was mixed uniformly into the diet because on d 34 and 35, three steers were treated for polioencephalomalacia (PEM). All diets were formulated to contain a minimum of 0.65% calcium, 0.60% potassium, and supply Rumensin (360 mg monensin/steer daily, Elanco Animal Health, Greenfield, IN), thiamine (130 mg/steer daily, International Nutrition, Omaha, NE), and Tylan (90 mg tylosin/steer daily, Elanco Animal Health). Feed ingredients were sampled weekly and dry matter was conducted by drying samples in a 60° C forced-air oven for 48 h. After the trial, all diet samples were composited by month and analyzed for CP and NDF.

The DRC, HMC, and CSIL were grown at the University of Nebraska research farm located at the Agricultural Research and Development Center (Ithaca, NE) during 2005. The HMC was rolled at time of harvest and stored in a concrete bunker. The average moisture during the feeding period for the HMC was 27.6%. The CSIL was non-irrigated and yielded 37,421 kg/ha at 35% DM. The ALF and CSTK were each purchased at one time from one supplier to eliminate variation of roughage sources during the



feeding period. The CSIL was coarsely chopped at harvest and ensiled in a plastic silo bag. Both the ALF and CSTK were ground through a tub grinder using a 12.7 cm screen. Roughage particle size was determined using dry sieving method with 8 sieves. United States Bureau of Standards sieves #1 (12,500  $\mu\text{m}$  screen opening), #2 (9,500  $\mu\text{m}$ ), #3.5 (6,300  $\mu\text{m}$ ), #5 (4,000  $\mu\text{m}$ ), #6 (3,350  $\mu\text{m}$ ), #8 (2,380  $\mu\text{m}$ ), #12 (1,700  $\mu\text{m}$ ), and #100 (150  $\mu\text{m}$ ) were placed on a vertical oscillating sieve shaker (W. S. Tyler, Inc., Mentor, OH). Approximately 50 g (DM basis) of sample was evenly distributed onto sieve #1 and a 5-min vibration period was used. Particles retained on each screen were weighed and geometric mean diameter (GMD) and geometric SD (GSD) was calculated according to the methods described by Behnke (1994). Particles retained on sieve #1 were considered to have a GMD of  $\text{Log}(9,500 \mu\text{m} \times 12,500 \mu\text{m})^{0.5}$ . Particles passing through sieve #100 and collected in the pan were considered to have a GMD of  $\text{Log}(150 \mu\text{m} \times 44 \mu\text{m})^{0.5}$ . Alfalfa hay, CSIL, and CSTK had an average GMD of 1,498, 2,927, and 4,323  $\mu\text{m}$ , respectively. The GSD of ALF, CSIL, and CSTK were 3.61, 2.83, and 2.90, respectively. Despite grinding the ALF and CSTK through the same screen, particle size was different between sources. Wet distillers grains plus solubles were obtained from a commercial ethanol plant (Abengoa Bioenergy, York, NE) and delivered on an as needed basis (approximately 1 semi-load /wk).

Cattle were adapted to grain by feeding a roughage mixture of ALF, CSIL, and CSTK on an equal NDF basis which replaced the corn mixture in the final diets. There were five steps formulated to supply NDF equal to 45%, 35%, 25%, 15%, and 8% ALF (DM basis). The 5 steps were fed for 3, 4, 6, 6, and 5 d, respectively, where the corn replaced the roughage mixture. Steers fed diets containing standard roughage levels, 6-

12% (NDF supply equal to 8% ALF), were fed their respective forage at step 5 on d 20. Steers fed diets containing low levels or no roughage were fed their respective diet on d 25. Steers were fed once daily and allowed ad libitum access to feed and water. All cattle were supplemented with Optaflexx (200 mg ractopamine/steer daily, Elanco Animal Health) the last 28 d of the feeding period. Cattle were fed for 139 d (January 25, 2006 to June 12, 2006) and harvested at a commercial packing plant (Greater Omaha Pack, Omaha, Nebraska). Hot carcass weight and liver score were collected the day of harvest and 12<sup>th</sup> rib fat, LM area, and USDA called marbling score were collected following a 24-h chill. Yield grade was calculated using the following equation ( $YG = (2.50 + (0.0017*HCW, \text{ kg}) + (0.2*KPH, \%) + (6.35*12^{\text{th}} \text{ rib fat, cm}) - (2.06*LM \text{ area, cm}^2))$ ) from Boggs et al. (1998). Final BW, ADG, and G:F were calculated using HCW divided by an average dressing percentage of 63%. During the trial, 7 steers were treated for PEM and two of these steers were removed from trial. Fourteen steers were treated for other health reasons not related to treatments and remained on trial. Two steers died due to reasons not related to treatment.

Data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) as a randomized complete block design. Pen served as the experimental unit and weight block was included in the model as a fixed effect. All treatments were analyzed using the Least Significance Difference method to separate least square means when a significant *F*-test was observed.

To evaluate the main effects of roughage source and inclusion level, a separate statistical analysis was completed using the MIXED procedure (SAS Inst. Inc.). Data were analyzed as a 3 x 2 factorial treatment arrangement. This model ignored the control

treatment and included three roughage sources and two roughage levels. Roughage source, roughage level, source x level, and weight block were included in the model as fixed effects. For all analysis in Exp. 1, a  $P \leq 0.05$  was deemed significant.

### *Exp. 2*

Six ruminally fistulated steers (BW = 411 kg) were used in a 6 x 6 Latin square to determine the effects of roughage source and level in feedlot diets containing WDGS. Treatments were arranged as a 2 x 3 factorial treatment structure with ALF included at 0, 4, or 8% and cornstalks included at 0, 3, or 6% on a DM basis (Table 2). The ALF and CSTK used in this trial were from the same source and processed similarly as in Exp. 1. Alfalfa hay and CSTK averaged 57.2% and 78.8% NDF, respectively and dietary treatments were formulated on an equal roughage NDF basis. All diets contained a mixture of DRC and HMC fed at a 1:1 ratio and 30% WDGS (DM basis). All diets were formulated to contain a minimum of 0.65% calcium, 0.60% potassium, and supply Rumensin (320 mg monensin/steer daily, Elanco Animal Health), thiamine (130 mg/steer daily, International Nutrition), and Tylan (90 mg tylosin/steer daily, Elanco Animal Health).

Before initiation of the experiment, steers were adapted to the finishing diets using the same procedure as described in Exp. 1. Periods were 14 d in length which included a 9-d adaptation period followed by a 5-d collection period. Steers were individually fed in 1.5 x 2.4 m slotted floor pens with rubber mats during the adaptation period in a temperature-controlled room (25°C). During the collection period, steers were moved into stanchions for continuous feed intake and ruminal pH measurements. Steers

were allowed ad libitum access to feed and water. Steers were fed once daily at 0730 and feed refusals were also collected daily if present. Feed ingredients were sampled weekly. Dry matter was conducted on feed ingredients and feed refusals by drying part of the samples in a 60° C forced air oven for 48 h. The remaining feed ingredients and feed refusal were frozen immediately. In period 1, data from the steer being fed 6% CSTK were removed because the steer did not have access to feed on d 11. In period 2, the steer being fed 0% ALF was removed from trial due to reduced DMI. In period 4 and 6, the steers being fed 0% CSTK were removed from trial due to reduced DMI. The 3 steers removed from trial had all been on treatments containing no roughage inclusion and their reduced DMI was likely due to acidosis. Steers were removed from trial when DMI was reduced below 1.0% of BW for 2 d or more.

Chromic oxide (7.5g/dose) was used as an indigestible marker for estimating fecal output and was dosed intraruminally at 0700 and 1900 daily from d 6 through d 14 of each period. Fecal grab samples were collected three times daily during the collection period (d 10 to 15) at 0, 6, and 12 h post-feeding. Fecal samples were composited by day and frozen immediately. On d 14, rumen fluid samples were collected via the rumen cannula using the suction strainer technique (Raun and Burroughs, 1962). Approximately 50 mL were collected at 0, 4, 8, 12, 16, and 24 h post-feeding and frozen immediately. Ruminant VFA were analyzed by gas chromatography (Series II, 5890; Hewlett-Packard, Avondale, MA) using a Supelco 12144 column (Supelco, Bellefonte, PA) according to the procedures as outlined by Erwin et al. (1961).

Feed intake data were collected using feed bunks suspended by load cells (Omega, Stamford, CT). Feed intake measurements included daily intake, number of

meals per day, total time spent eating, and intake rate and were calculated as described by Cooper et al. (1999). Ruminant pH was measured using submersible pH probes (Sensorex, Scranton, CA) fitted through the rumen cannula and extended approximately 40 cm into the rumen below the ruminal mat layer. Ruminant pH measurements included average, maximum, and minimum pH, magnitude of pH change, pH variance, time spent below pH 5.6 and 5.3, and area of pH below 5.6 and 5.3 and were calculated as described by Cooper et al. (1999). Data for feed intake and ruminant pH were collected using computer software (Labtech, Wilmington, MA) that collected a reading every 20 s and averaged every 1 min (1,440 data points/d).

Feed ingredients, feed refusals, and fecal samples were freeze-dried, ground to pass through a 1-mm screen using a Wiley mill (No. 4, Thomas Scientific, Swedesboro, NJ), and composited by period. Feed, feed refusals, and fecal samples were analyzed for OM, NDF, and CP content. Percent OM was calculated by ashing samples at 600°C for 6 h. Percentage NDF was determined by placing samples in filter bags (Ankom Inc., Fairport, NY) which were washed in 100°C NDF solution (Midland Scientific, Omaha, NE) containing 7.5 g of NaSO<sub>3</sub> and 2.0 mL of heat stable  $\alpha$ -amylase (Ankom Inc.) per liter using an Ankom 200 fiber analyzer (Ankom Inc.). Filter bags were then rinsed three times for three min using 100°C distilled water. Percentage CP was determined by the combustion method (AOAC, 2005) using a nitrogen analyzer (LECO FP-528, LECO Corp., St. Joseph, MI). Fecal samples were analyzed for chromium concentration using atomic absorption spectrophotometry (Varian Spectra AA-30, Walnut Creek, CA; Williams et al., 1962).

Data were analyzed as a 2 x 3 factorial treatment arrangement in a 6 x 6 Latin square experimental design using the MIXED procedure (SAS Inst. Inc.). Period, roughage source, roughage level, and source x level were included in the model as fixed effects and steer was included in the model as a random effect. Orthogonal contrasts were used to detect linear and quadratic relationship for the main effect of roughage level if no interaction was detected ( $P > 0.10$ ). If an interaction occurred, only simple effects were tested. A repeated measure analysis was used for VFA concentrations, with h repeated, and for ruminal pH and intake patterns, with d repeated. An autoregressive -1 (AR-1) covariance structure was used for repeated measure analysis. For all analysis in Exp. 2, a  $P \leq 0.10$  was deemed significant.

## RESULTS AND DISCUSSION

### *Exp. 1*

***Finishing Cattle Performance.*** Across treatments, shrunk BW, final BW, DMI, and ADG were different ( $P < 0.01$ ; Table 3). Cattle fed CON had the numerically lowest final BW and ADG which was similar ( $P > 0.05$ ) to steers fed LALF or LCSIL. Final BW and ADG were similar ( $P > 0.05$ ) between steers fed LCSTK or standard roughage levels. Dry matter intake was reduced ( $P < 0.01$ ) for steers fed CON (10.1 kg/d) compared with steers fed roughages (11.4 kg/d). There were no differences ( $P > 0.05$ ) observed in DMI between steers fed low roughage inclusion levels or between steers fed LCSTK and standard roughage inclusion levels. Treatments had no effect ( $P = 0.09$ ) on G:F although cattle fed CON had the highest numeric G:F.

There were no roughage source x roughage level interactions ( $P \geq 0.34$ ) observed for any performance measurements made in Exp. 1 (Table 4). Additionally, there were no differences ( $P \geq 0.11$ ) in finishing cattle performance due to roughage sources observed in this study although there was a tendency ( $P = 0.11$ ) for ADG to be greater for cattle fed CSTK compared to cattle fed ALF or CSIL. Initial BW was statistically different ( $P = 0.05$ ) between roughage levels although they were numerically similar. Cattle fed low roughage levels had an initial BW of 347.3 kg compared 346.5 kg for the initial BW of cattle fed standard roughage levels. This statistical difference is likely due to the large number of pens (15 pens) averaged for each roughage level. Shrunken BW, DMI, and ADG were greater ( $P \leq 0.04$ ) for cattle fed standard levels of roughage compared to cattle fed low roughage inclusion levels. There was a tendency ( $P = 0.07$ ) for cattle fed standard roughage levels to have greater final BW compared to cattle fed low roughage inclusion levels. Although roughage is not absolutely necessary in grain-based finishing diets, addition of roughage promotes greater DMI. The observed increase in DMI and ADG, due to roughage level, in the current study are commonly observed in studies investigating the effects of roughage levels in beef finishing diets without WDGS (Stock et al., 1990; Shain et al., 1999; Turgeon et al., 2010).

In a review of the literature, Arelovich et al. (2008) performed a meta-analysis to evaluate the relationship between DMI with total dietary NDF in finishing diets without byproducts. The authors reported a strong positive linear relationship ( $r^2 = 0.965$ ) between dietary NDF and DMI (kg/d). This is in agreement with observations made by Galyean and Defoor (2003) who also reported a positive linear relationship ( $r^2 = 0.920$ ) between roughage NDF and DMI (% BW). Both Galyean and Defoor (2003) and

Arelovich et al. (2008) concluded that NDF content could be used to exchange roughages in finishing cattle diets. Based on the results of the finishing cattle performance in this study, it appears additional NDF from roughage has a similar effect in diets containing WDGS and that roughage sources can be exchanged on an equal NDF basis in beef finishing diets containing WDGS.

In finishing diets containing WCGF, several studies have indicated that roughage levels may be reduced without negatively affecting cattle performance (Sindt et al., 2003; Farran et al., 2006; Parsons et al., 2007). May et al. (2010) reported that CSIL levels can be reduced in SRC-based finishing diets without negatively impacting ADG or G:F. Furthermore, Uwituze et al. (2010) reported that ALF and CSIL have similar feeding values in SFC-based finishing cattle diets containing 25% DDGS when included on an equal NDF basis. Depenbusch et al. (2009) reported that elimination of roughage in SFC-based finishing diets containing sorghum WDGS or DDGS resulted in reduced DMI, ADG, and HCW without affecting G:F. However, the interaction between roughage level and distillers grains plus solubles (DGS) type was not evaluated. Carcass adjusted ADG and HCW were numerically similar between cattle fed 0 or 6% ALF in diets containing 16% sorghum WDGS while ADG and HCW were increased for cattle fed diets containing 16% sorghum DDGS with 6% ALF compared to 0% ALF. This implies that roughage could be eliminated in SFC-based finishing diets containing 16% sorghum WDGS with minimal effects on finishing cattle performance.

***Carcass Characteristics.*** Across treatments, HCW, 12<sup>th</sup> rib fat, and yield grade were different ( $P \leq 0.02$ ; Table 3). Cattle fed CON had numerically the lowest HCW and



12<sup>th</sup> rib fat. Hot carcass weight was similar ( $P > 0.05$ ) between cattle fed CON, LALF, and LCSIL and between cattle fed LCSTK and standard roughage inclusion levels. There was no difference ( $P > 0.05$ ) in 12<sup>th</sup> rib fat between cattle fed CON or LCSIL or for calculated USDA yield grade between cattle fed CON or CSIL. Additionally, there were no differences ( $P > 0.05$ ) observed for 12<sup>th</sup> rib fat or calculated USDA yield grade between steers fed ALF, CSTK or SCSIL. No other differences were observed in carcass characteristics due to dietary treatments.

There were no roughage source x roughage level interactions ( $P \geq 0.26$ ) observed for any carcass characteristics measured in Exp. 1 (Table 4). In addition, there were no differences ( $P \geq 0.07$ ) in carcass characteristics due to roughage level observed in this study although there was a tendency ( $P = 0.07$ ) for HCW to be greater for cattle fed standard roughage levels compared to cattle fed low inclusion levels of roughage. Cattle fed CSIL had decreased 12<sup>th</sup> rib fat and yield grade ( $P = 0.03$ ) compared to cattle fed ALF or CSTK.

Overall, it can be concluded that roughage sources can be exchanged on an equal NDF basis suggesting that low quality roughages, such as corn stalks, have similar roughage values compared to alfalfa in DRC:HMC-based finishing diets containing 30% WDGS. Additionally, this study is in agreement with results observed when feeding 35% WCGF (Farran et al., 2006) or 16% DDGS (Depenbusch et al., 2009) whereby DMI and ADG were reduced without affecting G:F when roughage was eliminated from finishing cattle diets containing corn-milling byproducts.

**Exp. 2*****Effects of Roughage Source and Inclusion Level on Intake and Apparent Total***

***Tract Digestibility.*** There were no roughage source x inclusion level interactions ( $P \geq 0.11$ ) observed for any intake or apparent total tract digestibility variables measured in this experiment, so only main effects are presented (Table 5). Roughage source had no effect ( $P \geq 0.27$ ) on any variables measured in this trial with the exception of apparent total tract digestion of NDF. Cattle fed ALF had a greater NDF digestibility ( $P = 0.05$ ) compared to cattle fed CSTK. Neither intake nor apparent total tract digestion (kg/d) of DM, OM, and CP was affected by roughage inclusion level ( $P \geq 0.26$ ) although intake numerically increased with increasing roughage inclusion for DM, OM, and CP. However, both NDF intake and kg/d of NDF digested increased linearly ( $P \leq 0.02$ ) with increased roughage inclusion levels. In contrast, as roughage inclusion level was increased, the percent apparent total tract digestibility of DM, OM, NDF, and CP linearly decreased ( $P \leq 0.07$ ). This is likely due to replacing the DRC:HMC blend with roughage which is less digestible. This is supported by Depenbusch et al. (2009) who reported that apparent total tract digestibility of DM and OM was decreased ( $P = 0.01$ ) in SFC-based finishing diets containing 16% sorghum DGS with 6% ALF compared to diets without ALF. The overall apparent total tract digestibility of DM, OM, and CP in this study appeared to be similar to other digestibility studies evaluating the effects of distillers grains plus solubles in finishing diets (Vander Pol et al., 2009; Corrigan et al., 2009; Uwituze et al., 2010). Apparent total tract digestibility of NDF appears to be more variable across trials. The NDF digestibility observed in the current study is similar to the

values observed by Vander Pol et al. (2009) but is increased approximately 50% compared to the values observed by Corrigan et al. (2009) and Uwituze et al. (2010).

***Effects of Roughage Source and Inclusion Level on Intake Patterns.*** There were no roughage source x inclusion level interactions ( $P \geq 0.11$ ) observed for any intake pattern variables measured in this experiment (Table 6). Steers fed ALF ate fewer meals per day but spent more time per eating per meal and consumed more per meal ( $P \leq 0.10$ ) compared to steers fed CSTK. Roughage levels had no effects on intake patterns ( $P \geq 0.11$ ) although there was a linear trend ( $P = 0.11$ ) for cattle to have larger meal size as roughage inclusion level was increased. This is in agreement with Crawford et al. (2008) who reported that roughage level had no effects on intake variables in a DRC:HMC based finishing diet without any byproduct inclusion.

***Effects of Roughage Source and Inclusion Level on Ruminal pH.*** There were no roughage source x inclusion level interactions ( $P \geq 0.16$ ) observed for any ruminal pH variables measured in this experiment (Table 7). Roughage source did not affect any ruminal pH variables measured in this experiment ( $P \geq 0.53$ ). Cattle fed ALF and CSTK had an average ruminal pH of 5.47 and 5.48, respectively, which indicates that ALF and CSTK have similar roughage value in DRC:HMC-based finishing diets containing 30% WDGS when included on an equal NDF basis. This supports the conclusions from Exp. 1 that roughage sources can be exchanged on an equal NDF basis. Uwituze et al. (2010) reported that cattle fed SFC-based finishing diets containing 25% DDGS with 5.6% ALF (DM basis) had increased ruminal pH compared to steers fed 11.0% CSIL (5.72 vs 5.31,

respectively). Although diets were formulated to contain equal amounts of dietary NDF in the study by Uwituze et al. (2010), diets containing CSIL had 13% more dietary NDF compared to ALF (19.2 vs. 17.0%). In addition, Shain et al. (1999) reported that ruminal pH was increased for cattle fed straw compared to cattle fed ALF when roughages were included on an equal NDF basis and ground through a 12.7 cm screen which is similar to the methods used in the current study.

As roughage inclusion level was increased, ruminal pH variables, with the exception of pH change, linearly increased ( $P \leq 0.09$ ). This is in agreement with Allen (1997) who reported that forage NDF was correlated positively with ruminal pH ( $r^2 = 0.63$ ) in dairy cattle. For cattle fed 0% roughage, ruminal pH averaged 5.25 and was below pH 5.6 and 5.3 for 1166 and 719 min/d, respectively. This corresponds to over 19 h/d that steers fed 0% roughage were experiencing subacute acidosis and approximately 12 h/d that was spent at a pH of less than 5.3. When roughage levels were increased to 3 and 4% or to 6 and 8%, time spent below pH 5.6 was reduced approximately 20 and 44%, or 4 and 8 h, respectively.

#### ***Effects of Roughage Source and Inclusion Level on Ruminal VFA profiles.***

There was a roughage source x inclusion level interaction ( $P \leq 0.02$ ) observed for molar proportions of ruminal propionate and acetate to propionate (A:P ratio, Table 8). There were no effects ( $P \geq 0.30$ ) of roughage source or roughage inclusion level on total ruminal VFA mM concentrations. Roughage source also did not affect molar proportions of acetate ( $P = 0.79$ ). However, molar proportions of acetate decreased linearly ( $P = 0.07$ ) as roughage inclusion level increased. As mentioned, there was an interaction for

molar proportions of propionate and for A:P ratio, primarily due the VFA profile of cattle fed 6% CSTK. The molar proportion of propionate was not different ( $P < 0.05$ ) for cattle fed 0, 4, 8% ALF although it was numerically greater for cattle fed 4% ALF. Since molar proportions of acetate linearly decreased, the A:P ratio was lower ( $P < 0.05$ ) for cattle fed 4 and 8% ALF compared to cattle fed 0% ALF. The molar proportion of propionate was increased and the A:P ratio was decreased for cattle fed 6% CSTK compared to cattle fed 0 or 3% CSTK.

It is unclear why the molar proportions of acetate and propionate were affected in the manner they were due to the dietary treatments in the current study. Compared to other studies evaluating WDGS in finishing diets (Vander Pol et al., 2009; Corrigan et al., 2009), the overall molar proportions of acetate are slightly increased while the overall molar proportions of propionate in this trial are low. This resulted in a relatively high A:P ratio for cattle fed finishing diets which averaged approximately 3.4 across all treatments. Lana et al. (1998) reported that ruminal pH was positively correlated ( $r^2 = 0.82$ ) with ruminal A:P ratio. As roughage level was increased in the current study, ruminal pH linearly increased as expected which should favor increased ruminal production of acetate (Sudweeks, 1977; Lana et al., 1998). However, the molar proportion of acetate was not different across roughage inclusion levels while the molar proportion of propionate increased for cattle fed 4% ALF or 6% CSTK which resulted in decreased A:P ratios for cattle fed ALF or 6% CSTK. As mentioned, ruminal pH and NDF are positively correlated in most finishing diets but recent research has found that although cattle fed 40% WDGS (DM basis) have greater NDF intakes, ruminal pH and A:P ratios are decreased while the molar proportion of propionate is greater compared to cattle fed corn

control diets (Vander Pol et al., 2009; Corrigan et al., 2009). This may help explain the increase in propionate and decrease in A:P ratio with increasing roughage levels if cattle are consuming more WDGS in relation to corn. However, ruminal pH increased and apparent total tract digestibility decreased with greater roughage inclusion levels. This suggests that there may be some interactions with rumen motility or passage rate. As discussed, apparent total tract digestion appears to be normal in the current study although total ruminal VFA production is slightly depressed. One explanation for the depression in total VFA production may be that site of digestion could be shifted to the small intestine or hindgut.

Based on the results of the Exp. 2, there appears to be an interaction between roughage source and level in finishing diets which result in molar proportions of VFA that is not commonly observed with increased NDF intakes. Based on the data from both experiments, it does appear that lower quality roughages such as CSTK have similar feeding values compared to alfalfa hay in DRC:HMC-based finishing diets containing 30% WDGS when included on an equal NDF basis. However, it does not appear that it is beneficial to reduce or eliminate roughage levels when WDGS is included in finishing diets.

**LITERATURE CITED**

- 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.
- AOAC. 2005. Official Methods of Analysis. 18th ed. Assoc. of Anal. Chem., Gaithersburg, MD.
- Arelovich, H. M., C. S. Abney, J. A. Vizcarra, and M. L. Galyean. 2008. Effects of dietary neutral detergent fiber on intakes of dry matter and net energy by dairy and beef cattle: analysis of published data. *Prof. Anim. Sci.* 24:375-383.
- Behnke, K. C. 1994. Feed Manufacturing Technology IV. Am. Feed Ind. Assoc. Inc., Arlington, VA.
- Boggs, D. L., R. A. Merkel, and M. E. Doumit. 1998. Livestock and Carcasses: An Integrated Approach to Evaluation, Grading, and Selection. 5th ed. Kendall/Hunt Publishing, Dubuque, IA.
- Cooper, R. J., T. J. Klopfenstein, R. A. Stock, C. T. Milton, D. W. Herold, and J. C. Parrott. 1999. Effects of imposed feed intake variation on acidosis and performance of finishing steers. *J. Anim. Sci.* 77:1093-1099.
- Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vanness, and K. J. Hanford. 2009. Effect of corn processing method and corn wet distillers grains plus solubles inclusion level in finishing steers. *J. Anim. Sci.* 87:3351-3362.
- 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.
- 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.
- Erwin, E. S., G. J. Marco, and E. M. Emery. 1961. Volatile fatty acid analyses of blood and rumen fluid by gas chromatography. *J. Dairy Sci.* 44:1768-1771.
- Farran, T. B., G. E. Erickson, T. J. Klopfenstein, C. N. Macken, and R. U. Lindquist. 2006. Wet corn gluten feed 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.
- Galyean, M. L. and P. J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. *J. Anim. Sci.* 81 (E. Suppl. 2):E8-E16.

- Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. *J. Anim. Sci.* 86:1223-1231.
- Krehbiel, C. R., R. A. Stock, D. W. Herold, D. H. Shain, G. A. Ham, and J. E. Carulla. 1995. Feeding wet corn gluten feed to reduce subacute acidosis in cattle. *J. Anim. Sci.* 73:2931-2939.
- Lana, R. P., J. B. Russell, and M. E. Van Amburgh. 1998. The role of pH in regulating ruminal methane and ammonia production. *J. Anim. Sci.* 76:2190-2196.
- 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 distiller's grains with solubles with reduced corn silage levels in beef finishing diets. *J. Anim. Sci.*, <http://jas.fass.org/cgi/reprint/jas.2009-2637v1> Accessed Mar. 22, 2010.
- 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 feed and roughage levels on performance, carcass characteristics, and feeding behavior of feedlot cattle. *J. Anim. Sci.* 85:3079-3089.
- Raun, N. S. and W. Burroughs. 1962. Suction strainer technique in obtaining rumen fluid samples from intact lambs. *J. Anim. Sci.* 21:454-457.
- 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.
- 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.
- Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedeken. 1990. Effects of grain type, roughage level and monensin level on finishing cattle performance. *J. Anim. Sci.* 68:3441-3455.
- Sudweeks, E. M. 1977. Chewing time, rumen fermentation and their relationship in steers as affected by diet composition. *J. Anim. Sci.* 44:694-701.
- 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.
- 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. Evaluation of dried distillers grains and roughage source in steam-flaked corn finishing diets. *J. Anim. Sci.* 88:258-274.



- 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.
- Vander Pol, K. J., M. K. Luebke, 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.
- Williams, C. H., D. J. David, and O. Iismaa. 1962. The determination of chromic oxide in feces samples by atomic absorption spectrophotometry. *J. Agric. Sci.* 59:381-385.

**Table 1. Composition of finishing diets and formulated nutrient analysis fed to steers in Exp. 1<sup>1</sup>**

Items	Treatment <sup>2</sup>						
	CON	LALF	LCSIL	LCSTK	SALF	SCSIL	SCSTK
Dry-rolled corn	32.50	30.50	29.43	30.98	28.50	26.37	29.46
High-moisture corn	32.50	30.50	29.43	30.98	28.50	26.37	29.46
Wet distillers grains plus solubles	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Alfalfa hay	---	4.00	---	---	8.00	---	---
Corn silage	---	---	6.13	---	---	12.26	---
Corn stalks	---	---	---	3.04	---	---	6.08
Dry supplement <sup>3</sup>							
Fine ground corn	3.464	3.464	3.464	3.464	3.464	3.464	3.464
Limestone	1.297	1.297	1.297	1.297	1.297	1.297	1.297
Tallow	0.130	0.130	0.130	0.130	0.130	0.130	0.130
Trace mineral premix <sup>4</sup>	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Rumensin-80 premix <sup>5</sup>	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Vitamin A-D-E premix <sup>6</sup>	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Thiamine premix <sup>7</sup>	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Tylan premix <sup>8</sup>	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Nutrient Analysis <sup>9</sup>							
CP	16.4	16.7	16.3	16.3	17.0	16.3	16.1
Roughage NDF <sup>10</sup>	0.00	2.44	2.65	2.30	4.89	5.31	4.60
Ether extract	5.98	5.79	5.80	5.79	5.69	5.73	5.69
Ca	0.65	0.70	0.67	0.66	0.75	0.68	0.68
P	0.48	0.48	0.48	0.48	0.47	0.48	0.47
K	0.63	0.68	0.68	0.67	0.73	0.72	0.70
S	0.23	0.24	0.24	0.29	0.24	0.24	0.30

<sup>1</sup>Values presented on a DM basis.

<sup>2</sup>CON = No roughage inclusion, LALF = low alfalfa hay inclusion, LCSIL = low corn silage inclusion, LCSTK = low corn stalks inclusion, SALF = standard alfalfa hay inclusion, SCSIL = standard corn silage inclusion, and SCSTK = standard corn stalks inclusion.

<sup>3</sup>Formulated to be fed at 5% of diet DM.

<sup>4</sup>Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, 0.05% Co.

<sup>5</sup>Premix contained 176 g/kg of monensin (Elanco Animal Health, Greenfield, IN).

<sup>6</sup>Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E per g.

<sup>7</sup>Premix contained 88 g/kg of thiamine.

<sup>8</sup>Premix contained 88 g/kg of tylosin (Elanco Animal Health).

<sup>9</sup>Based on actual nutrient analysis of each dietary ingredient.

<sup>10</sup>Roughage NDF = NDF supplied from roughage source included in the diet.

**Table 2. Composition of finishing diets and formulated nutrient analysis fed to steers in Exp. 2<sup>1</sup>**

Roughage source:	Alfalfa hay			Corn stalks		
	0	4	8	0	3	6
Roughage level <sup>2</sup> :						
Dry-rolled corn	32.50	30.50	28.50	32.50	30.98	29.46
High-moisture corn	32.50	30.50	28.50	32.50	30.98	29.46
Wet distillers grains plus solubles	30.00	30.00	30.00	30.00	30.00	30.00
Alfalfa hay	---	4.00	8.00	---	---	---
Corn stalks	---	---	---	---	3.04	6.08
Dry supplement <sup>3</sup>						
Fine ground corn	3.177	3.177	3.177	3.177	3.177	3.177
Limestone	1.581	1.581	1.581	1.581	1.581	1.581
Tallow	0.130	0.130	0.130	0.130	0.130	0.130
Trace mineral premix <sup>4</sup>	0.050	0.050	0.050	0.050	0.050	0.050
Rumensin-80 premix <sup>5</sup>	0.020	0.020	0.020	0.020	0.020	0.020
Thiamine premix <sup>6</sup>	0.016	0.016	0.016	0.016	0.016	0.016
Vitamin A-D-E premix <sup>7</sup>	0.015	0.015	0.015	0.015	0.015	0.015
Tylan premix <sup>8</sup>	0.011	0.011	0.011	0.011	0.011	0.011
Nutrient Analysis <sup>9</sup>						
CP	16.4	16.8	17.3	16.4	16.3	16.3
Roughage NDF <sup>10</sup>	0.00	2.62	5.25	0.00	2.56	5.11
Ether extract	5.98	5.79	5.69	5.98	5.79	5.69
Ca	0.65	0.70	0.75	0.65	0.66	0.68
P	0.48	0.48	0.47	0.48	0.48	0.47
K	0.63	0.68	0.73	0.63	0.67	0.70
S	0.23	0.24	0.24	0.23	0.29	0.30

<sup>1</sup>Values presented on a DM basis.

<sup>2</sup>Percent of dietary DM.

<sup>3</sup>Formulated to be fed at 5% of diet DM.

<sup>4</sup>Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, 0.05% Co.

<sup>5</sup>Premix contained 176 g/kg of monensin (Elanco Animal Health, Greenfield, IN).

<sup>6</sup>Premix contained 88 g/kg of thiamine 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E per g.

<sup>7</sup>Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E per g.

<sup>8</sup>Premix contained 88 g/kg of tylosin (Elanco Animal Health).

<sup>9</sup>Based on actual nutrient analysis of each dietary ingredient.

<sup>10</sup>Roughage NDF = NDF supplied from roughage source included in the diet.

**Table 3. Simple effects of roughage source and inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 1)**

Item	Treatment <sup>1</sup>							SEM	P-value
	CON	LALF	LCSIL	LCSTK	SALF	SCSIL	SCSTK		
Roughage <sup>2</sup> :	0.00	4.00	6.13	3.04	8.00	12.26	6.08		
Performance									
Initial BW, kg	347	347	347	348	347	346	347	1	0.31
Shrunk BW, <sup>3</sup> kg	621 <sup>a</sup>	633 <sup>abc</sup>	630 <sup>ab</sup>	647 <sup>cd</sup>	650 <sup>d</sup>	644 <sup>bcd</sup>	648 <sup>d</sup>	5	<0.01
Final BW, <sup>4</sup> kg	620 <sup>a</sup>	635 <sup>abc</sup>	633 <sup>ab</sup>	651 <sup>d</sup>	648 <sup>bcd</sup>	646 <sup>bcd</sup>	650 <sup>cd</sup>	5	<0.01
DMI, kg/d	10.1 <sup>a</sup>	11.1 <sup>b</sup>	11.0 <sup>b</sup>	11.3 <sup>bc</sup>	11.7 <sup>c</sup>	11.5 <sup>c</sup>	11.6 <sup>c</sup>	0.1	<0.01
ADG, kg	1.97 <sup>a</sup>	2.07 <sup>abc</sup>	2.06 <sup>ab</sup>	2.18 <sup>d</sup>	2.16 <sup>cd</sup>	2.16 <sup>bcd</sup>	2.19 <sup>d</sup>	0.04	<0.01
G:F <sup>5</sup>	0.195	0.186	0.186	0.192	0.185	0.188	0.188	0.002	0.09
Carcass Characteristics									
HCW, kg	391 <sup>a</sup>	400 <sup>ab</sup>	399 <sup>ab</sup>	410 <sup>c</sup>	408 <sup>bc</sup>	407 <sup>bc</sup>	409 <sup>c</sup>	3	<0.01
Dressing, %	62.9	63.1	63.2	63.4	62.7	63.2	63.2	0.3	0.53
12 <sup>th</sup> rib fat, cm	1.44 <sup>a</sup>	1.66 <sup>c</sup>	1.47 <sup>ab</sup>	1.66 <sup>c</sup>	1.63 <sup>c</sup>	1.60 <sup>bc</sup>	1.68 <sup>c</sup>	0.07	<0.01
LM area, cm <sup>2</sup>	88.6	88.0	90.7	89.6	88.6	89.8	88.6	1.3	0.81
Marbling score <sup>6</sup>	489	497	494	489	503	501	510	11	0.80
Yield grade <sup>7</sup>	3.19 <sup>a</sup>	3.53 <sup>b</sup>	3.18 <sup>a</sup>	3.53 <sup>b</sup>	3.52 <sup>b</sup>	3.42 <sup>ab</sup>	3.57 <sup>b</sup>	0.13	0.02
Liver abscesses, %	5.45	5.45	5.45	11.82	0.00	3.64	7.45	3.80	0.52

<sup>a-d</sup>Means in the same row without common superscript differ ( $P < 0.05$ ).

<sup>1</sup>CON = No roughage inclusion, LALF = low alfalfa hay inclusion, LCSIL = low corn silage inclusion, LCSTK = low corn stalks inclusion, SALF = standard alfalfa hay inclusion, SCSIL = standard corn silage inclusion, and SCSTK = standard corn stalks inclusion.

<sup>2</sup>Inclusion level of each roughage source in the finishing diet (DM basis).

<sup>3</sup>Final BW shrunk 4%.

<sup>4</sup>Final BW calculated as hot carcass weight divided by a common dressing percentage of 63%.

<sup>5</sup>Calculated as total BW gain divided by total DMI.

<sup>6</sup>400 = Slight<sup>0</sup>, 450 = Slight<sup>50</sup>, 500 = Small<sup>0</sup>.

<sup>7</sup>USDA yield grade calculated as  $2.50 + [(0.0017 * \text{HCW, kg}) + (0.2 * \text{KPH, \%}) + (6.35 * 12^{\text{th}} \text{ rib fat, cm}) - (2.06 * \text{LM area, cm}^2)]$   
from Boggs et al. (1998).

**Table 4. Main effects of roughage source and inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 1)**

Item	Roughage Source <sup>1</sup>			Roughage Level <sup>2</sup>		SEM	P-Value <sup>3</sup>		
	ALF	CSIL	CSTK	Low	Standard		Source	Level	S x L
Performance									
Initial BW, kg	347	346	347	347	347	1	0.29	0.05	0.76
Shrunk BW, <sup>4</sup> kg	642	637	647	637	647	4	0.18	0.03	0.34
Final BW, <sup>5</sup> kg	641	640	650	639	648	4	0.14	0.07	0.36
DMI, kg/d	11.4	11.3	11.5	11.2	11.6	0.1	0.34	<0.01	0.57
ADG, kg	2.12	2.11	2.18	2.10	2.17	0.03	0.11	0.04	0.38
G:F <sup>6</sup>	0.186	0.187	0.190	0.188	0.187	0.002	0.23	0.49	0.61
Carcass Characteristics									
HCW, kg	404	403	410	403	408	2	0.13	0.07	0.35
Dressing, %	62.9	63.2	63.3	63.2	63.1	0.1	0.31	0.41	0.76
12 <sup>th</sup> rib fat, cm	1.65 <sup>a</sup>	1.54 <sup>b</sup>	1.67 <sup>a</sup>	1.60	1.64	0.04	0.03	0.32	0.26
LM area, cm <sup>2</sup>	88.3	90.2	88.0	89.4	89.0	1.0	0.40	0.71	0.82
Marbling score <sup>7</sup>	500	468	500	494	505	7	0.96	0.17	0.71
Yield grade <sup>8</sup>	3.53 <sup>a</sup>	3.30 <sup>b</sup>	3.55 <sup>a</sup>	3.41	3.51	0.07	0.03	0.22	0.36
Liver abscesses, %	2.73	4.55	9.64	7.58	3.70	2.84	0.23	0.25	0.90

<sup>a-b</sup>Means in the same row without common superscript differ ( $P < 0.05$ ).

<sup>1</sup>ALF = alfalfa hay, CSIL = corn silage, CSTK = corn stalks.

<sup>2</sup>Low = low roughage inclusion level, Standard = standard roughage inclusion level.

<sup>3</sup>Source = main effects of roughage source, Level = main effects of roughage inclusion level, S x L

<sup>4</sup>Final BW shrunk 4%.

<sup>5</sup>Final BW calculated as hot carcass weight divided by a common dressing percentage of 63%.

<sup>6</sup>Calculated as total BW gain divided by total DMI.



<sup>7</sup>400 = Slight<sup>0</sup>, 450 = Slight<sup>50</sup>, 500 = Small<sup>0</sup>.

<sup>8</sup>USDA yield grade calculated as  $2.50 + [(0.0017 * \text{HCW, kg}) + (0.2 * \text{KPH, \%}) + (6.35 * 12^{\text{th}} \text{ rib fat, cm}) - (2.06 * \text{LM area, cm}^2)]$   
from Boggs et al. (1998).

**Table 5. Effects of roughage source and inclusion level on intake and apparent total tract digestibility in steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2)**

Item	Roughage Source <sup>1</sup>		Roughage Level <sup>2</sup>			SEM	P-Value <sup>3</sup>		
	ALF	CSTK	0	3-4	6-8		Source	Lin	Quad
Intake, kg/d									
DM	9.58	9.66	9.42	9.60	9.83	0.56	0.84	0.45	0.37
OM	9.21	9.30	9.10	9.24	9.43	0.54	0.83	0.54	0.86
NDF	2.27	2.28	2.02	2.28	2.53	0.13	0.89	<0.01	0.97
CP	1.60	1.57	1.53	1.58	1.64	0.09	0.67	0.26	0.97
Nutrient digestion, kg/d									
DM	8.09	8.01	8.21	7.96	7.99	0.48	0.82	0.65	0.69
OM	7.90	7.84	8.05	7.78	7.77	0.47	0.86	0.56	0.71
NDF	1.73	1.65	1.56	1.68	1.84	0.13	0.29	0.02	0.78
CP	1.25	1.22	1.22	1.23	1.26	0.07	0.55	0.56	0.76
Apparent total tract digestibility, %									
DM	84.0	83.0	86.9	82.5	81.0	0.9	0.30	<0.01	0.13
OM	85.5	84.5	88.2	84.0	82.7	0.9	0.27	<0.01	0.12
NDF	76.1	72.6	77.2	73.2	72.7	2.3	0.05	0.07	0.33
CP	78.2	77.9	79.9	77.5	76.8	0.8	0.78	0.02	0.33

<sup>1</sup>ALF = alfalfa hay, CSIL = corn silage, CSTK = corn stalks.

<sup>2</sup>Percent of dietary DM.

<sup>3</sup>Effect of roughage source x roughage inclusion level ( $P \geq 0.11$ ). Source = main effects of alfalfa hay versus cornstalks; Lin = Contrast for the linear effect of roughage inclusion level; Quad = Contrast for the quadratic effect of roughage inclusion level.

**Table 6. Effects of roughage source and inclusion level on intake patterns in steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2)**

Item	Roughage Source <sup>1</sup>		Roughage Level <sup>2</sup>			SEM	P-Value <sup>3</sup>		
	ALF	CSTK	0	3-4	6-8		Source	Lin	Quad
Meals per day	11.8	12.8	12.4	12.5	12.0	0.7	0.06	0.52	0.61
Time per meal, min	50.6	46.1	46.7	48.2	50.0	2.8	0.10	0.34	0.95
Time per day, min	567	574	560	584	569	27	0.72	0.75	0.34
Meal size, kg of DM	0.88	0.78	0.79	0.80	0.90	0.05	0.06	0.11	0.45
Rate, %/h	18.9	18.4	18.6	17.4	20.0	1.6	0.73	0.49	0.26

<sup>1</sup>ALF = alfalfa hay, CSIL = corn silage, CSTK = corn stalks.

<sup>2</sup>Percent of dietary DM.

<sup>3</sup>Effect of roughage source x roughage inclusion level ( $P \geq 0.11$ ). Source = main effects of alfalfa hay versus cornstalks; Lin = Contrast for the linear effect of roughage inclusion level; Quad = Contrast for the quadratic effect of roughage inclusion level.

**Table 7. Effects of roughage source and inclusion level on ruminal pH variables of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2)**

Item	Roughage Source <sup>1</sup>		Roughage Level <sup>2</sup>			SEM	P-Value <sup>3</sup>		
	ALF	CSTK	0	3-4	6-8		Source	Lin	Quad
Average pH	5.47	5.48	5.25	5.48	5.68	0.14	0.93	0.03	0.89
Maximum pH	6.13	6.09	5.81	6.08	6.43	0.11	0.72	<0.01	0.76
Minimum pH	4.83	4.97	4.50	5.11	5.08	0.26	0.58	0.09	0.22
pH change	1.28	1.12	1.29	0.99	1.33	0.26	0.53	0.90	0.24
pH variance	0.06	0.05	0.03	0.05	0.09	0.02	0.55	< 0.01	0.37
Time < 5.6, min/d	923	909	1166	927	654	185	0.94	0.04	0.92
Area < 5.6, min/d <sup>4</sup>	333	361	495	344	202	134	0.76	0.04	0.96
Time < 5.3, min/d	500	520	719	511	300	239	0.89	0.06	0.99
Area < 5.3, min/d <sup>4</sup>	121	145	215	124	60	73	0.64	0.05	0.80

<sup>1</sup>ALF = alfalfa hay, CSIL = corn silage, CSTK = corn stalks.

<sup>2</sup>Percent of dietary DM.

<sup>3</sup>Effect of roughage source x roughage inclusion level ( $P \geq 0.16$ ). Source = main effects of alfalfa hay versus cornstalks; Lin = Contrast for the linear effect of roughage inclusion level; Quad = Contrast for the quadratic effect of roughage inclusion level.

<sup>4</sup>Area below pH of 5.6 or 5.3 is calculated as = time below x magnitude below.

**Table 8. Effects of roughage source and inclusion level on ruminal VFA profiles of steers fed finishing diets containing 30% wet distillers grains plus solubles (Exp. 2)**

Roughage Source	Alfalfa hay			Corn stalks			SEM	<i>P</i> -Value <sup>2</sup>		
	0	4	8	0	3	6		Source	Level	S x L
Acetate, mol/100 mol	62.2	59.0	56.1	62.5	57.3	59.0	4.1	0.79	0.07	0.61
Propionate, mol/100 mol	18.8 <sup>ab</sup>	20.3 <sup>b</sup>	17.7 <sup>ab</sup>	18.1 <sup>ab</sup>	17.3 <sup>a</sup>	25.1 <sup>c</sup>	2.2	0.16	0.01	< 0.01
Total VFA, mM	115.6	123.3	112.1	119.5	114.7	113.4	6.8	0.73	0.30	0.30
Acetate:propionate	3.92 <sup>a</sup>	3.03 <sup>c</sup>	3.24 <sup>bc</sup>	3.81 <sup>ab</sup>	3.68 <sup>ab</sup>	2.70 <sup>c</sup>	0.50	0.99	< 0.01	0.02

<sup>1</sup>Percent of dietary DM.

<sup>2</sup>Source = main effects of alfalfa hay versus cornstalks; Level = Contrast main effects of roughage inclusion level; S x L = *P*-value for the effect of roughage source x roughage inclusion level.

**CHAPTER III****Effects of wet corn gluten feed and roughage inclusion level in beef finishing diets  
containing corn modified distillers grains plus solubles<sup>3</sup>**

J. R. Benton\*, G. E. Erickson\*<sup>4</sup>, T. J. Klopfenstein\*, M. K. Luebbe\*, R. U. Lindquist†

\*Department of Animal Science, University of Nebraska, Lincoln 68583-0908;

and †Archer Daniels Midland Company, Columbus, NE 68601

---

<sup>3</sup> A contribution of the University of Nebraska Agricultural Research Division, supported in part by funds provided through the Hatch Act.

<sup>4</sup> Corresponding author: [geericks@unlnotes.unl.edu](mailto:geericks@unlnotes.unl.edu)

ABSTRACT: Four-hundred fifty crossbred steer calves ( $297 \pm 20$  kg) were fed for 167 d in a finishing experiment with a randomized complete block design to evaluate wet corn gluten feed (WCGF) and roughage inclusion level in finishing diets containing modified distillers grains plus solubles (MDGS). Forty-five pens were used with 3 BW blocks, 5 pens per diet, and 10 steers per pen. Treatments consisted of WCGF at 0, 15, or 30% inclusion and roughage at 0, 7.5, or 15% inclusion (DM basis) in a 3 x 3 factorial design. Corn silage was used as roughage and all diets contained 30% MDGS, 5% supplement (DM basis), and a mixture of dry-rolled and high-moisture corn fed at a 1:1 ratio which was replaced as WCGF or roughage increased. There were no significant ( $P > 0.10$ ) WCGF x roughage inclusion level interactions observed. There was a quadratic response ( $P < 0.05$ ) for final BW, DMI, and ADG due to WCGF inclusion level which were lowest for cattle fed 30% WCGF. Final BW and ADG also responded quadratically ( $P < 0.05$ ) due to roughage inclusion level and were lowest for cattle fed 0% corn silage. Increasing roughage inclusion level resulted in a linear increase ( $P < 0.01$ ) in DMI. Gain:feed decreased linearly ( $P < 0.01$ ) with increasing WCGF and roughage inclusion levels. There was a quadratic response ( $P \leq 0.01$ ) for HCW due to WCGF and roughage inclusion level which was lowest for cattle fed 30% WCGF and 0% corn silage. There was a linear increase ( $P \leq 0.02$ ) for 12<sup>th</sup> rib fat, marbling score, yield grade, or percent Choice or greater due to increasing roughage inclusion levels. Feeding 15% WCGF resulted in similar cattle performance and carcass traits to cattle fed no WCGF in diets containing 30% MDGS, but feeding diets with 60% total byproduct inclusion made up of 30% WCGF and 30% MDGS negatively impacted finishing cattle performance and carcass traits. Reducing corn silage inclusion level to 7.5% resulted in similar finishing

cattle performance and carcass traits to cattle fed 15% corn silage in diets containing 30% MDGS with or without inclusion of WCGF. However, elimination of roughage in these diets resulted in negative impacts on finishing cattle performance and carcass traits.

**Key words:** corn, distillers grains, finishing cattle, gluten feed, roughage

## INTRODUCTION

As the ethanol industry has grown, feedlots have an increased opportunity to utilize wet distillers grain plus solubles (WDGS) and wet corn gluten feed (WCGF). During ethanol production, starch is the primary nutrient fermented and the remaining byproducts are excellent sources of fiber and protein. Feeding a combination of byproducts provides further opportunities for many operations, primarily due to the complementary nutrient profile of WDGS and WCGF because of the differences in fiber, protein, and fat content. Combinations of WDGS and WCGF up to 60% of dietary DM have been shown to improve finishing cattle performance (Loza et al., 2010). In addition, the inclusion of WCGF in finishing diets is beneficial in controlling acidosis (Krehbiel et al., 1995) and roughage levels can be reduced in finishing diets containing WCGF (Farran et al., 2006), dried distillers grains plus solubles (DDGS; May et al., 2010), or a combination of WDGS plus WCGF (Loza et al., 2010). However, complete elimination of roughage in diets containing DDGS or a combination of WDGS and WCGF does not appear to be beneficial (Deppenbusch et al., 2009; Loza et al., 2010). Another byproduct available for cattle feeders is modified distillers grains plus solubles (MDGS) which has a similar nutrient profile compared to WDGS but has a greater DM. Some ethanol plants partially dry wet distillers grains before they add the condensed distillers solubles, thus



increasing the DM content of the byproduct. The effects of feeding a combination of MDGS and WCGF have not been evaluated.

Therefore, the objectives of the current study were to examine 1) the effects of WCGF inclusion level, and 2) the effects of roughage inclusion level in feedlot diets containing MDGS on finishing cattle performance and carcass characteristics.

## MATERIALS AND METHODS

A 167-d finishing trial used four hundred fifty crossbred steer calves (BW = 297 ± 20 kg) in a randomized complete block design. All procedures used for this trial involving animal care were approved by the University of Nebraska Institutional Animal Care and Use Committee. Steers were received at the University of Nebraska beef research facility located at the Agricultural Research and Development Center (ARDC, Ithaca, NE) in the fall of 2007. Upon arrival, steers were individually weighed and identified, vaccinated with BoviShield Gold 5 (for prevention against infectious bovine rhinotracheitis virus, bovine viral diarrhea virus types 1 and 2, parainfluenza-3 virus, and bovine respiratory syncytial virus; Pfizer Animal Health, New York, NY), Somubac (for prevention against *Haemophilus somnus*; Pfizer Animal Health), and Dectomax Injectable (for protection against internal and external parasites; Pfizer Animal Health). Calves were weighed and revaccinated approximately 18 d after arrival with Somubac/Ultrabac 7 (for prevention against *Clostridium chauvoei*, *Cl. septicum*, *Cl. novyi*, *Cl. sordellii*, *Cl. perfringens* types C and D, and *Haemophilus somnus*; Pfizer Animal Health) and a second dose of BoviShield Gold 5 (Pfizer Animal Health) and injected with Piligaurd Pinkey Triview (for prevention against *Moraxella bovis*;

Intervet/Schering-Plough Animal Health, Union, NJ). Steers were weaned on smooth brome grass for approximately 4 wk. Steers were then allowed to graze sorghum stalks for 15 d. While on stalks, steers were supplemented with 2.3 kg/hd daily of WCGF. Steers were brought to the feedlot 5 d before initiation of the trial and limit-fed a diet consisting of 50% wet corn gluten feed and 50% alfalfa hay (DM basis) at 2% of BW. On d 0 and d 1, steers were individually weighed in order to get an accurate initial BW. The weights from d 0 were used to assign steers to pen. Steers were blocked by BW into 3 blocks, stratified by weight within block and assigned randomly to pen (10 steers/pen). There were 2 light, 1 medium, and 2 heavy BW blocks. Pens were assigned randomly to one of 9 finishing diets within block (5 pens/diet). On d 1, all steers were implanted with Synovex-Choice (containing 100 mg of trenbolone acetate and 14 mg of estradiol benzoate; Fort Dodge/Pfizer Animal Health, Overland Park, KS). On d 64, all steers were re-implanted with Synovex-Choice (containing 100 mg of trenbolone acetate and 14 mg of estradiol benzoate; Fort Dodge/Pfizer Animal Health) and poured with Durasect II (containing permethrin, pyrethrins, and piperonyl butoxide; Pfizer Animal Health). During the trial, four steers died and one steer was removed for health reasons. All causes for removal from trial were determined to be unrelated to dietary treatments.

The dietary treatments (Table 1) were arranged in a 3 x 3 factorial design. The two factors included in this trial were WCGF inclusion level at 0, 15, or 30% (Archers Daniels Midland Company, Columbus, NE) and roughage inclusion level at 0, 7.5, or 15% (DM basis). Corn silage was used as the roughage source. All diets contained a mixture of dry-rolled (DRC) and high-moisture corn (HMC) fed at a 1:1 ratio, 30% MDGS, and 5% supplement (DM basis). Diets were formulated to contain a minimum of

0.65 % calcium, 0.60% potassium, and supply 360 mg/steer Rumensin<sup>®</sup> (Elanco Animal Health, Greenfield, Indiana), 90mg/steer Tylan<sup>®</sup> (Elanco Anima Health), and 130mg/steer thiamine daily. Feed ingredients were sampled weekly and DM was conducted by drying samples in a 60° C forced air oven for 48 h.

Cattle were adapted to grain by feeding 37.5, 27.5, 17.5, 7.5, and 3.75% alfalfa hay, which replaced the corn mixture in the finishing diets, for 3, 4, 6, 6, and 5 days, respectively. The first 4 steps included 15% corn silage and were formulated to supply 45, 35, 25, and 15% roughage (DM basis). For step 5, corn silage was reduced from 15 to 7.5% for finishing diets containing 0 or 7.5% corn silage. Corn silage was assumed to be 50% forage and 50% grain (DM basis). Steers were fed once daily and allowed ad libitum access to feed and water. Cattle were fed for 167 d (December 13, 2007 to May 27, 2007) and harvested at a commercial packing plant (Greater Omaha Pack, Omaha, Nebraska). Hot carcass weight and liver score were collected the day of harvest and 12<sup>th</sup> rib fat, LM area, and USDA called marbling score were collected following a 24-hr chill. Yield grade was calculated using the following equation ( $YG = (2.50 + (0.0017*HCW, \text{ kg}) + (0.2*KPH, \%) + (6.35*12^{\text{th}} \text{ rib fat, cm}) - (2.06*LM \text{ area, cm}^2))$ ) from Boggs et al. (1998). Final BW, ADG, and feed:gain were calculated using hot carcass weight divided by an average dressing percentage of 63%.

Data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) as a 3 x 3 factorial design. Wet corn gluten feed, roughage, and WCGF x roughage inclusion levels were included in the model as fixed effects. Pen served as the experimental unit and weight block was included in the model as a random effect. Orthogonal contrasts were used to detect linear and quadratic relationships for the main effect of WCGF

inclusion level and roughage inclusion level if no interaction was detected ( $P > 0.05$ ). If an interaction occurred, only simple effects were tested. For all analyses, a  $P \leq 0.05$  was deemed significant.

## RESULTS AND DISCUSSION

The hypothesis was that cattle performance would improve with increasing WCGF level and decreasing roughage levels. Interestingly, this was not the case as there were no significant WCGF x roughage inclusion level interactions observed ( $P \geq 0.24$ ) for any variables measured in this study. Therefore, only main effects of either WCGF level or roughage level are presented.

*Effects of WCGF Inclusion Level.* For the main effect of WCGF inclusion level (Table 2), there was a quadratic ( $P < 0.05$ ) response for final BW, DMI, and ADG. Final BW, DMI, and ADG were greatest for cattle fed 15% WCGF but similar to cattle fed 0% WCGF in diets containing 30% MDGS. As WCGF inclusion level increased, G:F decreased linearly ( $P < 0.01$ ) although G:F was numerically similar for cattle fed 0 or 15% WCGF (quadratic,  $P = 0.13$ ). There was a quadratic ( $P < 0.01$ ) response for HCW and yield grade and a linear ( $P = 0.03$ ) decrease for marbling score as inclusion level of WCGF increased. Cattle fed 0 and 15% WCGF had similar HCW, marbling score, and yield grade. There was a trend ( $P = 0.07$ ) for a quadratic response due to WCGF inclusion level for 12<sup>th</sup> rib fat which was greatest for cattle fed 15% WCGF and lowest for cattle fed 30% WCGF. No differences due to WCGF inclusion level were observed ( $P \geq 0.11$ ) in LM area, percentage choice or greater, and percentage of liver abscesses.

These data suggest performance was similar between cattle fed either 0 or 15% WCGF and cattle performance was decreased when feeding 30% WCGF (60% total byproduct inclusion; DM basis) in finishing diets containing 30% MDGS.

Similar results were observed in a series of three trials conducted by Loza et al. (2010). In Trial 1, cattle were fed finishing diets containing 30% WDGS, 30% WCGF, or a blend of WDGS and WCGF (1:1 DM basis) at 30 or 60% (DM basis). In Trial 2, cattle were fed finishing diets containing a blend of WDGS and WCGF (1:1 DM basis) at 25, 50, or 75% dietary DM. In Trial 3, six dietary treatments consisted of 30% WCGF plus 0, 10, 15, 20, 25, or 30% WDGS (DM basis). The WCGF (Sweet Bran, Cargill, Blair, NE) used in the trials by Loza et al. (2010) was from a different source. The authors observed that performance was optimized for cattle fed diets containing 25 to 50% of the byproduct blends and that DMI and ADG were decreased for cattle fed diets containing 60 or 75% of the byproduct blends. In Trial 3, G:F was decreased for cattle fed diets containing 30% WCGF plus 30% WDGS which supports the current trial. However, Loza et al. (2010) also included a corn control diet without byproducts in all three trials and found that cattle fed diets containing 60% byproduct combinations had improved performance compared to cattle fed the corn control.

***Effects of Roughage Inclusion Level.*** For the main effect of roughage inclusion level (Table 3), there was a quadratic ( $P \leq 0.01$ ) effect on final BW and ADG. Both final BW and ADG were lowest for cattle fed 0% roughage. As roughage inclusion level increased, DMI linearly increased but G:F decreased linearly ( $P < 0.01$ ). Cattle fed 15% corn silage had the lowest G:F (quadratic;  $P=0.06$ ). Roughage level had a quadratic ( $P =$

0.01) effect on HCW which was lowest for cattle fed 0% roughage. A linear ( $P < 0.05$ ) increase due to roughage inclusion levels was observed for 12<sup>th</sup> rib fat thickness, marbling score, yield grade, and percentage choice or greater. The LM area and percentage of liver abscesses was not affected by roughage inclusion level ( $P \geq 0.19$ ).

The observed increase in DMI and ADG in the current study are in agreement with Benton et al. (2007) which evaluated the effects of roughage source and level in finishing diets containing WDGS. The increase in DMI and ADG due to increased roughage levels are also commonly observed in studies investigating the effects of roughage levels in beef finishing diets without WDGS (Stock et al., 1990; Shain et al., 1999; Turgeon et al., 2010). The increase in DMI due to increasing roughage level is likely due to reduced incidence of acidosis if ADG improves (7.5% corn silage) or may be due to an energy dilution effect whereby the cattle are attempting to eat to a constant energy level (15% corn silage) if ADG is maximal. In the current study, DMI, ADG, and 12<sup>th</sup> rib fat thickness were increased for cattle fed diets containing 7.5 or 15% corn silage compared to cattle fed diets without roughage (0% corn silage),

In finishing diets containing single byproducts or combinations, other studies have also indicated that roughage levels may be reduced (Farran et al., 2006; Loza et al., 2010; May et al., 2010) without negatively affecting cattle performance. In addition, Loza et al. (2010) observed that when roughage was eliminated in finishing diets containing a blend of WDGS and WCGF (1:1 DM basis) at 75% dietary DM, cattle performance was similar to that of cattle fed a corn control diet containing 7.5% alfalfa hay (DM basis). The reason cattle performance is not decreased when roughage levels are decreased in finishing diets containing byproducts suggests that byproducts may help reduce the

negative effects of acidosis. In contrast, Benton et al. (2007) concluded that it was not beneficial to reduce or eliminate roughage in finishing diets containing WDGS.

It appears that finishing cattle performance begins to decline when the dietary inclusion of byproduct combinations reach 60% dietary DM. The reduction in performance of cattle fed 30% WCGF and 30% MDGS or of cattle fed diets without roughage in the current trial may be due to the increased level of dietary S. There is some evidence suggesting that roughage may interact with dietary S tolerance which could affect performance and incidence of polioencephalomalacia (PEM, Loza et al., 2010). The interaction between roughage, S tolerance, and PEM incidence may be linked by rumen pH (Vanness et al., 2009) which may explain why cattle performance was decreased in the current study when roughage was completely removed.

In conclusion, feeding 0 or 15% WCGF with 30% MDGS improved cattle performance compared to feeding 30% WCGF with 30% MDGS. Furthermore, it appears that roughage levels may be reduced from 15 to 7.5% corn silage in finishing diets containing 30% MDGS with or without WCGF.

**LITERATURE CITED**

- Boggs, D. L., R. A. Merkel, and M. E. Doumit. 1998. *Livestock and Carcasses: An Integrated Approach to Evaluation, Grading, and Selection*. 5th ed. Kendall/Hunt Publishing, Dubuque, IA.
- 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.
- Farran, T. B., G. E. Erickson, T. J. Klopfenstein, C. N. Macken, and R. U. Lindquist. 2006. Wet corn gluten feed 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.
- Krehbiel, C. R., R. A. Stock, D. W. Herold, D. H. Shain, G. A. Ham, and J. E. Carulla. 1995. Feeding wet corn gluten feed to reduce subacute acidosis in cattle. *J. Anim. Sci.* 73:2931-2939.
- Loza, P. L., C. D. Buckner, K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein, and R. A. Stock. 2010. Effect of feeding combinations of wet distillers grains and wet corn gluten feed to feedlot cattle. *J. Anim. Sci.* 88:1061-1072.
- 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 distiller's grains with solubles with reduced corn silage levels in beef finishing diets. *J. Anim. Sci.*, <http://jas.fass.org/cgi/reprint/jas.2009-2637v1> Accessed Mar. 22, 2010.
- 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.
- Stock, R. A., M. H. Sindt, J. C. Parrott, and F. K. Goedeken. 1990. Effects of grain type, roughage level and monensin level on finishing cattle performance. *J. Anim. Sci.* 68:3441-3455.
- 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.



**Table 1. Composition of finishing diets and formulated nutrient analysis fed to steers<sup>1</sup>**

Roughage source <sup>2</sup> :	0.0			7.5			15.0		
	0.0	15.0	30.0	0.0	15.0	30.0	0.0	15.0	30.0
Wet corn gluten feed level <sup>3</sup> :									
Dry-rolled corn	32.50	25.00	17.50	28.75	21.25	13.75	25.00	17.50	10.00
High-moisture corn	32.50	25.00	17.50	28.75	21.25	13.75	25.00	17.50	10.00
Modified distillers grains plus solubles	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Wet corn gluten feed	---	15.00	30.00	---	15.00	30.00	---	15.00	30.00
Corn silage	---	---	---	7.50	7.50	7.50	15.00	15.00	15.00
Dry supplement <sup>4</sup>									
Fine ground corn	2.673	2.673	2.673	2.673	2.673	2.673	2.673	2.673	2.673
Limestone	1.686	1.686	1.686	1.686	1.686	1.686	1.686	1.686	1.686
Iron Carbonate	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.395
Tallow	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130	0.130
Trace mineral premix <sup>5</sup>	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Rumensin-80 premix <sup>6</sup>	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Vitamin A-D-E premix <sup>7</sup>	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Thiamine premix <sup>8</sup>	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Tylan premix <sup>9</sup>	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
Tribasic copper	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
Formulated Nutrient Analysis <sup>10</sup>									
CP	16.2	17.9	19.5	16.5	17.8	19.4	16.1	17.7	19.3
Ether extract	6.72	6.63	6.54	6.67	6.58	6.49	6.61	6.52	6.43
Ca	0.68	0.69	0.70	0.70	0.71	0.72	0.71	0.72	0.74
P	0.45	0.54	0.64	0.45	0.54	0.63	0.45	0.54	0.63
K	0.60	0.73	0.86	0.67	0.80	0.92	0.73	0.86	0.99
S	0.31	0.35	0.39	0.31	0.35	0.39	0.31	0.35	0.39

<sup>1</sup>Values presented on a DM basis.

<sup>2</sup>Dietary inclusion levels of corn silage in the finishing diet (DM basis).

<sup>3</sup>Dietary inclusion levels of wet corn gluten feed in the finishing diet (DM basis).

<sup>4</sup>Formulated to be fed at 5% of diet DM.

<sup>5</sup>Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, 0.05% Co.

<sup>6</sup>Premix contained 176 g/kg of monensin (Elanco Animal Health, Greenfield, IN).

<sup>7</sup>Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E per g.

<sup>8</sup>Premix contained 88 g/kg of thiamine 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E per g.

<sup>9</sup>Premix contained 88 g/kg of tylosin (Elanco Animal Health).

<sup>10</sup>Based on actual nutrient analysis of each dietary ingredient.

**Table 2. Effects of wet corn gluten feed (WCGF) inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% modified distillers grains plus solubles .**

WCGF Inclusion Level <sup>1</sup> :	0.0	15.0	30.0	SEM	Lin <sup>2</sup>	Quad <sup>3</sup>
Performance						
Initial BW, kg	297	297	297	1	0.83	0.58
Final BW, <sup>4</sup> kg	603	604	589	2	<0.01	<0.01
DMI, kg/d	10.1	10.2	10.0	0.1	0.15	0.04
ADG, kg	1.83	1.84	1.75	0.01	<0.01	<0.01
G:F <sup>5</sup>	0.181	0.181	0.176	0.001	<0.01	0.13
Carcass Characteristics						
HCW, kg	380	380	371	1	<0.01	<0.01
12 <sup>th</sup> rib fat, cm	1.42	1.47	1.35	0.04	0.10	0.07
LM area, cm <sup>2</sup>	91.2	90.3	91.5	0.9	0.81	0.35
Marbling score <sup>6</sup>	511	512	487	8	0.03	0.15
Yield grade <sup>7</sup>	2.97	3.05	2.79	0.05	0.02	0.01
Choice or greater, %	51.6	53.6	41.6	0.1	0.11	0.19
Liver Abscesses, %	7.33	5.33	6.07	3.80	0.72	0.66

<sup>1</sup>Percent dietary inclusion levels of WCGF in the finishing diet (DM basis).

<sup>2</sup>Contrast for the linear effect of WCGF inclusion level P-value.

<sup>3</sup>Contrast for the quadratic effect of WCGF inclusion level P-value.

<sup>4</sup>Final BW calculated as hot carcass weight divided by a common dressing percentage of 63%.

<sup>5</sup>Calculated as total BW gain divided by total DMI.

<sup>6</sup>400 = Slight<sup>0</sup>, 450 = Slight<sup>50</sup>, 500 = Small<sup>0</sup>.

<sup>7</sup>USDA yield grade calculated as  $2.50 + [(0.0017 \times \text{HCW, kg}) + (0.2 \times \text{KPH, \%}) + (6.35 \times 12^{\text{th}} \text{ rib fat, cm}) - (2.06 \times \text{LM area, cm}^2)]$  from Boggs et al. (1998).

**Table 3. Effects of roughage inclusion level on performance and carcass characteristics of steers fed finishing diets containing 30% modified distillers grains plus solubles .**

Roughage Inclusion Level <sup>1</sup> :	0.0	7.5	15.0	SEM	Lin <sup>2</sup>	Quad <sup>3</sup>
<b>Performance</b>						
Initial BW, kg	297	297	297	1	0.13	0.23
Final BW, <sup>4</sup> kg	588	603	605	2	<0.01	0.01
DMI, kg/d	9.6	10.1	10.6	0.1	<0.01	0.33
ADG, kg	1.74	1.83	1.85	0.01	<0.01	<0.01
G:F <sup>5</sup>	0.182	0.181	0.174	0.001	<0.01	0.06
<b>Carcass Characteristics</b>						
HCW, kg	370	380	381	1	<0.01	0.01
12 <sup>th</sup> rib fat, cm	1.30	1.45	1.47	0.04	<0.01	0.25
LM area, cm <sup>2</sup>	91.4	91.2	90.3	0.9	0.40	0.74
Marbling score <sup>6</sup>	490	503	517	8	0.02	0.90
Yield grade <sup>7</sup>	2.75	2.98	3.08	0.05	<0.01	0.32
Choice or greater, %	40.9	48.2	57.6	0.1	0.01	0.85
Liver Abscesses, %	8.74	6.00	4.00	3.80	0.19	0.90

<sup>1</sup>Percent dietary inclusion levels of corn silage in the finishing diet (DM basis).

<sup>2</sup>Contrast for the linear effect of roughage inclusion level P-value.

<sup>3</sup>Contrast for the quadratic effect of roughage inclusion level P-value.

<sup>4</sup>Final BW calculated as hot carcass weight divided by a common dressing percentage of 63%.

<sup>5</sup>Calculated as total BW gain divided by total DMI.

<sup>6</sup>400 = Slight<sup>0</sup>, 450 = Slight<sup>50</sup>, 500 = Small<sup>0</sup>.

<sup>7</sup>USDA yield grade calculated as  $2.50 + [(0.0017 \times \text{HCW, kg}) + (0.2 \times \text{KPH, \%}) + (6.35 \times 12^{\text{th}} \text{ rib fat, cm}) - (2.06 \times \text{LM area, cm}^2)]$  from Boggs et al. (1998).