EFFECTS OF DRY VERSUS MODIFIED WET DISTILLERS GRAINS WITH SOLUBLES WITH OR WITHOUT CALCIUM OXIDE ON ECONOMICS, GROWTH PERFORMANCE, AND RUMINAL METABOLISM OF BEEF FEEDLOT STEERS

BY

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THESIS

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Abstract

Objectives of this research were to determine the interaction of feeding dry (**DDGS**) or modified wet (**MDGS**) distillers grains with solubles (**DGS**) with or without calcium oxide (**CaO**) treatment to feedlot steers on: (1) growth performance, economics of gain, and USDA carcass grades; (2) pattern of intake and meal distribution; and (3) diet digestibility and rumen parameters. *Exp. 1*: Steers (n = 139; average initial BW = 336 ± 75 kg) were used in a randomized complete block design. Treatments were arranged in a 2 × 2 factorial and pens were randomly allotted to 1 of 4 dietary treatments: (1) 50% DDGS with 0% CaO, (2) 48.8% DDGS treated with 1.2% CaO, (3) 50% MDGS with 0% CaO, or (4) 48.8% MDGS treated with 1.2% CaO. The remainder of the diet was husklage, dry rolled corn, and vitamin and mineral supplement. (*Exp. 2:* Fistulated steers (n = 8; average initial BW = 540 ± 250 kg) were used in a replicated 4 × 4 Latin square design with the same dietary treatments as in *Exp. 1*). There was no interaction ($P \geq 0.14$) of type of DGS and CaO inclusion on DMI, ADG, final BW, or USDA Yield and Quality grades. However, steers fed CaO treated distillers grains (**DGS**) had reduced ($P < 0.01$) DMI, regardless of DGS type. Because CaO treatment decreased DMI without affecting ($P = 0.66$) ADG, steers fed CaO treated DGS had increased ($P < 0.01$) G:F when compared to steers that were not fed CaO. Variation in DMI found in this experiment could be explained by differences in meal size and distribution. Steers fed CaO treated DGS ate a similar number of meals ($P = 0.36$), but ate smaller meals ($P < 0.01$). No effects ($P \geq 0.55$) of CaO treatment or its interaction with DGS type were found for total tract DM or NDF digestibility. However, steers fed MDGS had increased ($P < 0.01$) NDF digestibility when compared to steers fed DDGS. Even though CaO treatment increased the ration cost $3.50 per metric ton of DM, the improved G:F in steers fed CaO treated DGS equated to a $0.098 feed savings ($P < 0.01$) per kg

of BW gain. Even though G:F was similar in steers fed DDGS compared to MDGS, feeding MDGS reduced ($P < 0.01$) cost of gain and total feed cost over the 95 d experiment ($P < 0.01$). *Exp. 2*: There were no interactions ($P \geq 0.12$) of DGS type and CaO addition on ruminal pH, VFA, enzymatic activity, methane concentration, or in situ DM and NDF disappearance; therefore, only main effects are discussed. Steers fed DDGS increased ($P < 0.01$) DMI compared to steers fed MDGS; however, CaO supplementation reduced ($P = 0.03$) DMI, regardless of DGS type. As expected, addition of CaO increased ($P < 0.01$) the pH of DGS in the diet by 1.7 pH units. This caused a time by CaO interaction ($P = 0.05$) for ruminal pH when CaO was added. Steers supplemented with CaO tended ($P = 0.09$) to have elevated ruminal pH at 1.5 h and had increased ($P = 0.03$) ruminal pH at 3 h post-feeding; however, ruminal pH did not differ ($P \geq 0.24$) the remainder of the day. There was a time by CaO interaction ($P < 0.01$) for ruminal cellulase activity. Cattle fed 1.2% CaO diets had greater ($P = 0.02$) ruminal cellulase activity at 0 h post-feeding than cattle fed 0% CaO. Furthermore, feeding supplemental CaO increased ($P = 0.04$) the ratio of acetate to propionate (**A:P**) regardless of type of DGS fed. Increased ruminal pH and cellulase activity from supplemental CaO did not increase ($P = 0.48$) in situ NDF disappearance. No differences ($P \geq 0.48$) in ruminal methane concentration were found when comparing DGS type or supplemental CaO. In conclusion, DGS type had little effect on ruminal metabolism. Although CaO increased ruminal pH and cellulase activity at some times post-feeding, it was not enough to affect in situ fiber disappearance or total tract fiber digestibility. However, steers fed CaO treated DGS still had increased feed efficiency and reduced cost of gain when compared to steers that were not fed CaO, regardless of DGS type.

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CHAPTER 1: REVIEW OF THE LITERATURE

INTRODUCTION

In recent years, production of ethanol from corn grain has increased substantially (USDA-WASDE, 2013). This has led to an increased inclusion of co-products, from ethanol production, in feedlot diets (Loy and Strohbehn, 2007; Lardy, 2007). Historically, beef producers relied on relatively inexpensive corn to provide much of the energy in ruminant diets (Wright, 2005); however, increased demand for corn grain for ethanol production has increased corn prices and, consequently, feed costs for beef producers (Hoffman and Baker, 2011). Increased feed costs have given producers economic incentives to feed cattle alternative energy sources to reduce ration costs (Sexton, 2006). One popular alternative feed is the ethanol production co-product, distillers grains with solubles (**DGS**).

During ethanol production, the starch portion of the corn kernel is fermented. Therefore, DGS recovered from the dry milling process contain all the nutrients of the initial corn, except the starch that has been fermented to ethanol (Davis, 2001). Corn is roughly two-thirds starch; therefore, removal of starch leaves the remaining protein, fiber, fat, and mineral nearly 3 times more concentrated in DGS when compared to corn (on a DM basis; NRC, 1996). The added nutrient density of DGS can increase average daily gain (**ADG**) and feed efficiency (**G:F**) of cattle fed DGS when compared to cattle fed traditional corn-based diets with no added DGS; however, optimum inclusion may vary depending on a number of factors (Klopfenstein et al., 2008).

While DGS can successfully replace much of the corn in the diet, they also come with their own set of unique feeding challenges. Sulfuric acid content of DGS (Felix and Loerch, 2011), acidic ruminal pH associated with feeding DGS (Loy et al., 2007; Felix and Loerch, 2011), and performance differences between wet DGS (**WDGS**) and dry DGS (**DDGS**; Ham et al., 1994) are some of the challenges that have been documented. However, research has not yet identified an effective solution to these problems. As corn prices continue to rise, reliance on DGS as a corn replacement feed is likely to increase. Therefore, research is needed to investigate ways to make DGS an economical alternative energy source for ruminants. Finding ways to use DGS in feedlot diets without negatively impacting growth and carcass characteristics is imperative to the opportunities for their use in the beef industry.

One possible way to address the challenges associated with feeding DGS is to treat DGS with an alkaline agent to increase the pH of the feed. Historically, sodium hydroxide (**NaOH**), a strong base, has been used as a forage treatment to increase digestibility (Berger et al., 1979). It is thought that the treatment of forages with an alkaline agent breaks the hydrogen bonds between cellulose, hemicellulose, and lignin found in the forage. This disruption of hydrogen bonding is thought to increase the digestibility of fibrous feeds (Kim and Holtzapple, 2006). Felix et al. (2012) showed that feeding DDGS that had been treated with NaOH increased ruminal pH and ruminal fiber degradation. While NaOH has proven to be effective in increasing the digestibility of forages, its practical usage is limited. For the average producer, NaOH is difficult to obtain in large quantities, it is expensive in relation to other alkaline agents, and its chemical properties make it dangerous to use (Chaudhry, 2000). Another alkaline agent, calcium oxide (**CaO**), may offer a safer, more economical and more readily available alternative (Chaudhry, 2000). Research has not yet investigated if treating DGS with CaO could raise the

pH of the rumen, altering the rumen environment and microbial activity, thus affecting digestibility.

FEEDING DISTILLERS GRAINS

Corn Processing and Distillers Grains Production

Distillers grains with solubles are a co-product of the ethanol production process. The ethanol production process has been described previously in several reviews (Stock et al., 2000; Davis, 2001; Klopfenstein et al., 2008; Vanness et al., 2009). In short, most ethanol, for beverage or fuel, is produced in a process called "dry milling". The process begins with grinding whole kernel corn into a fine meal. The next step is called liquefaction. This step includes mixing the meal with water to form a slurry and adding an alpha amylase to hydrolyze the corn starch and create dextrin. This dextrin mixture is called 'mash'. After liquefaction is complete, the mash is cooked to remove any unwanted microbial contamination and is then cooled to 90˚F. The cooled mash is then pumped into a fermentation tank and pH is adjusted using sulfuric acid to obtain a stable pH between 5 and 6. After pH adjustment, yeast are added to convert the dextrose into ethanol and carbon dioxide. The fermented mash is called 'beer'. The beer is then sent to a distillation vessel to collect the ethanol. The remaining residuals after distillation are centrifuged to separate the solids, called wetcake, and liquids, referred to as thin stillage. The thin stillage can be evaporated to create condensed distillers solubles (**CDS**). The wetcake and CDS are typically recombined to create WDGS and this wet product can be sold as-is, partially dried to form modified DGS (**MDGS**), or thoroughly dried to form DDGS (Davis, 2001).

Nutritional composition

Distillers grains recovered from the dry milling process, described above, contain all the nutrients of the incoming corn except the starch, which is consumed during fermentation (Davis, 2001). The NRC (1996) lists the nutrient composition of DDGS: 91.00% DM, 46.00% NDF, 30.40% CP, 10.70% fat, and 4.60% ash; and WDGS: 25.00% DM, 40.00% NDF, 29.70% CP, 9.20% fat, and 8.00% ash. For MDGS, reported nutrient values are 50.00% DM, 34.40% NDF, 31.00% CP, and 12.4% fat (Nuttelman et al., 2011). However, variation in nutrient content is common for DGS (Batal and Dale, 2003). The values can change between plants or even within a plant due to variation in corn selection, fermentation type, drying temperature, and duration of drying (Berger and Good, 2007).

Similarly to the nutrient content, sulfur (**S**) and phosphorus (**P**) are variable in DGS as well (Buckner et al., 2007). While excess P in the diet of feedlot cattle is easily managed by supplementing calcium, excess S content in the diet poses more challenges (Klopfenstein et al., 2008). Buckner et al. (2007) analyzed 1,200 samples of WDGS which averaged 0.79% S (DM basis). The NRC (1996) explains that the maximum dietary S inclusion for beef cattle is 0.40% of diet DM. Inclusions above that threshold can cause polioencephalomalacia characterized by restlessness, diarrhea, and muscular twitching, followed by death if no treatment is administered (Vanness et al., 2009). Kandylis (1984) discovered that increasing S concentration, even if dietary S remains below the NRC threshold of 0.40%, can decrease feed intake and reduce growth of feedlot cattle. When providing DGS as an energy source to cattle, this recommended threshold is often exceeded which may contribute to issues with animal growth which will be discussed later. Ways to mitigate effects of S in feedlot cattle diets are still unknown.

Ruminal Digestibility

In DGS, carbohydrates, as well and protein and fats, may be used by the rumen microbes as substrates (Hungate, 1966). The change in these substrates can influence the proportion of volatile fatty acids (**VFA**) in the rumen (Van Soest, 1982). Fermentation of carbohydrates by rumen microbes yields high energy ATP for use by microbes, and VFA are excreted (Russell, 2002). While VFA are a waste product to the microbes, VFA make up approximately 50% of metabolizable energy in cattle (Van Soest, 1982). Numerous VFA are excreted by microbes; however, the VFA acetate, propionate, and butyrate make up the majority of those absorbed by ruminants (Hungate, 1966).

Although most of the energy in DGS is in the form of fiber, cattle consuming DGS-based diets have a much different VFA profile than cattle consuming traditional fiber-based diets (Leupp et al., 2009b). Cattle consuming forage based diets typically have a VFA profile of 65 to 70% acetate, 15 to 25% propionate and 5 to 10% butyrate (Fluharty, 2009). However, when cattle are fed concentrate-based diets, VFA profile is approximately 50 to 60% acetate, 35 to 40% propionate, and 5 to 10% butyrate (Fluharty, 2009). Therefore, as fiber fermentation increases in the diet, the relative proportion of acetate in the rumen increases (Van Soest, 1982). As DGS contain predominantly fiber (NRC, 1996), it was theorized that DGS fermentation in the rumen would be similar to that of forage and increase acetate to propionate ratio (**A:P**; Reinhardt et al., 2007). However, cattle consuming DGS-based diets have a much different VFA profile than cattle consuming traditional fiber-based diets (Leupp et al., 2009a). Leupp et al. (2009a) found that cattle fed 60% DDGS diets had approximately 57% acetate, 22% propionate, and 14%

butyrate at 3 h post-feeding. Firkens et al. (1985) found acetate concentrations decreased, and propionate concentrations increased linearly at 3, 6, and 9 h post-feeding when dry corn gluten feed was increased in the diet of lambs, compared to a forage based control. Similarly, Vander Pol et al. (2009) reported decreased acetate and increased propionate in cattle consuming diets containing WDGS compared to corn bran. Felix et al. (2012) examined increasing levels of DDGS from 0% to 60% of the diet DM in beef cattle diets and discovered a time post-feeding by treatment interaction. At 0h post feeding they observed a linear decrease in acetate and total VFA; however, at 3 h post feeding there was a linear increase in acetate, propionate, *and* total VFA as DDGS inclusion increased. However, by 6 h there were no differences in acetate, propionate, and total VFA. With the prevalence of DGS in feedlot cattle diets, it is important to understand how ruminal VFA concentrations are affected. However, experiments conducted in this area have not thoroughly explained why fibrous, DGS-based diets are not fermented similarly to fibrous, forage based diets.

While distillers grains have become an important energy source to potentially replace corn (Klopfenstein, 2001), the greater protein concentration of DGS in relation to corn makes it an important protein source as well (Klopfenstein, 1978). McDonald (1954) explained that the corn protein "zein" is only about 40% degraded by rumen microorganisms, leaving the remaining protein intact for digestion and absorption in the lower digestive tract. As zein is the predominant protein found in corn, and subsequently DGS, it can be reasoned that much of the protein in DGS may not be degraded in the rumen (Klopfenstein et al., 2008). In fact, the NRC (1996) estimates that 54.91% of CP in WDGS and 73.65% of CP in DDGS is rumen undegradable protein (**RUP**). However, more recent research indicates RUP levels are variable with roughly 53 to 55% of CP in WDGS and 52 to 72% of CP in DDGS present as RUP

(Kleinschmit et al., 2007). The elevated RUP in DGS may be beneficial to growing beef cattle as ruminal degradation of protein results in N losses of 10 to 12 g per day (Gill and Beever, 1982).

Similarly, only a portion of the lipids in DGS are degraded by rumen microorganisms. Vander Pol et al. (2009) conducted a metabolism study to determine the digestibility of lipid in WDGS as well as the duodenal concentrations of lipid in diets containing either WDGS or corn oil as a lipid source. They discovered that adding 5% corn oil to the diet reduced G:F by 10%; however, when the same amount of lipid was added using WDGS, G:F was increased by 8%. Duodenal concentrations of unsaturated fatty acids showed that diets containing WDGS had a greater percentage of lipid in the duodenum (30.9%), indicating that some of the lipid in WDGS is protected from ruminal digestion. Plascencia et al. (2003) used steers with ruminal and duodenal cannulae and found that digestion of fat is diminished by hydrogenation that occurs in the rumen. Because protein and fat in DGS often escape rumen fermentation, and, therefore, are protected from the losses associated with microbial fermentation, they may be responsible for part of the increase in the feeding value of DGS for ruminants. Larson et al. (1993) actually predicted that the RUP and fat in DGS accounts for nearly 20% of the increased feeding value found in DGS compared to corn.

CHALLENGES WITH FEEDING DISTILLERS GRAINS

Performance Differences between Wet and Dry DGS

Despite the nutritional advantages DGS have compared to other feeds, they pose challenges that limit their use in feedlot diets (Klopfenstein et al., 2008). One challenge associated with feeding DGS to cattle is the animal performance differences when feeding

WDGS versus DDGS. Ham et al. (1994) compared diets comprised of 40% WDGS or 40% DDGS (DM basis) in feedlot cattle and discovered that gains were similar; however, cattle fed WDGS consumed less feed (DM basis) and were more efficient than cattle fed DDGS. A meta-analysis of 9 experiments by Klopfenstein et al. (2008) compared the feeding value of DDGS versus WDGS when compared to corn. They found that, at 20% dietary inclusion, WDGS had 142% the feeding value of corn whereas DDGS had 123%. When dietary inclusion was increased to 40%, both DDGS and WDGS feeding values declined, however DDGS was reduced more, to 100%, compared to WDGS at 131% of the feeding value of corn. Numerous reasons for the increased feeding value of WDGS compared to DDGS have been discussed (Firkins et al., 1984; Britton et al., 1986; Ham et al., 1994). One reason suggested for this difference in feeding value is the possibility of heat damage from the drying process for DDGS. However, Klopfenstein (1996) found no difference in protein digestibility between wet and dry DGS, indicating heat damage in DDGS may play only a minor role in the change in feed values. Moisture level of the feed has been suggested as another possible explanation for the change in feeding values between wet and dry DGS. Ham et al. (1994) explained that adding water to DDGS reduced DMI and rate of passage from the rumen, and increased NDF digestibility. Similarly, in earlier experiments, Ham et al. (1993) discovered that adding water to other feedlot diets will reduce feed intake but maintain feed efficiency. In addition to the impacts moisture has on rate of passage, the added moisture of the WDGS may also have a conditioning effect on the diet when dry forages are fed. Garcia and Kalscheur (2007) discovered that the moisture content of WDGS can reduce separation of ingredients in a mixed ration, which can positively influence performance and efficiency of feedlot cattle. Plascencia et al. (2003) explained part of the decreased feeding value of DGS with increasing inclusion could be caused by decreased fatty

acid digestion. They found that as fatty acid intake increased, intestinal digestion of fatty acids decreased. Although multiple reasons for the decreased feeding value of DGS with increased dietary inclusion have been investigated, research on the direct causative mechanism underlying the performance differences between cattle fed wet and dry DGS is lacking.

Sulfuric Acid and Ruminal pH

Another challenge associated with feeding DGS is the acidic ruminal pH associated with feeding DGS (Loy et al., 2007; Felix and Loerch, 2011). Sulfuric acid is used in ethanol production for pH control and cleaning (Vanness et al., 2009). Residual sulfuric acid from the ethanol production process can remain in DGS (Vanness et al., 2009). Felix and Loerch (2011) explained that this sulfuric acid residue is likely the cause of the acidity of DDGS. They found that dry DGS in a mixture of 1 part DDGS to 4 parts distilled water had a pH of 3.76 (Felix and Loerch, 2011). Similarly, another study reported that WDGS measured in a mixture of 1 part WDGS to 2 parts distilled water had a pH of 3.2 (Kalscheur et al., 2003). However, because DGS varies from one ethanol plant to the next (Batal and Dale, 2003), the acidity of DGS may also vary. In a study conducted by Felix and Loerch (2011), 8 ruminally fistulated steers, fed a 60% DDGS diet, had an average rumen pH prior to feeding of 6.04, but pH decreased to 5.09 at 1.5 h post-feeding, and remained below pH 5.0 for 12 h after feeding. As much of the energy in DGS-based diets comes from the fiber in DGS, it is imperative to control rumen pH to ensure successful fiber digestion in the rumen; however, practical methods of ruminal pH control when feedlot cattle are fed DGS-based diets have not yet been determined.

Ruminal Acidity and Pattern of Intake

Rumen pH below 5.5 can be considered subacute ruminal acidosis (Owens et al., 1998). Ruminal acidosis is characterized by an accumulation of organic acids in the rumen and a subsequent reduction in rumen pH (Owens et al., 1998). This reduction in rumen pH can shift rumen microbial populations, affecting rumen fermentation and digestibility of some substrates (Nagaraja and Titgemeyer, 2007). Acidotic animals may suffer from decreased nutrient absorption, variable feed intake, and subsequent reduced performance (Owens et al., 1998). Risk of acidosis is greatly influenced by carbohydrate source and meal size (Yang and Varga, 1989). Dietary inclusion of concentrate versus forage, forage quality, particle size, and diet DM all influence animal intake (Hungate, 1966; Van Soest, 1982; Russell, 2002; Garcia and Kalscheur, 2007). Acidosis symptoms may be minimized by ensuring a uniform intake with smaller, more frequent meals (Pritchard and Knutsen, 1995) because variation in DMI can cause acidotic conditions in the rumen (Britton and Stock, 1987).

Variation in feed intake among cattle is most closely related to appetite and rumen volume (Hungate, 1966). Increased nutritional needs for young ruminants can correlate with an increased appetite and faster rumen turnover compared to an adult animal (Hungate, 1966). Feed delivery influences intake pattern of feedlot steers (Pritchard and Bruns, 2003). Britton and Stock (1987) explain that intake fluctuation can cause acidosis and reduced DMI. Galyean et al. (1992) varied daily feed delivery by 10% and discovered it reduced cattle gain and feed efficiency compared to cattle receiving unvaried delivery. Various bunk management strategies seek to alter intake patterns to minimize digestive upsets. Galyean (1999) explained ad-libitum feeding is used to maximize DMI, but variable daily intakes are common. Cattle fed restricted diets have

reduced variation in daily DMI because cattle adapt to consume fewer, but larger, meals than cattle fed ad-libitum (Galyean, 1999).

Studies that investigate how these variations in animal intake influence rumen pH, feed digestibility, and animal performance have produced conflicting results (Schwartzkopf-Genswein, 2003). Meal size and meal distribution patterns have not been examined in cattle consuming DGS-based diets. Moisture differences in wet versus dry DGS influence diet palatability and subsequently intake (Ham et al., 1993); however, research has not yet investigated if this can influence meal size and pattern of intake. With the implications pattern of intake and meal size have on ruminal metabolism, it is imperative to examine the intake pattern of cattle consuming DGS-based diets.

RUMEN METABOLISM

Cattle feed contains numerous substrates on which rumen microbes can potentially thrive, including proteins, fats, and carbohydrates (Van Soest, 1982). The rumen environment is anaerobic with a pH of 5.5 to 7.0 and a temperature of 39 to 40˚C (Hungate, 1966). Optimum digestibility of feed relies on synergy among the rumen microbial population and their environment (Van Soest, 1982). Thousands of species of microbes are known to inhabit the rumen ecosystem. All three domains of life, archaea, bacteria, and eukaryotes, thrive in the rumen environment (Russell, 2002). Bacteria, archaea, protozoa, and fungi live in a symbiotic relationship with the host, converting complex feed ingredients into energy for the cell (Russell, 2002). Understanding how these rumen microbes are affected by the rumen environment, and

changes that can occur when DGS are fed, is crucial for more optimal use of DGS in beef cattle rations.

Microbial Fermentation of Carbohydrates

The primary fermentation substrate in cattle feeds are carbohydrates (Hungate, 1966). Complex carbohydrates, such as cellulose and hemicellulose, are composed of mono- and oligosaccharides strung together by β 1,4 linkages (Russell, 2002). Hydrogen bonds link the strands together into rigid sheets (Van Soest, 1982). Fungi and bacteria in the rumen produce enzymes, such as cellulase, xylanase and amylase that degrade complex carbohydrate molecules into mono-, di-, and oligosaccharides that can be absorbed by the microbial cell (Russell, 2002). Subsequently, these oligosaccharides are used as substrates for fermentation by the rumen microbes to produce high energy adenosine triphosphate (**ATP**) and volatile fatty acids (Russell, 2002). While the ATP is used by microbes as an energy source, VFA are excreted as a waste product (Russell, 2002). While these VFA are a waste product to the microbes, they are readily absorbed by the rumen epithelium and provide an important source of metabolizable energy for cattle (Van Soest, 1982).

Ruminal Cellulase and Xylanase Activity

The first step in converting dietary carbohydrates into useable substrates for fermentation is enzymatic digestion. Cellulases are enzymes secreted by fungi and bacteria that can effectively degrade cellulose over time into its constituents, glucose and cellobiose (Mould et al., 1983). The

most abundant carbohydrate on earth is cellulose, making up roughly 20 to 40% of the DM of all plants (Van Soest, 1982). While cellulose is a major component of plant cell walls, and is commonly found in large quantities in the ruminant diet, it is a very difficult polymer to degrade (Wilson and Irwin, 1999). Rumen environment greatly influences the success of cellulolytic bacteria (Hungate, 1966). Stewart (1977) experimented in vitro with cellulose disappearance from rumen contents at various pH. He discovered that a pH reduction from 6.6 to 5.2 decreased cellulose disappearance by 31%. Reduction in pH also altered culturable rumen bacteria counts; decreasing cellulolytic populations and increasing lactic acid producing and utilizing bacteria. Mould et al. (1983) described that, for optimum cellulose metabolism in the rumen, a pH range of 6.0 to 6.7 should be maintained. As cattle consuming DGS-based diets typically have a more acidic rumen pH than this optimum threshold (Felix et al., 2012), cellulase activity *could* be decreased in cattle consuming DGS-based diets. However, the effect of DGS-based diets on microbial cellulase activity is currently unknown.

In addition to cellulose, hemicellulose is another major component of plant cell walls. Nearly 25% of DGS DM is hemicellulose (NRC, 1996). While cellulose structure is crystalline, making it resistant to hydrolysis, hemicellulose has a more amorphous structure. This difference makes hemicellulose more easily hydrolyzed by acids as well as by hemicellulose degrading enzymes, such as xylanase (Russell, 2002). Similarly to cellulose, hemicellulose digestibility is directly affected by rumen pH and dietary carbohydrate source (Mould et al., 1983). Rooke et al. (1987) discovered that a continuous supply of soluble carbohydrates depressed hemicellulose disappearance in rumen fluid in vitro, even in highly buffered solutions with an optimal pH because the hemicellulolytic bacteria preferentially used the soluble carbohydrates for fermentation in place of hemicellulose. Huhtanen and Khalili (1992) completed an experiment to

determine if the same implications could be realized in situ. Their study compared direct infusion of sucrose into the rumen versus 2 time-point doses of sucrose in the rumen. Cattle receiving continuous infusion of sucrose had increased mean rumen pH compared to the mean pH of cattle dosed sucrose; however, hemicellulose disappearance was reduced in cattle infused with sucrose. Again, suggesting that hemicellulolytic bacteria preferentially used soluble carbohydrates as an energy source in place of hemicellulose. In addition, Huhtanen and Khalili (1992) conducted another experiment that involved dosing the rumen of cattle fed a forage based diet twice a day with sucrose with or without sodium bicarbonate as a buffer. They measured rumen pH, as well as cellulase and xylanase activity, to determine the effect of pH on hemicellulose degradation. They found that addition of bicarbonate as a buffer when dosing the rumen with sucrose increased rumen pH, and cellulase and xylanase activity.

As DGS are predominantly composed of fiber (NRC, 1996), cellulolytic and hemicellulolytic microbial activity may play a major role in the digestibility of DGS-based diets. While numerous studies confirm that rumen pH and carbohydrate solubility greatly impact fiber digestion in the rumen (Huhtanen and Khalili, 1992; Mould et al., 1983; Rooke et al., 1987), few studies have examined hemicellulolytic bacteria activity in *DGS-based* diets. One way to indirectly measure the success of cellulolytic and hemicellulolytic microbes in the rumen is through measuring carboxymethylcellulase and arabinoxylanase activity from rumen contents (Hankin and Anagnostakis, 1977). However, research in this area when cattle are fed a DGS-based diet is lacking. Furthermore, while alkalinizing distillers grains has proven to increase ruminal pH (Felix et al., 2012), as discussed in a separate section below, the effects of this treatment on enzymatic activity and subsequent diet digestibility have not been investigated.

Ruminal Methane Production

While the rumen microbes previously discussed convert carbohydrates to ATP and excrete VFA through fermentation reactions, other rumen microbes use by-products of these fermentation reactions to produce methane (Russell and Gahr, 2000). Johnson and Johnson (1995) explained that methane production in ruminants marks a significant loss of energy to the animal. Approximately 2 to 12% of gross energy intake is lost through eructated methane (Johnson and Johnson, 1995). Methane is produced by methanogenic archaea that use hydrogen ions to reduce carbon dioxide and produce methane and water (Russell and Gahr, 2000). Therefore, rumen carbohydrate fermentation and hydrogen ion concentration are the main factors that affect methane emissions (Johnson and Johnson, 1995).

Carbohydrate fermentation releases VFA into the rumen, decreasing ruminal pH which in turn, decreases the success of methanogenic archaea, and subsequently reduces rumen methane emissions (Moe and Tyrrell, 1979). Experiments conducted by Martin et al. (2010) indicate that methane production is reduced as pH decreases even if the acetate to propionate ratio remains constant. However, a decrease in A:P ratio can coincide with a decrease in methane production (Russell, 1998). The first step in fermentation reactions converts sugars to pyruvate (Russell, 2002). This reaction reduces nicotinamide adenine dinucleotide (**NAD**$^{+}$) to NADH (Russell and Gahr, 2000). Pyruvate can then be converted into various fermentation end products to yield ATP (Russell, 2002). The conversion of pyruvate to acetate reduces the greatest number of NAD to NADH compared to other common VFA, and releases carbon in the form of carbon dioxide (Russell, 2002). As hydrogen and carbon dioxide are the most common substrates for methanogenesis, an increase in methanogenesis can be realized when acetate production is increased (Russell and Gahr, 2000).

As mentioned earlier, although it was previously speculated that DGS-based diets would increase acetate and decrease propionate production in the rumen (Reinhardt et al., 2007), Leupp et al. (2009a) found that ruminal acetate concentrations decreased linearly with increasing DGS in the diet. This decrease in acetate combined with the acidic ruminal pH associated with DGS-based diets implies that methane production should be decreased. Behlke et al. (2007) conducted in vitro experiments replacing forage with DDGS as an energy source. They found that increasing DDGS in rumen fluid in vitro resulted in less acetate and methane production. However, when corn was replaced with DDGS in vitro, acetate production increased as DDGS inclusion increased as did methane production (Behlke et al., 2008). While it is known that rumen pH is also affected by feeding cattle DGS-based diets (Felix et al., 2012), previous research on methane production has been done in highly buffered in vitro systems. Ruminal methane production in cattle fed DGS-based diets is currently unknown. Furthermore, the effect of including a buffering agent in vivo for these acidic diets has not been investigated.

ALKALINE TREATMENT OF FEEDS

Most of the digestive processes described above rely on cattle maintaining an optimal ruminal pH. One possible way to elevate rumen pH is through alkalinizing the diet (Emery and Brown, 1961). Traditionally, alkaline treatments have been used to improve the digestibility of poor quality forages. Rumen microbial degradation of some structural carbohydrates can be limited because of the chemical structure of the cell wall (Wilkie, 1979). The chemical structure of the cell wall can be altered with treatment by an alkaline agent (Kim and Holtzapple, 2006). Over time, alkaline treatment reduces hydrogen bonding between hemicellulose, cellulose, and

lignin (Kong et al., 1992). By altering the chemical structure of the cell wall, stearic hindrance to microbes is reduced, allowing for greater microbial attachment and increased digestibility (Kong et al., 1992). Therefore, alkaline agents have been used extensively as a treatment for fibrous feeds to increase digestibility (Berger et al., 1979; Chaudhry, 2000; Klopfenstein, 1978). Kim and Holtzapple (2006) measured delignification and hemicellulose breakdown occurring in corn stover treated with CaO. After 1 week, breakdown of lignin and hemicellulose plateaued at nearly 90% degradation. Due to these changes in structure, in situ fiber digestibility increases with alkaline treatment of feeds (Berger et al., 1979; Garrett et al., 1979; Chessen, 1981; Chaudhry, 2000; Wang et al., 2004).

Although the benefits of alkaline treatment on fibrous feeds are well documented, little research has been conducted on treating wet or dry DGS in the diet. Some of the benefit may be explained by improved rumen environment, thereby improving microbial growth (Wanapat et al., 2009). Berger et al. (1979) explained that alkaline treatment of corn cobs with NaOH brought the pH of the corn cobs up from 5.6 before treatment to 9.7 after treatment. Wanapat et al. (2009) fed rice straw based diets with or without CaO to fistulated dairy cattle and found that CaO treatment was effective in increasing the pH of the straw, subsequently increasing rumen pH and cellulolytic bacterial counts. Some of the more recent research on the effects of alkaline treatment on ruminal metabolism have related to corn co-products. For example, Offer and Offer (1992) compared malt distillers grains with various calcium hydroxide (**$Ca(OH)_2$**) treatments to a non-treated control. They found that rumen pH, VFA production and hay digestibility were not affected by $Ca(OH)_2$ treatment in the in-situ trials; however, performance trials found that $Ca(OH)_2$ treatment increased intake and performance of growing wethers. Felix et al. (2012) found that by neutralizing the acid in DDGS with NaOH prior to feeding, increased ruminal pH

and fiber digestibility more than 50%. Nuñez et al. (2013) experimented with increasing levels of CaO in 60% DDGS diets. They found that CaO added up to 1.6% of the diet DM was effective at decreasing DMI, and increasing ADG and feed efficiency. While alkaline agents are proven to improve digestibility and subsequent growth performance in beef cattle, animal responses to the alkaline agents when wet versus dry distillers grains are fed have not yet been investigated.

CONCLUSION

With the increased interest in including DGS in beef cattle rations as an energy source, optimizing its feeding value is crucial. The feeding value of DGS decreases as inclusion increases, and performance differences between DDGS and WDGS (Ham et al., 1994) make it challenging to feed diets comprised primarily of DGS. While numerous experiments have analyzed the use of DGS in beef cattle diets, much remains unclear. Rumen parameters such as pH and VFA concentration have been studied in cattle consuming DGS based diets; however, research that can explain why fiber from DGS-based diets does not appear to be fermented similarly to fiber from forage-based diets in the rumen is still lacking. One possible way to answer this is to directly measure enzymatic activity in the rumen; however, no studies have currently attempted this. In addition, Ham et al. (1993) explained that adding water to DDGS decreased DMI; however, how added moisture can affect pattern of intake and subsequent ruminal metabolism has not been investigated. A thorough analysis of animal DMI, meal size, and pattern of intake throughout the day is important to help understand dry versus wet DGS fermentation, and why feeding value of dry and wet DGS diminishes as their inclusion in the diet increases.

Inclusion of DGS in beef cattle diets is also restricted by the sulfuric acid content of DGS (Felix and Loerch, 2011) which leads to acidic ruminal pH (Felix and Loerch, 2011; Loy et al., 2007). To more effectively use DGS in beef cattle rations, a solution to these problems must be found. Addition of CaO could be a possible additive to help alleviate the problems associated with the acidic DGS and could equalize the performance difference between WDGS and DDGS. Therefore, there exists a need to explore alkaline treatment of wet and dry DGS and the resulting effects feeding these treated DGS-based diets have on ruminal metabolism and animal growth performance.

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CHAPTER 2: EFFECTS OF CALCIUM OXIDE TREATMENT OF DRY AND MODIFIED WET DISTILLERS GRAINS PLUS SOLUBLES ON GROWTH PERFORMANCE AND APPARENT DIGESTIBILITY OF FEEDLOT STEERS

ABSTRACT

The objectives of this study were to determine the interaction of feeding dry (**DDGS**) or modified wet (**MDGS**) distillers grains with or without CaO treatment to feedlot steers on: (1) growth performance, economics of gain, and USDA carcass grades; and (2) diet digestibility, pattern of intake, and meal distribution. *Exp. 1*: Steers (n = 139; average initial BW = 336 kg ± 75 kg) were used in a randomized complete block design. Treatments were arranged in a 2 × 2 factorial and pens were randomly allotted to 1 of the 4 dietary treatments: (1) 50% DDGS untreated, (2) 48.8% DDGS treated with 1.2% CaO, (3) 50% MDGS untreated, or (4) 48.8% MDGS treated with 1.2% CaO. The remainder of the diet was husklage, dry rolled corn, and vitamin and mineral supplement. *Exp. 2:* Fistulated steers (n = 8; average initial BW = 540 kg ± 250 kg) were used in a replicated 4 × 4 Latin square design with the same dietary treatments as in Exp. 1. There was no interaction ($P \geq 0.14$) of type of DGS and CaO inclusion on DMI, ADG, final BW, or USDA Yield and Quality grades. However, steers fed CaO treated distillers grains (**DGS**) had reduced ($P < 0.01$) DMI, regardless of DGS type. Because CaO treatment decreased DMI without affecting ($P = 0.66$) ADG, steers fed CaO treated DGS had increased ($P < 0.01$) G:F when compared to steers that were not fed CaO. Variation in DMI found in this experiment could be explained by differences in meal size and distribution. Steers fed CaO treated DGS ate a similar number of meals ($P = 0.36$), but ate smaller meals ($P < 0.01$). No effects ($P \geq 0.55$) of

CaO treatment or its interaction with DGS type were found for total tract DM or NDF digestibility. However, steers fed MDGS had increased NDF digestibility ($P < 0.01$) when compared to steers fed DDGS. Even though CaO treatment increased the ration cost $3.50 per metric ton of DM, the improved G:F in steers fed CaO treated DGS equated to a $0.07 feed savings ($P < 0.01$) per kg of BW gain. Even though G:F was similar in steers fed DDGS compared to MDGS, feeding MDGS reduced ($P < 0.01$) cost of gain and total feed cost over the 95 d experiment ($P < 0.01$). In conclusion, CaO treatment of DGS increased feed efficiency and reduced cost of gain when DGS-based diets were fed but did not improve digestibility.

Key Words: (distillers grains, calcium oxide, beef cattle)

INTRODUCTION

One challenge associated with feeding distillers grains (**DGS**) to cattle is the difference in animal performance when feeding dry DGS (**DDGS**) versus wet DGS (**WDGS**; Klopfenstein et al., 2008). Ham et al. (1994) compared feeding diets comprised of 40% DDGS or 40% WDGS (DM basis) to feedlot cattle and reported that ADG was similar, but cattle fed WDGS consumed less DM and were more efficient than cattle fed DDGS. A meta-analysis of 9 experiments compared the feeding value of WDGS and DDGS to corn and found that, at 20% dietary DM inclusion, feeding values were 142% and 123% of corn for WDGS and DDGS, respectively (Klopfenstein et al., 2008). When dietary DM inclusion was increased to 40%, both DDGS and WDGS feeding values declined; however, DDGS was reduced more than WDGS (100% versus 131% of corn, respectively). Perhaps a larger issue with both WDGS and DDGS is pH. Sulfuric acid used in ethanol production causes DGS to be acidic (Felix and Loerch, 2011). This acidity reduces ruminal pH as dietary DDGS inclusion increases (Felix et al., 2012). Acidic ruminal pH can inhibit fiber fermentation (Mould et al., 1983). The major energy component of DGS is fiber

(NRC, 1996); therefore, ruminal pH and subsequent fiber digestibility may influence animal performance when DGS-based diets are fed. Treating DDGS with alkaline agents prior to feeding improves digestibility (Felix et al., 2012) and subsequent growth performance in beef steers (Nuñez et al., 2013). However, animal response to the alkaline agent calcium oxide (**CaO**) when wet versus dry DGS are fed has not yet been investigated. Therefore, the objectives of this study were to determine the interaction of feeding DDGS and modified wet DGS (**MDGS**) with or without CaO treatment to feedlot steers on: (1) growth performance, economics of gain, and USDA carcass grades, and (2) diet digestibility, pattern of intake, and meal distribution.

MATERIALS AND METHODS

All animal procedures were approved by the University of Illinois Institute of Animal Care and Use Committee and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Experiment 1

Animal and Diet Management

One hundred and thirty-nine crossbred steers (average initial BW = 336 ± 75 kg) were used for this experiment at the University of Illinois Beef Cattle and Sheep Field Research Laboratory in Urbana, IL. Steers were housed in confinement barns on slatted, concrete floors that are covered by interlocking rubber matting. Pen dimensions are 4.88 m × 4.88 m constructed of 5.08 cm galvanized steel tubing. Feed intake was measured on individual animals using a GrowSafe system (GrowSafe Systems Ltd., Airdrie, AB Canada).

Steers were adapted to experimental diets over 21 d. The initial diet consisted of 50% husklage, 20% hay, 5% supplement, and 25% corn (DM basis). Dry DGS and MDGS replaced hay and husklage in the rations gradually over the 21d. Steers were then weighed, using a Flying W squeeze chute equipped with a Tru-Test (Tru-Test Incorporated, Mineral Wells, Texas) weighing system, on 2 consecutive d (d 0 and d 1) to determine initial BW. Steers were blocked by BW into a heavy (average start weight = 370 ± 25 kg) and light (average start weight 315 ± 28 kg) block, then steers within block were stratified by d 0 BW and allotted to treatment pens on d 1 such that each pen within block had the same initial starting pen weight. Treatments were arranged in a 2 × 2 factorial and 20 pens were randomly assigned to 1 of 4 treatments: (1) 50% DDGS untreated, (2) 48.8% DDGS treated with 1.2% CaO, (3) 50% MDGS untreated, or (4) 48.8% MDGS treated with 1.2% CaO. There were 5 pens per treatment with 7 steers per pen. The remainder of the diet was husklage, dry rolled corn, and vitamin and mineral supplement (DM basis, Table 2.1). To maintain dietary Ca across treatments, diets treated with CaO were fed a reduced Ca supplement, while diets without CaO addition received an elevated Ca supplement. Steers were fed once daily for ad-libitum intakes. Treated DDGS and MDGS were made every 3 to 7 d by adding 2.5% CaO (of the DGS DM; 1.2% inclusion of the total dietary DM) to the DGS and mixing in a Keenan MF-320 (Richard Keenan and Co. Ltd., Carlow, Ireland) feed mixing wagon for 15 min.

Dietary ingredient samples were collected every 7 d throughout the trial for nutrient analysis and DM adjustment. Steers were implanted with Component TE-S (Elanco Animal Health, Greenfield, IN) at the start of the trial (d 0). Steers were weighed approximately every 28 d throughout the feeding phase. On d 95, steers were hauled approximately 300 km to a commercial harvest facility and were humanely slaughtered under USDA inspection.

Immediately post-harvest, HCW was collected, and carcasses were chilled for 24 h at -4˚C. After approximately 24 h chill, USDA Yield and Quality Grade were collected.

Sampling and Analysis

Feed samples from the entire trial were composited, freeze-dried (FreeZone, Labconco, Kansas City, MO), then ground through a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA). Individual ingredient composites were analyzed for nutrient composition, and the resulting values were used to calculate nutrient composition of the diets. All samples were analyzed for DM (24 h at 105°C). All freeze-dried samples were subjected to perchloric acid digestion and inductively coupled plasma atomic emission spectroscopy analysis of complete minerals (method 975.03: AOAC, 1988). Freeze-dried samples were also analyzed for ADF and NDF (using Ankom Technology method 5 and 6, respectively; Ankom^{200} Fiber Analyzer, Ankom Technology, Macedon, NY), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat (ether extract method; Ankom Technology), and total ash (500° C for 12 h, HotPack Muffle Oven Model: 770750, HotPack Corp., Philadephia, PA). Distillers grains pH was measured using an Accumet Basic AB15 pH meter with an Accumet accuCap glass body, gel-filled electrode (Fisher Scientific, Pittsburg, PA). Fifty g of DGS sample was mixed with 200 mL of distilled water for 30 s before the pH electrode was submersed in the mixture and pH was recorded.

Economic analysis was completed using actual feed prices paid by the University of Illinois Beef Cattle and Sheep Field Research Laboratory during the duration of the trial (December 2011 through March 2012). Ration costs were calculated on a DM basis and reported as a cost per metric ton of DM. Cost of gain was calculated by the following equation: ((DMI × ration cost) × ADG^{-1}). Total feed costs were calculated by the following equation: (DMI × days

on feed × ration cost). All cattle were managed the same and harvested in a one day kill, therefore other variable costs in feedlot profitability would be similar across treatments and were not accounted for in cost of gain. Carcass value was not taken into account.

Statistical Analysis

This experiment was a randomized complete block design with a 2 × 2 factorial arrangement of treatments. The data were analyzed using the MIXED procedures of SAS (SAS Institute, Cary, NC). The model was:

$$Y_{ijkl} = \mu + b_i + D_j + C_k + (DC)_{jk} + e_{ijkl}$$

where, Y_{ijkl} = response variable; μ = mean; b_i = effect of BW block (light and heavy); D_j = the fixed effect of DGS type (DDGS or MDGS); C_k = the fixed effect of CaO addition (0% or 1.2%); $(DC)_{jk}$ = the fixed effect of the interaction of the DGS type and CaO addition; and e_{ijkl} = the experimental error. Pen was defined as the experimental unit. Significance was declared at $P \leq 0.05$. Trends are discussed at $0.05 < P < 0.10$.

Experiment 2

Animal and Diet Management

Four Angus-Simmental crossbred steers (average initial BW = 635 ± 50 kg) and 4 Angus-Simmental crossbred steers (average initial BW = 450 ± 40 kg), previously fitted with rumen cannula, were blocked by BW (large and small block) and used in a replicated 4 × 4 Latin square design. Steers were housed in metabolism stalls at the University of Illinois Beef Cattle and Sheep Field Research Laboratory in Urbana, IL. Stalls (2.3 x 1.3 m) are equipped with individual

feed bunks and non-siphoning automatic water bowls. The barn is equipped with a heating, ventilation, and air-conditioning system, providing a controlled environment set at 18.3° C. Treatments were the same as in Exp. 1 (Table 2.2). Dietary treatment sequence was assigned according to procedures outlined by Patterson and Lucas (1962). Feed was delivered once daily to allow ad libitum access to assigned diets.

At the initiation of this study, a partial rumen evacuation (12 L) was completed and 3 subsets (4 L each) of rumen contents were frozen to save for re-inoculation after each period. Following the initial rumen evacuation a 14 d acclimation period took place to adjust the steers to the experimental diets.

Sampling and Analysis

Sampling periods were 21 d beginning with a 14 d acclimation phase followed by a 7 d collection phase. After each sampling period, steers were re-inoculated with rumen contents from the initial collection (4 L) before being transitioned to the next experimental diet.

Feed and feed refusals, were collected and weighed once daily over a 120 h collection phase. Feces were collected in canvas bags secured by a leather harness attached to the girth and under the neck. Feces were emptied from the bag and weighed twice daily over the 120 h collection phase. Feed samples from the entire trial were composited, freeze-dried (FreeZone, Labconco, Kansas City, MO), then ground through a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA). Individual ingredient composites were analyzed for nutrient composition, and the resulting values were used to calculate nutrient composition of the diets. Feed, refusal (20% as-is), and fecal (5% as-is) samples were composited, freeze-dried

(Labconco, FreeZone Kansas City, MO), and analyzed for DM, NDF, and ADF as described in Exp. 1.

Apparent DM digestibility was calculated by subtracting the weight of feces (DM basis) from the weight of feed consumed (DM basis) and dividing the resulting value by weight of feed consumed (DM basis). This value was converted to a percent basis by multiplying by 100. The following equation was used: $\left(\frac{((DM\ Offered - DM\ Refusal) - DM\ Output)}{(DM\ Offered - DM\ Refusal)}\right) * 100$. Digestibility of NDF was calculated by multiplying the weight of feed consumed (DM basis) by the percent NDF of the ration. The resulting value was considered NDF offered. Feed refusals were analyzed for NDF as described above and the weight of feed refused (DM basis) was multiplied by the NDF content of the feed refusal to determine NDF refused. Lastly, feces were analyzed for NDF and this NDF value was used to determine NDF output. Apparent NDF digestibility was calculated using the following equation: $\left(\frac{((NDF\ Offered - NDF\ Refused) - NDF\ Output)}{(NDF\ Offered - NDF\ Refused)}\right) * 100.$

Statistical Analysis

The experimental design was a replicated 4 × 4 Latin square with a 2 × 2 factorial arrangement of treatments. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The Bayesian information criterion was used to select the compound symmetry covariance structure. The model was:

$$Y_{ijklmn} = \mu + S_i + c_{j(i)} + p_k + D_l + C_m + (DC)_{lm} + e_{ijklmn}$$

where, Y_{ijkmn} = response variable; μ = mean; S_i = the fixed effect of square; $c_{j(i)}$ = the random effect of calf nested within square; p_k = the random effect of period; D_l = the fixed effect of DGS type (DDGS or MDGS); C_m = the fixed effect of CaO addition (0% or 1.2%); $(DC)_{lm}$ = the fixed effect of the interaction of the DGS type and CaO addition; and e_{ijklmn} = the experimental error.

Individual animal was the experimental unit. Significance was declared at $P < 0.05$. Trends are discussed at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

In Exp, 1, there was no interaction ($P \geq 0.14$) of type of DGS, dry or modified, and CaO treatment on DMI, ADG, final BW, or carcass characteristics (Table 2.3). However, steers fed MDGS tended to have reduced ($P = 0.06$) DMI when compared to steers fed DDGS, though this did not affect ($P = 0.56$) G:F. Ham et al. (1994) compared diets comprised of 40% WDGS or 40% DDGS (DM basis) in feedlot cattle and discovered that gains were similar; however, cattle fed WDGS consumed less feed (DM basis) and were more efficient than cattle fed DDGS. Previous research has shown that increasing moisture in diets caused decreased DMI (Ham et al. 1993, 1994). Ham et al. (1994) explained that adding water to DDGS reduced DMI and rate of passage from the rumen. Similarly, in earlier experiments, Ham et al. (1993) discovered that adding water to other feedlot diets will reduce feed intake but maintain feed efficiency. In addition to the impacts moisture has on rate of passage, the added moisture of the MDGS may also have a conditioning effect on the diet when dry forages are fed. Garcia and Kalscheur (2007) discovered that the moisture content of WDGS can reduce separation of ingredients in a mixed ration, which can positively influence performance and efficiency of feedlot cattle. Although the DDGS diets were 13 percentage units drier than the MDGS diets, steers in Exp. 1 were fed corn husklage, a wet, fermented product, and were unlikely experiencing conditioning of the forage.

There was no main effect ($P \geq 0.36$) of CaO treatment on ADG or final BW. However, steers fed CaO treated DGS had reduced ($P < 0.01$) DMI, regardless of DGS type, when compared to steers fed untreated DGS. This is similar to previous research by Nuñez et al. (2013) where steers fed diets containing 60% DDGS had linearly reduced DMI with increasing dietary CaO, up to 2.4% of the diet DM. Because DMI was reduced without affecting ADG, steers fed CaO treated DGS had increased ($P < 0.01$) G:F when compared to steers that were not fed CaO, regardless of DGS type. Nuñez et al. (2013) found adding CaO up to 1.6% of the diet DM increased ADG and feed efficiency; however, when included at 2.4% of the diet DM, feeding CaO had no effect on ADG and gains were similar to steers fed 0% CaO.

Variation in DMI in Exp. 1 could be explained by differences in meal size and distribution (Table 2.4). Galyean (1999) explained that variable daily DMI is common in ad libitum feeding management. There were no interactions of CaO treatment and DGS type on number of meals per day, average meal size, or meal duration ($P \geq 0.34$). However, there was a DGS by CaO interaction ($P < 0.01$) for percentage of meals consumed from 0 to 3 h post-feeding. While CaO treatment had no effect on percentage of meals consumed from 0 to 3 h post-feeding in steers fed MDGS, when steers were fed DDGS, CaO treatment decreased the percentage of meals eaten from 0 to 3 h post-feeding. Furthermore, the present data suggest, CaO treatment delayed meal intake, evidenced by an increased percentage of meals consumed from 6 to 9 h post-feeding ($P < 0.01$).When steers were fed CaO, regardless of DGS type, they ate a similar number of meals ($P = 0.36$) but ate smaller meals ($P < 0.01$).

Ruminal acidosis is characterized by an accumulation of organic acids in the rumen and a subsequent reduction in rumen pH (Owens et al., 1998). This reduction in rumen pH can shift rumen microbial populations, affecting rumen fermentation and digestibility of some substrates

(Nagaraja and Titgemeyer, 2007). Previous research has explained that acidosis symptoms may be minimized by ensuring a uniform intake with smaller, more frequent meals (Britton and Stock, 1987; Pritchard and Knutsen, 1995). Therefore, part of the improvement in G:F noted in steers fed CaO could be due to a reduced risk for acidosis due to eating smaller meals spread further apart during the peak eating time (0 to 6 h post feeding). Moreover, steers fed CaO supplemented diets ate feed that was nearly 1.7 pH units higher than steers fed no CaO; which could also reduce the risk of acidosis.

In addition to CaO, moisture differences in wet versus dry DGS influence diet palatability and DMI as well (Ham et al., 1993). In this experiment, steers fed MDGS, regardless of CaO, spent less time eating each meal ($P = 0.05$); however they consumed more meals per day ($P = 0.01$), and ate smaller meals ($P < 0.01$) when compared to steers fed DDGS. Furthermore, while steers consuming MDGS consumed 1.2 more meals per day ($P = 0.01$) than steers consuming DDGS, they shifted when those meals were consumed. Steers fed MDGS, regardless of CaO treatment, consumed fewer ($P < 0.01$) meals from 6 to 9 hrs post-feeding but increased ($P \leq 0.02$) number of meals from 9 to 12 hr and 18 to 21 hr post-feeding. This shift to a more delayed meal pattern may have decreased over-eating shortly after feeding which could decrease acidosis risk. The pH of MDGS in this trial was 3.82 whereas the pH of DDGS was 4.78, suggesting steers fed the MDGS were dealing with significantly more acidity when consuming a diet of 50% MDGS compared to the diets containing 50% DDGS. Further data suggest that cattle consuming wetter diets will eat less feed (Ham et al., 1994). While overall DMI when comparing DGS type only tended to differ ($P = 0.06$) in Exp. 1, this could have been enough to cause the subtle shift in meal pattern changes recorded as a percent of meals consumed in Table 2.4.

With the effects CaO treatment and type of DGS have on steer performance, added costs from CaO treatment and cost differences in dry versus modified wet DGS make it important to analyze the economic practicality of these diets. While CaO treatment increased the ration cost, the improved G:F in steers fed CaO treated DGS equated to a $0.065 feed savings ($P < 0.01$) per kg of BW gain (Table 2.5). However, although CaO treatment reduced cost of gain, labor requirements to treat and store DGS were not factored into these experiments and may make CaO treatment impractical. Typically, MDGS offers a cost advantage over DDGS when purchased from a plant located within 40 miles of the farm as drying and transportation cost is greatly reduced (Buckner et al., 2011). Even though G:F was similar in steers fed DDGS compared to MDGS, eliminating drying costs reduced cost of gain ($P < 0.01$) for MDGS and total feed cost over the 95 d experiment ($P < 0.01$). Although costs differed, factors would need to be considered on an individual operator basis. In addition to distance from the plant, storage and handling issues should also be considered. In this trial, MDGS was treated every 3 to 7 days. Treatment varied because longevity of the product varied as temperatures fluctuated. This trial began in December 2011 and ended in March 2012. By the end of the trial, MDGS was being treated every 3 d to reduce spoilage. The pH of the original MDGS was 4.28. This low pH likely acts as a preservative for the MDGS. Treating with 1.2% CaO on a DM basis increased MDGS pH to 7.21. The shelf life of MDGS at this greater pH was reduced. If CaO treatment technologies are to be adopted, new storage applications may be needed.

While we had hypothesized that part of the improved G:F realized when CaO treated DGS are fed could be from increased ruminal pH and increased fiber digestibility, no effects ($P \geq 0.55$) of CaO treatment or its interaction with DGS type were found for total tract DM or NDF digestibility (Table 2.6). However, steers fed MDGS had an increased NDF digestibility ($P <$

0.01) when compared to steers fed DDGS. Differences in NDF digestibility have not previously been able to explain animal performance differences noted when feeding wet versus dry DGS, as much of the research in this area has produced conflicting results. Ham et al. (1994) explained that adding water to DDGS reduced DMI and rate of passage from the rumen, subsequently increasing NDF digestibility. However, Firkins et al. (1984) compared cattle fed wet versus dry DGS at 25% of the diet DM and found no differences in NDF digestibility. At the 50% dietary inclusion, as was used in this experiment, information is lacking on effects of DGS type on digestibility. The MDGS and DDGS used in these trials did come from different sources; therefore, it is difficult to predict the amount of solubles actually added back to each product and how that may affect digestibility. While fiber composition of these sources was fairly similar (Table 2.2), MDGS had less fat and a reduced pH when compared to DDGS. As discussed above in Exp. 1, steers fed MDGS shifted their meal patterns to consume more, albeit smaller, meals. Smaller more frequent meals can improve digestibility (Galyean et al., 1992); however, steers fed CaO treated DGS also had smaller meals with no effect on digestibility. Therefore, the digestibility differences noted between MDGS and DDGS in this study were likely a function of the source, plant, variation in the DGS composition and not related to intake patterns.

CONCLUSIONS

We hypothesized that addition of CaO to DGS would improve growth performance of steers, with steers fed DDGS eliciting the greatest response. In this experiment, while steers fed MDGS had increased NDF digestibility and tended to have reduced DMI, this did not equate to differences in ADG or G:F. This indicates MDGS or DDGS can be fed interchangeably with little risk of affecting animal performance. However, MDGS based diets reduced feed costs over

the 95 d experiment by nearly 20%. Because acidity of DGS can cause numerous challenges when included at 50% of the diet DM we had further hypothesized that treating DGS with CaO would neutralize the inherent acidity of DGS which subsequently could improve ruminal fiber digestibility. While no differences in fiber digestibility were realized when DGS were treated with CaO, G:F was increased. Therefore, this trial provides new information that supplementing or treating DGS with CaO reduced cost of gain over 4%, by improving feed efficiency.

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TABLES

Table 2.1. Composition of diets (DM basis) to compare dry distillers grains with solubles (DDGS) and modified wet distillers grains with solubles (MDGS) treated with 0% calcium oxide (CaO) or 1.2% CaO fed to feedlot steers in Experiment 1

		DDGS		MDGS	
Item, % DM basis	%CaO[1]	0	1.2	0	1.2
MDGS[2]		--	--	50.0	48.8
DDGS[3]		50.0	48.8	--	--
Cracked Corn		20.0	25.0	20.0	25.0
Husklage [4]		20.0	20.0	20.0	20.0
HC Supplement[5]		10.0	--	10.0	--
LC Supplement[6]		--	5.0	--	5.0
Calcium Oxide		--	1.2	--	1.2
Analyzed Composition					
NDF		28.59	27.44	24.70	24.11
ADF		14.13	13.81	14.84	14.26
CP		18.59	18.32	18.40	18.39
EE		7.22	6.85	5.56	5.49
Ca		1.00	0.95	0.94	1.06
P		0.54	0.59	0.49	0.49
S		0.27	0.29	0.36	0.35

[1] CaO (MicroCal® OF200; Mississippi Lime Company, St. Louis, MO) treatment is listed as a % of the dietary DM

[2] MDGS (ADM West Plant, Decatur, IL) analyzed values: DM: 49.0%; NDF: 28.1%; ADF: 18.8%; CP: 28.2%; EE: 8.1%; Ca: 0.05%; P: 0.73%; S: 0.55%

[3] DDGS (Aventine Renewable Energy, INC, Pekin, IL) analyzed values: DM: 86.2; NDF: 35.9%; ADF: 17.4%; CP: 28.6%; EE: 11.4%; Ca: 0.18%; P: 0.83%; S: 0.36%

[4] Husklage is ensiled corn shucks derived from seed-corn processing analyzed values: DM, 37.1%; NDF, 37.4%; ADF, 22.0%; CP, 10.3%; EE, 2.5%

[5] High-calcium (HC) vitamin and mineral supplement fed to cattle receiving 0% CaO treated diets contained 75.35% ground corn; 22.72% limestone; 0.91% dairy trace mineral salt (included: 8.5% Ca (as $CaCO_3$), 5% Mg (as MgO and $MgSO_4$), 7.6% K (as KCl_2), 6.7% Cl (as KCl_2) 10% S (as S_8, prilled), 0.5% Cu (as $CuSO_4$ and Availa-4 (Zinpro Performance Minerals; Zinpro Corp, Eden Prairie, MN)), 2% Fe (as $FeSO_4$), 3% Mn (as $MnSO_4$ and Availa-4), 3% Zn (as $ZnSO_4$ and Availa-4), 278 ppm Co (as Availa-4), 250 ppm I (as $Ca(IO_3)_2$), 150 Se (Na_2SeO_3), 2,205 KIU/kg VitA (as retinyl acetate), 662.5 KIU/kg VitD (as cholecalciferol), 22,047.5 IU/kg VitE (as DL-α-tocopheryl acetate), and less than 1% CP, fat, crude fiber, salt); 0.15% Rumensin 90 (200g/kg; Elanco, Greenfield, IN); 0.10% Tylosin 40 (88g/kg; Elanco); 0.766% fat

[6] Low-calcium (LC) vitamin and mineral supplement fed to cattle receiving 2.5% CaO treated diets contained 87.27% ground corn; 8.94% limestone; 1.79% dairy trace mineral salt; 0.30% Rumensin 90; 0.20% Tylosin 40; 1.51% fat

Table 2.2 Composition of diets to compare dry distillers grains with solubles (DDGS) and modified wet distillers grains with solubles (MDGS) treated with 0% calcium oxide (CaO) or 1.2% CaO (DM basis) fed to metabolism steers in Experiment 2

		DDGS		MDGS	
Item, % DM basis	%CaO[1]	0	1.2	0	1.2
MDGS[2]		--	--	50.0	48.8
DDGS[3]		50.0	48.8	--	--
Cracked Corn		20.0	25.0	20.0	25.0
Husklage[4]		20.0	20.0	20.0	20.0
HC Supplement[5]		10.0	--	10.0	--
LC Supplement[6]		--	5.0	--	5.0
Calcium Oxide		--	1.2	--	1.2
Analyzed Composition					
NDF		26.81	26.75	25.77	25.73
ADF		13.42	13.26	14.45	14.26
CP		21.56	21.40	21.56	21.41
EE		6.74	6.63	5.84	5.75
Ca		1.10	1.23	1.12	1.25
P		0.51	0.51	0.49	0.49
S		0.25	0.23	0.42	0.40
Dietary pH		4.93	6.98	4.70	6.30

[1] CaO (MicroCal® OF200; Mississippi Lime Company, St. Louis, MO) supplement is listed as a % of the dietary DM

[2] MDGS (ADM West Plant, Decatur, IL) analyzed values: DM: 49.0%; NDF: 32.3%; ADF: 20.1%; CP: 29.3%; EE: 8.27%; Ca: 0.09%; P: 0.69%; S: 0.67%; pH: 4.28

[3] DDGS (Aventine Renewable Energy, INC, Pekin, IL) analyzed values: DM: 84.4%; NDF: 34.4%; ADF: 18.1%; CP: 29.3%; EE: 10.1%; Ca: 0.05%; P: 0.75%; S: 0.31%; pH: 5.05

[4] Husklage is ensiled corn shucks derived from seed-corn processing. Analyzed values: DM, 34.0%; NDF, 30.6%; ADF, 13.3%; CP, 11.4%; EE, 3.4%

[5] High-calcium (HC) vitamin and mineral supplement fed to cattle receiving 0% CaO treated diets contained 75.35% ground corn; 22.72% limestone; 0.91% dairy trace mineral salt (included: 8.5% Ca (as $CaCO_3$), 5% Mg (as MgO and $MgSO_4$), 7.6% K (as KCl_2), 6.7% Cl (as KCl_2) 10% S (as S_8, prilled), 0.5% Cu (as $CuSO_4$ and Availa-4 (Zinpro Performance Minerals; Zinpro Corp, Eden Prairie, MN)), 2% Fe (as $FeSO_4$), 3% Mn (as $MnSO_4$ and Availa-4), 3% Zn (as $ZnSO_4$ and Availa-4), 278 ppm Co (as Availa-4), 250 ppm I (as $Ca(IO_3)_2$), 150 Se (Na_2SeO_3), 2,205 KIU/kg VitA (as retinyl acetate), 662.5 KIU/kg VitD (as cholecalciferol), 22,047.5 IU/kg VitE (as DL-α-tocopheryl acetate), and less than 1% CP, fat, crude fiber, salt); 0.15% Rumensin 90 (200g/kg; Elanco, Greenfield, IN); 0.10% Tylosin 40 (88g/kg; Elanco); 0.766% fat

[6] Low-calcium (LC) vitamin and mineral supplement fed to cattle receiving 2.5% CaO treated diets contained 87.27% ground corn; 8.94% limestone; 1.79% dairy trace mineral salt; 0.30% Rumensin 90; 0.20% Tylosin 40; 1.51% fat

Table 2.3. Effects of feeding dry (DDGS) and modified wet (MDGS) distillers grains with solubles treated with 0% calcium oxide (CaO) or 1.2% CaO (DM basis) to beef steers on feedlot performance characteristics in Experiment 1

	DDGS		MDGS			*P*-value [2]		
Item %CaO[1]	0	1.2	0	1.2	SEM	D	C	D x C
Initial BW, kg	344	341	343	341	3.65	0.93	0.57	0.90
Final BW, kg	530	530	529	521	6.09	0.38	0.50	0.53
DOF[3]	95	95	95	95	-	-	-	-
ADG, kg	1.96	1.99	1.96	1.89	0.05	0.28	0.66	0.36
DMI, kg d^{-1}	11.5	11.0	11.3	10.3	0.22	0.06	<0.01	0.27
G:F	0.1704	0.1809	0.1734	0.1835	0.004	0.56	<0.01	0.82
USDA Yield Grade								
1, %	5.7	11.8	14.3	5.9	0.73	0.84	0.88	0.14
2, %	31.4	29.4	31.4	41.2	0.38	0.47	0.65	0.47
3, %	60.0	58.8	51.4	52.9	0.35	0.39	0.99	0.87
4, %	2.9	0	2.9	0	1.01	1.00	0.10	1.00
USDA Quality Grade								
Choice, %	62.9	58.8	45.7	58.9	0.35	0.31	0.60	0.31
Select, %	28.6	35.3	51.4	41.2	0.37	0.08	0.88	0.31
HCW, kg	324	330	320	321	4.78	0.72	0.68	0.52

[1] CaO treatment is listed as a % of the dietary DM
[2] D = the main effect of type of distillers grains, C = main effect of CaO treatment, and D x C = the interaction of distillers grains type x CaO
[3] Days on feed

Table 2.4. Intake distribution of steers fed dry (DDGS) and modified wet (MDGS) distillers grains with solubles treated with 0% calcium oxide (CaO) or 1.2% CaO (DM basis) in Experiment 1

	DDGS		MDGS			*P*-value [2]		
Item %CaO [1]	0	1.2	0	1.2	SEM	D	C	D x C
Meals per day	18.36	18.83	19.57	19.98	0.49	0.01	0.36	0.95
Meal size, kg	0.61	0.58	0.55	0.48	0.02	< 0.01	< 0.01	0.34
Meal Duration, min[3]	6.5	6.8	6.1	6.4	0.24	0.05	0.23	0.93
Percentage of meals consumed								
0-3h[4]	28.3	24.8	25.8	25.6	0.54	0.08	<0.01	<0.01
3-6h	23.8	23.8	23.0	24.4	0.46	0.62	0.16	0.20
6-9h	14.9	17.8	13.5	15.6	0.41	<0.01	<0.01	0.27
9-12h	7.1	7.6	8.4	7.9	0.28	<0.01	0.99	0.12
12-15h	6.9	7.3	7.7	7.4	0.26	0.07	0.67	0.25
15-18h	4.3	4.4	4.5	4.6	0.23	0.22	0.99	0.87
18-21h	7.4	6.9	8.8	7.3	0.43	0.02	0.02	0.35
21-24h	7.2	7.2	8.1	7.1	0.40	0.31	0.25	0.20

[1] CaO supplement is listed as a % of the dietary DM

[2] D = the main effect of type of distillers grains, C = main effect of CaO treatment, and D x C = the interaction of distillers grains type x CaO

[3] Average time eating per meal

[3] Hour post-feeding

[4] Values reported as a percentage of total meals

Table 2.5. Effects of feeding dry (DDGS) and modified wet (MDGS) distillers grains with solubles treated with 0% calcium oxide (CaO) or 1.2% CaO (DM basis) on feed costs in Experiment 1

	DDGS		MDGS			*P*-value [2]		
Item %CaO[1]	0	1.2	0	1.2	SEM	D	C	D x C
Feed Expense								
Ration, $/metric ton of DM	$277	$280	$232	$236	-	-	-	-
Cost of Gain, $/ kg of BW gain	$1.63	$1.55	$1.34	$1.29	0.006	<0.01	<0.01	0.88
Total Feed, $/ steer [3, 4]	$303	$293	$249	$231	3.89	<0.01	<0.01	0.37

[1] CaO treatment is listed as a % of the dietary DM

[2] D = the main effect of type of distillers grains , C = main effect of CaO treatment, and D x C = the interaction of distillers grains type x CaO

[3] Total feed cost per steer for the duration of the 95d experiment

[4] Ingredient prices per kg of DM: DDGS $0.31; MDGS $0.22; Husklage $0.17; Corn $0.28; High Calcium Supplement $0.32; Low Calcium Supplement $ 0.40; CaO $0.41

Table 2.6. Total tract apparent digestibility in steers fed dry (DDGS) and modified wet (MDGS) distillers grains with solubles supplemented with 0% calcium oxide (CaO) or 1.2% CaO (DM basis) in Experiment 2

		DDGS		MDGS			*P* value [2]		
Item	%CaO[1]	0	1.2	0	1.2	SEM	D	C	D x C
DMD[3], %		71.1	73.0	73.6	73.7	1.58	0.31	0.55	0.58
NDF digestibility, %		60.42	63.08	70.11	69.52	2.68	< 0.01	0.70	0.55

[1] CaO supplement is listed as a % of the dietary DM

[2] D = the main effect of type of distillers grains, C = main effect of CaO treatment, and D x C = the interaction of distillers grains type x CaO

[3] DMD = DM digestibility of the diet

CHAPTER 3: EFFECTS OF FEEDING DRY OR MODIFIED WET DISTILLERS GRAINS WITH SOLUBLES WITH OR WITHOUT SUPPLEMENTAL CALCIUM OXIDE ON RUMINAL METABOLISM AND MICROBIAL ENZYMATIC ACTIVITY OF BEEF CATTLE

ABSTRACT

Objectives of this study were to determine the interaction of feeding dry (**DDGS**) or modified wet (**MDGS**) distillers grains with solubles with or without supplemental CaO on in situ DM and NDF disappearance; ruminal pH, VFA, and methane concentration; and cellulase and xylanase activity. Fistulated steers (n = 8; average initial BW = 540 kg ± 250 kg) were used in a replicated 4 × 4 Latin square design. Treatments were arranged in a 2 × 2 factorial and steers were randomly allotted to 1 of 4 dietary treatments: (1) 50% DDGS with 0% CaO, (2) 48.8% DDGS supplemented with 1.2% CaO, (3) 50% MDGS with 0% CaO, or (4) 48.8% MDGS supplemented with 1.2% CaO. The remainder of the diet was husklage, dry rolled corn, and vitamin and mineral supplement. There were no interactions ($P \geq 0.12$) of DGS type and CaO addition on any parameters measured. Steers fed DDGS had a 17% increase ($P < 0.01$) in DMI compared to steers fed MDGS; however, CaO supplementation reduced ($P = 0.03$) DMI by 12%, regardless of DGS type. As expected, addition of CaO increased the pH of the diet 1.82 pH units. This caused a time by CaO interaction ($P = 0.05$) for ruminal pH. Regardless of DGS type, steers supplemented with CaO tended to have increased ($P = 0.09$) ruminal pH at 1.5 h and had increased ($P = 0.03$) ruminal pH at 3 h post-feeding; however, ruminal pH did not differ ($P \geq 0.24$) the remainder of the day. There was no difference ($P = 0.46$) in ruminal cellulase activity when comparing type of DGS fed. However, there was a time by CaO interaction ($P < 0.01$);

cattle fed 1.2% CaO diets had 28% greater ruminal cellulase activity only at 0 h post-feeding when compared to cattle fed 0% CaO. Furthermore, feeding supplemental CaO increased (P = 0.04) A:P regardless of type of DGS fed. Increased initial ruminal pH and cellulase activity from supplemental CaO did not increase (P = 0.48) in situ NDF disappearance. No differences ($P \geq$ 0.48) in ruminal methane concentration were found when comparing DGS type or supplemental CaO. In conclusion, type of DGS fed had little effect on ruminal metabolism. Even though CaO increased ruminal pH and cellulase activity at some times post-feeding, it was not enough to affect in situ fiber disappearance.

Keywords: (beef cattle, calcium oxide, distillers grains)

INTRODUCTION

At nearly 3 times the fat and protein concentrations of corn, distillers grains with solubles (**DGS**) are a nutrient dense, alternative feedstuff for cattle (Lardy, 2007; Loy and Strohbehn, 2007; Klopfenstein et al., 2008). However, sulfuric acid content of DGS (Felix and Loerch, 2011), acidic ruminal pH associated with feeding DGS (Loy et al., 2007; Felix and Loerch, 2011), and performance differences between dry DGS (**DDGS**) and wet DGS (Ham et al., 1994) present challenges when adding DGS to cattle diets. Cattle fed 60% DDGS-based diets had decreased ruminal pH from 6.04 pre-feeding to 5.09 at 1.5 h post-feeding, and ruminal pH remained below 5.0 from 3 h to 12 h post-feeding (Felix and Loerch, 2011). Ruminal pH below 5.5 is indicative of sub-acute ruminal acidosis (Owens et al., 1998). Acidotic animals have reduced nutrient absorption, variable feed intake, and depressed performance (Owens et al. 1998). Acidic ruminal pH can also shift rumen microbial populations, affecting rumen fermentation and digestibility (Nagaraja and Titgemeyer, 2007). Optimum fiber digestion in the

rumen occurs between pH 6.0 and 6.7 (Mould et al., 1983). As much of the energy in DGS-based diets comes from fiber in DGS, it is imperative to control pH to optimize fiber digestion in the rumen. Treating DDGS with NaOH prior to feeding improves in situ fiber digestibility (Felix et al., 2012); however, ruminal metabolism in cattle fed wet versus dry DGS with added CaO has not yet been investigated. We hypothesize that supplementing DDGS and modified wet distillers with solubles (**MDGS**) -based diets with CaO prior to feeding would improve ruminal fiber digestibility, and increase ruminal pH and microbial activity, with DDGS showing the greatest improvements. Therefore, objectives of this study were to determine the interaction of feeding DDGS or MDGS with or without supplemental CaO on in-situ DM and NDF disappearance; ruminal pH, VFA and methane concentrations; and cellulase and xylanase activity.

MATERIALS AND METHODS

All animal procedures were approved by the University of Illinois Institute of Animal Care and Use Committee and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Animal and Diet Management

Four Angus × Simmental crossbred steers (average initial BW = 635 ± 50 kg) and 4 Angus × Simmental crossbred steers (average initial BW = 450 ± 40 kg), previously fitted with rumen cannula, were blocked by BW (large and small block) and used in a replicated 4 × 4 Latin square design. Steers were housed in metabolism stalls at the University of Illinois Beef Cattle and Sheep Field Research Laboratory in Urbana, IL. Stalls (2.3 x 1.3 m) are equipped with individual feed bunks and non-siphoning automatic water bowls. The barn is equipped with a

heating, ventilation, and air-conditioning system, providing a controlled environment set at 18.3° C. There was a 2 × 2 factorial arrangement of treatments and steers were assigned to 1 of 4 dietary treatments: (1) 50% DDGS with 0% CaO, (2) 48.8% DDGS supplemented with 1.2% CaO, (3) 50% MDGS with 0% CaO, or (4) 48.8% MDGS supplemented with 1.2% CaO. The remainder of the diet was 20% husklage, 20% dry rolled corn, and a vitamin and mineral supplement (DM basis, Table 3.1). Supplementation with CaO occurred daily by mixing into the ration. Dietary treatment sequence was assigned according to procedures outlined by Patterson and Lucas (1962). To maintain dietary Ca across treatments, cattle fed diets supplemented with CaO were fed a reduced Ca supplement, while cattle fed diets without CaO received an elevated Ca supplement. Cattle were fed once daily for ad-libitum intake.

Sampling and Analysis

Sampling periods were 21 d beginning with a 14 d acclimation phase followed by a 7 d collection phase (included a 5 d digestibility collection (Schroeder et al. unpublished data), a 1 d rumen fluid collection and a 1 d in-situ incubation phase. After each sampling period, steers were re-inoculated with rumen contents from the initial collection (4 L) before being transitioned to the next experimental diet.

Individual dietary ingredient and feed refusal samples were collected and weighed daily over the 5 d digestibility collection. Individual ingredient samples were then analyzed for DM (24 h at 105°C). Wet dietary ingredient samples were composited within period and freeze-dried (FreeZone, Labconco, Kansas City, MO), then ground through a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA). Ground dietary ingredient samples were analyzed for ADF and NDF (using Ankom Technology method 5 and 6, respectively; Ankom^{200} Fiber Analyzer, Ankom Technology, Macedon, NY), CP (Leco TruMac, LECO Corporation, St. Joseph, MI), fat

(ether extract method; Ankom Technology), and total ash (500° C for 12 h, HotPack Muffle Oven Model: 770750, HotPack Corp., Philadephia, PA). The resulting values were used to calculate nutrient composition of the diets. Dietary ingredient composites were subjected to perchloric acid digestion and inductively coupled plasma atomic emission spectroscopy analysis of complete minerals (method 975.03: AOAC, 1988). Composited ingredients were also analyzed for pH using an Accumet® Basic AB15 pH meter with an Accumet® accuCap glass body, gel-filled electrode (Fisher Scientific, Pittsburg, PA). Fifty g of each dietary ingredient was mixed with 200 mL of distilled water for 30 s before the pH electrode was submersed in the mixture and pH was recorded. The solution was then titrated with 1 *M* NaOH to a final pH of 7.0 and mL of NaOH used was recorded. The resulting values were used to determine total dietary pH and titratable acidity. Feed refusal (10% as-is) samples were also collected for 5 d of the 7 d collection phase. Feed refusals were analyzed for DM, NDF and ADF as described above.

On d 6 of each collection, rumen pH was measured by collecting whole, mixed rumen content via rumen cannula at 0, 1.5, 3, 6, 9, and 12 h post-feeding. Rumen samples were then filtered through 2 layers of cheesecloth and immediately analyzed for pH using a FiveEasy™ FiveGo™ pH meter FE20/FG2 with a LE438 polyoxymethylene body gel-filled electrode with Ag/AgCl reference system and 1.2m; BNC/Cinch connection (Mettler Toledo, Columbus, OH).

Rumen fluid samples for VFA analysis were collected at 0 and 3 h post-feeding. Samples were strained through 2 layers of cheesecloth and 50 to 75 mL of rumen fluid was mixed with 10 mL of H_3PO_4 and deionized water was added to achieve a 2:1 dilution (by weight). The mixture was then placed in a refrigerator and remixed by shaking several times per day for 2 d. On d 3, samples were removed from the refrigerator and 40 mL of diluted rumen fluid was centrifuged at 20,000 × g at 25°C for 20 min. Supernatant was filtered through a 0.45 µm filter. Filtered sample

was then transferred in 1-mL aliquots to gas chromatography vials with 0.1 mL of 2-ethyl butyrate as an internal standard. Vials were then stored at -20°C until analyzed via gas-chromatography (**GC**; Model 5890A, Hewlett-Packard, Palo Alto, CA) for VFA.

Ruminal methane (**CH_4**) concentration was analyzed by sampling rumen gas via cannula puncture with an 18 gauge needle. The gas was collected at 3 h post-feeding and CH_4 concentration was measured via GC (Gow-Mac 580TCD with a silica gel 60/80 mesh column, Gow-Mac Instrument Co., Bethlehem, PA). Nitrogen was used as a carrier gas with a flow rate of 60 mL per minute.

Cellulase and xylanase activity of whole rumen contents were analyzed by collecting whole, mixed rumen content at 0 and 3 h post-feeding. Whole rumen contents (60 to 70 mL) were placed in a 75 mL conical centrifuge tube and immediately frozen at -80° C for later analysis. Frozen samples were thawed for 24 h at 4° C then centrifuged for 20 minutes at 12,000 × g for 20 min. Supernatant was filtered through a 0.45-µm filter and centrifuged again at 5,000 × g for 15 min in an Amicon Ultra-15 10K centrifugal filter to concentrate the sample. The sample (40 µL) was pipetted into PCR plates containing either 90 µL 1% (wt/vol) carboxymethylcellulose (**CMC**; made by adding 10 mg CMC powder per mL of 0.05 M sodium phosphate and 0.15 M sodium chloride buffer with pH of 6.0) to determine cellulase activity or 90 µL 1% (wt/vol) wheat-arabinoxylan (**WAX**; made by adding 10 mg WAX powder per mL of 0.05 M sodium phosphate and 0.15 M sodium chloride buffer with pH of 6.0) to determine xylanase activity. Plates were then incubated at 37°C for 0, 7, or 15 min to allow enzymatic breakdown of CMC or WAX into glucose. After incubation, plates were boiled at 100°C for 10 minutes to cease further enzymatic degradation of substrate and cooled to 25°C. The concentration of glucose equivalents was subsequently quantified with the *para*-hydroxybenzoic

acid hydrazide (***p*HBAH**) method as described previously (Lever, 1972). Rate of glucose equivalents released was determined for each sample using values from 0, 7, and 15 min incubations.

Rumen fiber degradation was estimated by the NDF disappearance of soybean hulls (**SBH**) in situ. Four replicate dacron bags (Ankom Technology, 10 × 20 cm) containing SBH were used for incubation in the rumen. Bags were tied shut with nylon string and then placed in larger mesh sacs with weights. These larger sacs were placed in the rumen on d 7 of the collection phase. After a 24 h incubation, bags were removed, rinsed, and dried at 55°C for 3 d. Following drying, samples were weighed to determine DM and ground to be analyzed for NDF (using Ankom Technology method 5). In addition, 4 bags were used to determine the "washout" (0 h) value of SBH from the in situ bags. These bags were not placed in the rumen but were subjected to the same rinsing and drying procedures as the incubated bags. To determine in-situ disappearance the following equation was used (DM basis):

$$\left(1 - \left(\frac{weight\ of\ SBH\ before\ incubation}{weight\ of\ SBH\ after\ incubation}\right) \times 100)\right) - \left(1 - \left(\frac{weight\ of\ SBH\ \ before\ washout}{weight\ of\ SBH\ \ after\ washout}\right) \times 100\right)$$

. To determine NDF disappearance, weight of SBH NDF was used in the same equation

Statistical Analysis

The experimental design was a replicated 4 × 4 Latin Square. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Repeated measures were used to analyze ruminal pH and VFA concentrations, and cellulase and xylanase activity. The model was:

$$Y_{ijklmno} = \mu + S_i + c_{j(i)} + p_k + D_l + C_m + (DC)_{lm} + T_n + (TD)_{ln} + (TC)_{nm} + (TDC)_{lmn} + e_{ijklmno}$$

where, Y_{ijkmno} = response variable; μ = mean; S_i = the fixed effect of square; $c_{j(i)}$ = the random effect of calf nested within square; p_k = the random effect of period; D_l = the fixed effect of DGS type (dry or modified wet); C_m = the fixed effect of CaO addition (0% or 1.2%); $(DC)_{lm}$ = the fixed effect of the interaction of the DGS type and CaO addition; T_n = the fixed effect of repeated time of collection; $(TD)_{ln}$ = the fixed effect of the interaction of time of collection and DGS type; $(TC)_{nm}$ = the fixed effect of the interaction of time of collection and CaO addition; $(TDC)_{lnm}$ = the fixed effect of the interaction of time of collection and DGS type and CaO addition; and $e_{ijklmno}$ = the experimental error.

Ruminal methane concentration and in situ DM and NDF disappearance were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The model was:

$$Y_{ijklmn} = \mu + S_i + c_{j(i)} + p_k + D_l + C_m + (DC)_{lm} + e_{ijklmn}$$

where, Y_{ijklmn} = response variable; μ = mean; S_i = the fixed effect of square; $c_{j(i)}$ = the random effect of calf nested within square; p_k = the random effect of period; D_l = the fixed effect of DGS type (dry or modified wet); C_m = the fixed effect of CaO addition (0% or 1.2%); $(DC)_{lm}$ = the fixed effect of the interaction of the DGS type and CaO addition; and e_{ijklmn} = the experimental error.

For both models, individual animal was the experimental unit. There were no interactions of DGS type and CaO addition ($P \geq 0.12$); therefore, only main effects will be discussed. Significance is declared at $P \leq 0.05$. Trends are discussed at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Despite the fact that diets containing MDGS were 0.45 pH units more acidic than diets containing DDGS (Table 3.2), there was no effect ($P = 0.21$) of DGS type on ruminal pH (Figure 3.1). There was a time by CaO interaction ($P = 0.05$) for ruminal pH. Steers fed CaO tended to have elevated ($P = 0.09$) ruminal pH at 1.5 h (6.10 compared to 5.92 for 1.2 and 0% CaO, respectively) and had elevated ($P = 0.03$) ruminal pH at 3 h post-feeding (5.99 compared to 5.75 for 1.2 and 0% CaO, respectively). However, steers fed 1.2% CaO had a similar ($P \geq 0.24$) ruminal pH to cattle fed 0% CaO at 0, 6, 9, and 12 h post-feeding. This could be explained in part by dietary pH. Diets containing supplemental CaO had 1.82 units greater ($P < 0.01$) pH than diets that did not contain CaO. The increase in pH of feed entering the rumen may have buffered initial ruminal pH in steers fed CaO supplemented diets. Despite the time differences, CaO addition did not affect mean ($P = 0.21$) ruminal pH (6.02 for 1.2% CaO and 5.91 for 0% CaO). Felix et al. (2012) compared 25% and 60% DDGS treated with 0% or 2% NaOH and found that neutralizing the acid in DDGS with NaOH prior to feeding increased mean ruminal pH.

While we had hypothesized that cellulase and xylanase activity would be affected by changes in ruminal pH. Although there were no differences ($P \geq 0.13$) when comparing DGS type or CaO addition on xylanase activity (Table 3.3), there was a time post-feeding by CaO addition interaction ($P < 0.01$) for cellulase activity. At 0 h post-feeding, steers fed 1.2% CaO diets had greater ($P = 0.02$) cellulase activity in rumen contents than cattle fed 0% CaO, but by 3 h post-feeding cellulase activity was not different ($P = 0.59$) between CaO inclusions. Despite increasing dietary pH as well as ruminal pH and cellulase activity at certain times, in the present study, addition of CaO decreased ($P = 0.05$) DM disappearance (**DMD**) of SBH in situ by approximately 13% (Table 3.2). The DMD of SBH in situ in the present experiment was greater

than reported by Felix et al. (2012) when they fed 60% DDGS-based diets with or without NaOH; however, they reported a 51% increase in 24 h in situ NDF disappearancewhen cattle were fed 2% NaOH compared to those fed 0% NaOH. In this trial, although CaO decreased DMD of SBH in situ, NDF disappearance was not affected ($P \geq 0.48$) by treatment.

One reason for the conflicting results in the current study when compared to Felix et al. (2012) could be the different alkaline agents used in each experiment. Felix et al. (2012) used 1 M NaOH, a stronger base ($pK_a = 13.2$), compared to CaO ($pK_a = 12.4$) used in the present study. However, although Felix et al. (2012) also used a greater concentration of alkaline agent in the diet than was used in this experiment (2% of diet DM compared to 1.2%, respectively), CaO supplemented diets in the current trial had a greater pH than NaOH treated 60% DDGS diets in the Felix et al. (2012) trial (6.63 versus 5.96, respectively), likely a result of the greater initial starting pH of the DGS used in the current trial. Mould et al. (1983) described that, for optimum cellulose metabolism in the rumen, a pH range of 6.0 to 6.7 should be maintained because bacterial species that contribute to fiber digestion in the rumen are greatly impeded at ruminal pH below 6.0. In this experiment, no cattle experienced ruminal pH below 5.6 and the average ruminal pH was 6.0, whereas, Felix et al. (2012) observed that ruminal pH was below 5.3 for 12 h. Rumen environment greatly influences the success of cellulolytic bacteria that produce cellulase (Hungate, 1966). Stewart (1977) experimented in vitro with cellulose disappearance from rumen contents at various pH and discovered that a pH reduction from 6.6 to 5.2 decreased cellulose disappearance by 31%. While numerous studies confirm that ruminal pH and carbohydrate solubility greatly impact fiber digestion in the rumen (Huhtanen and Khalili, 1992, Mould et al., 1983; Rooke et al., 1987) few studies have examined hemicellulolytic bacteria activity in *DGS-based* diets.

One of the biggest differences in the 2 trials, however, is the method of alkaline agent delivery. Felix et al. (2012) treated batches of DDGS weekly instead of supplementing the alkaline agent to the diet. A plethora of previous data supports the theory that pre-treating fibrous feeds will increase fiber digestibility (Berger et al., 1979; Kim and Holtzapple, 2006; Kong et al., 1992); however, most of this work theorizes that the improvement occurs because lignin and hemicellulose bonding is disrupted. While the lignin content of DGS is reportedly minimal (4.35 to 10% of the NDF; NRC 1996), there has not been any research to date on the efficacy of treating versus supplementing alkaline agents for cattle fed DGS-based diets.

Because of the fiber content of DGS, we had hypothesized that increasing the pH of the diet would improve rumen fermentation; however, there was no CaO by time interaction ($P \geq 0.24$) on ruminal VFA concentrations (Table 3.4). In addition, there was no effect of DGS type ($P \geq 0.25$) or its interaction with time ($P \geq 0.06$) on ruminal VFA concentrations. There was a tendency ($P = 0.07$) for decreased ruminal propionate concentration when CaO was added to the diet which increased A:P ($P = 0.04$), regardless of type of DGS fed. But, acetate and total ruminal VFA at 3 h post-feeding were not different ($P \geq 0.22$) when comparing steers fed 0% with those fed 1.2% CaO. Although most of the energy in DGS is in the form of fiber, cattle consuming DGS-based diets have a much different VFA profile than cattle consuming traditional fiber-based diets (Leupp et al., 2009). Cattle consuming forage-based diets typically have a VFA profile of 65 to 70% acetate, 15 to 25% propionate, and 5 to 10% butyrate (Fluharty, 2009). However, when cattle are fed grain-based diets VFA profile is approximately 50 to 60% acetate, 35 to 40% propionate, and 5 to 10% butyrate (Fluharty, 2009). Ruminal VFA profiles in this experiment are more similar to cattle fed grain-based diets with approximately 55% acetate, 33% propionate, and 14% butyrate at 3 h post-feeding, despite the 50% dietary inclusion of DGS

which elevated dietary fiber concentrations. Ruminal VFA concentrations in this experiment were similar to previous research where cattle were fed 60% DDGS diets and had approximately 57% acetate, 22% propionate, and 14% butyrate at 3 h post-feeding (Leupp et al., 2009).

Similar to its effects on other aspects of ruminal fermentation previously mentioned, decreasing ruminal pH decreases the activity of methanogenic archaea, and subsequently reduces ruminal methane emissions (Moe and Tyrrell, 1979). We had hypothesized, therefore, that the acidic ruminal pH associated with DGS-based diets (Felix and Loerch, 2011) would decrease methane production and that CaO addition would raise ruminal pH, altering ruminal fermentation as discussed above, subsequently increasing methane concentrations. However, no differences ($P \geq 0.48$) were found in methane concentration when comparing steers fed 0% CaO to steers fed 1.2% CaO or when comparing steers fed MDGS to steers fed DDGS-based diets (Figure 3.2). Behlke et al. (2007) conducted in vitro experiments replacing forage with DDGS as an energy source and found that increasing DDGS in rumen fluid in vitro resulted in decreased methane production. However, when corn was replaced with DDGS in vitro, methane production increased as DDGS inclusion increased (Behlke et al., 2008). While dietary DGS inclusions were not varied in the present study, the ruminal pH was increased with 1.2% CaO inclusion in the diet with no effect on methane concentrations.

CONCLUSIONS

Sulfuric acid content of DGS and acidic rumen pH associated with feeding DGS can make including DGS in beef cattle diets challenging. Acidic ruminal pH, even for a short time, can shift rumen microbial populations and decrease fiber digestibility. As much of the energy in DGS-based diets comes from the fiber in DGS, it is important to control rumen pH to ensure

successful fiber digestion in the rumen. In this experiment, adding CaO in DGS-based diets neutralized the acidity in DGS and increased rumen pH at some timepoints. However, increased ruminal pH did not successfully increase fiber disappearance in situ. Further research investigating greater dietary inclusions of CaO may be necessary to improve utilization of DGS in beef cattle diets.

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TABLES AND FIGURES

Table 3.1. Composition of diets supplementing 0% calcium oxide (CaO) or 1.2% CaO (DM basis) to steers fed dry (DDGS) or modified wet (MDGS) distillers grains with solubles based diets on a DM basis

		DDGS		MDGS	
Item, % DM basis	%CaO[1]	0	1.2	0	1.2
MDGS[2]		--	--	50.0	48.8
DDGS[3]		50.0	48.8	--	--
Cracked Corn		20.0	25.0	20.0	25.0
Husklage [4]		20.0	20.0	20.0	20.0
HC Supplement[5]		10.0	--	10.0	--
LC Supplement[6]		--	5.0	--	5.0
Calcium Oxide		--	1.2	--	1.2
Analyzed Composition					
NDF		28.59	27.44	24.70	24.11
ADF		14.13	13.81	14.84	14.26
CP		18.59	18.32	18.40	18.39
EE		7.22	6.85	5.56	5.49
Ca		1.00	0.95	0.94	1.06
P		0.54	0.59	0.49	0.49
S		0.27	0.29	0.36	0.35

[1] CaO (MicroCal OF200; Mississippi Lime Company, St. Louis, MO) treatment is listed as a % of the dietary DM

[2] MDGS (ADM West Plant, Decatur, IL) analyzed values: DM, 49.0%; NDF, 28.1%; ADF, 18.8%; CP, 28.2%; EE, 8.1%; Ca, 0.05%; P, 0.73%; S, 0.55%; pH, 3.82

[3] DDGS (Aventine Renewable Energy, INC, Pekin, IL) analyzed values: DM, 84.4, ; NDF, 35.9%; ADF, 17.4%; CP, 28.6%; EE, 11.4%; Ca, 0.18%; P, 0.83%; S, 0.36%; pH, 4.78

[4] Husklage is ensiled corn shucks derived from seed-corn processing analyzed values: DM, 34.0%; NDF, 28.7%; ADF, 12.5%; CP, 11.4%; EE, 3.4%

[5] High-calcium (HC) vitamin and mineral supplement fed to cattle receiving 0% CaO treated diets contained 75.35% ground corn; 22.72% limestone; 0.91% dairy trace mineral salt (included: 8.5% Ca (as $CaCO_3$), 5% Mg (as MgO and $MgSO_4$), 7.6% K (as KCl_2), 6.7% Cl (as KCl_2) 10% S (as S_8, prilled), 0.5% Cu (as $CuSO_4$ and Availa-4 (Zinpro Performance Minerals; Zinpro Corp, Eden Prairie, MN)), 2% Fe (as $FeSO_4$), 3% Mn (as $MnSO_4$ and Availa-4), 3% Zn (as $ZnSO_4$ and Availa-4), 278 ppm Co (as Availa-4), 250 ppm I (as $Ca(IO_3)_2$), 150 Se (Na_2SeO_3), 2,205 KIU/kg VitA (as retinyl acetate), 662.5 KIU/kg VitD (as cholecalciferol), 22,047.5 IU/kg VitE (as DL-α-tocopheryl acetate), and less than 1% CP, fat, crude fiber, salt); 0.15% Rumensin 90 (200g/kg; Elanco, Greenfield, IN); 0.10% Tylosin 40 (88g/kg; Elanco); 0.766% fat

[6] Low-calcium (LC) vitamin and mineral supplement fed to cattle receiving 2.5% CaO treated diets contained 87.27% ground corn; 8.94% limestone; 1.79% dairy trace mineral salt; 0.30% Rumensin 90; 0.20% Tylosin 40; 1.51% fat

Table 3.2. Effects of supplementing 0% calcium oxide (CaO) or 1.2% CaO (DM basis) to steers fed dry (DDGS) or modified wet (MDGS) distillers grains with solubles based diets on DM intake, and in situ digestibility in steers

						P-value [1]	
Item	DDGS	MDGS	0% CaO	1.2% CaO	SEM	D	C
DMI, kg	9.82	8.13	9.57	8.38	0.37	<0.01	0.03
Dietary pH	5.95	5.50	4.81	6.63	0.08	<0.01	<0.01
NaOH to buffer dietary acidity[2], mL/g	0.17	0.21	0.29	0.08	0.01	<0.01	<0.01
NaOH to buffer dietary acidity[3], L/d	1.62	1.77	2.77	0.62	0.08	0.21	<0.01
SBH DMD[4], %	27.0	26.6	28.7	25.0	1.24	0.83	0.05
NDF Disappearance of SBH, %	22.2	22.6	23.1	21.7	1.39	0.86	0.48

[1] D = the main effect of distiller grains (DGS) type; C = main effect of CaO treatment. There was no interaction ($P > 0.12$) of D × C.

[2] mL of 1 M NaOH needed to titrate 1 g of the diet to pH 7.00

[3] L of 1 M NaOH needed to titrate daily DMI to pH 7.00

[4] SBH DMD = in situ dry matter disappearance of soybean hulls (SBH)

Table 3.3. Effects of supplementing 0% calcium oxide (CaO) or 1.2% CaO (DM basis) to steers fed dry (DDGS) or modified wet (MDGS) distillers grains with solubles based diets on cellulase and xylanase activity in whole rumen contents

						P-value [2]			
Item	DDGS	MDGS	0% CaO	1.2% CaO	SEM	D	C	D x T	CxT
Cellulase Activity [3]					0.004	0.46	0.26	0.52	< 0.01
0[4]	0.049	0.043	0.039	0.054			0.02		
3	0.047	0.045	0.048	0.044			0.59		
Xylanase Activity					0.012	0.46	0.13	0.73	0.16
0	0.148	0.156	0.133	0.171					
3	0.137	0.152	0.139	0.150					

[1] CaO treatment is listed as a % of the dietary DM

[2] The *P*- values in the row with the enzyme name are from the repeated-measures model, where D = the main effect of distillers grains (DGS) type, C = the main effect of CaO treatment, D x T = the interaction of DGS × Time, and C x T = the interaction of CaO × Time. There was no interaction ($P \geq 0.70$) for D × C. When an interaction of C × T occurred ($P < 0.05$), the SLICE option (SAS Inst. Inc., Cary, NC) was used to compare treatments at each time period. The SEM shown is associated with the main effect × T interaction

[3] Enzyme activity is reported as the release of glucose equivalents over time

[4] Hour post-feeding

Table 3.4. Effects of supplementing 0% calcium oxide (CaO) or 1.2% CaO (DM basis) to steers fed dry (DDGS) or modified wet (MDGS) distillers grains with solubles based diets on ruminal VFA concentrations over time

						P-value [1,2,3]			
Item	DDGS	MDGS	0% CaO	1.2% CaO	SEM	D	C	DxT	CxT
Acetate, m*M*					2.06	0.25	0.22	0.73	0.61
0 [4]	42.7	44.9	41.8	45.7					
3	53.5	56.9	54.1	56.3					
Propionate, m*M*					2.36	0.61	0.07	0.06	0.24
0	17.5	18.4	20.1	15.8					
3	34.6	30.5	36.2	28.9					
A:P [5]					0.17	0.29	0.04	0.25	0.57
0	2.7	2.9	2.5	3.1					
3	1.7	2.0	1.7	2.1					
Total VFA, m*M*					4.64	0.87	1.00	0.58	0.72
0	74.2	77.0	75.0	76.2					
3	109.3	108.2	109.4	108.1					

[1] D = the main effect of distillers grains (DGS) type, C = the main effect of CaO treatment, D × T = the interaction of DGS × Time, and C × T = the interaction of CaO × Time

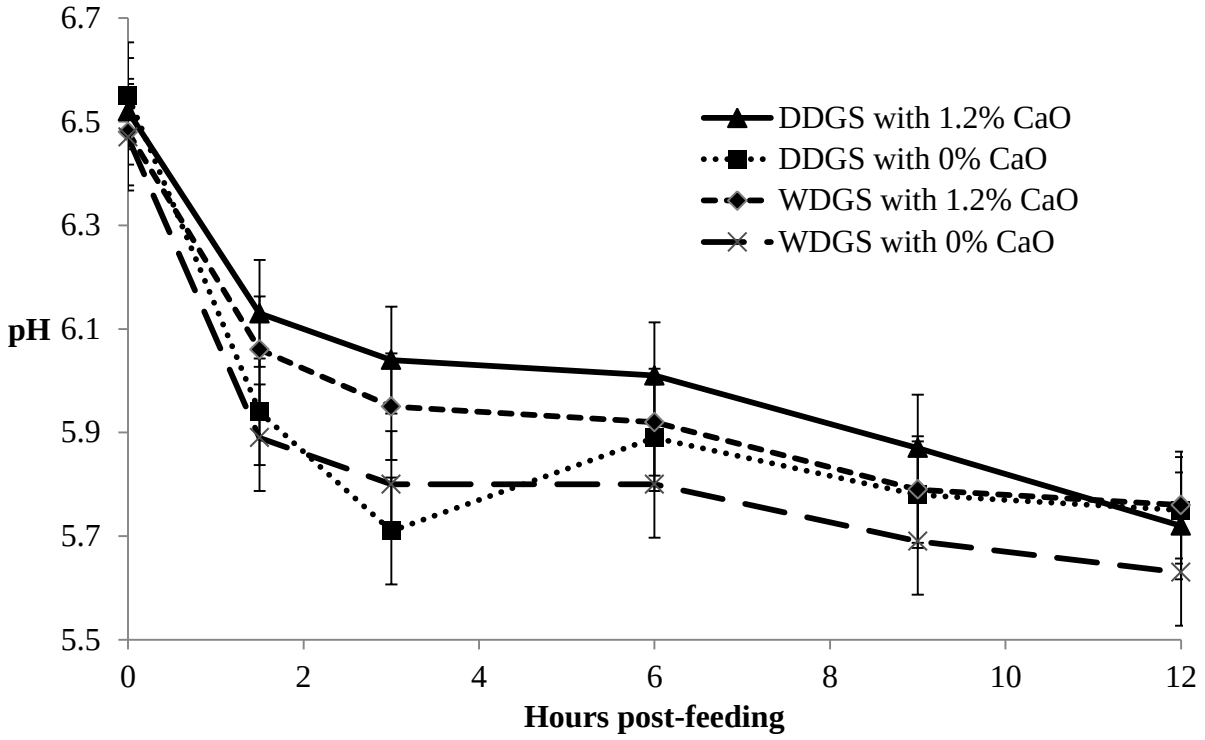
[2] No other VFA were significant and therefore were not reported

[3]Effect of time was significant for all VFA at $P < 0.01$. There was no interaction ($P \geq 0.12$) of D × C or D × C × T for ruminal VFA or enzyme activity. When an interaction of C × T occurred ($P < 0.05$), the SLICE option (SAS Inst. Inc., Cary, NC) was used to compare treatments at each time period

[4] Hour post-feeding

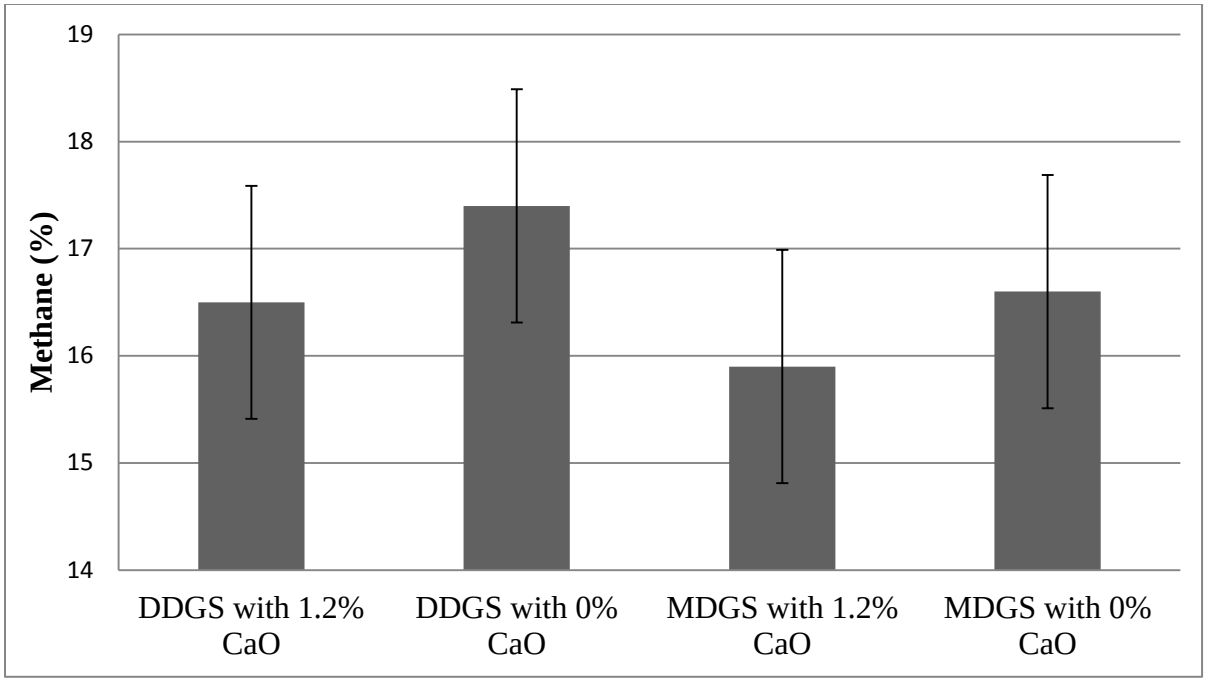
[5] Ratio of Acetate : Propionate

Figure 3.1



Effects of supplementing 0% calcium oxide (CaO) or 1.2% CaO (DM basis) to beef steers fed dry (DDGS) or modified wet (MDGS) distillers grains with solubles based diets on ruminal pH over time. Diets were either 48.8% DDGS with 1.2% supplemental CaO (▲), 50% DDGS with 0% CaO (×), 48.8% MDGS with 1.2% supplemental CaO (■), or 50% MDGS with 0% CaO (♦).There were no interactions ($P \geq 0.50$) of distillers grains (DGS) type × CaO addition × time, DGS type × time, or DGS type × CaO addition There were no main effects $P \geq 0.21$) of DGS type or CaO addition There was an effect ($P < 0.01$) of time and a CaO × time interaction was detected ($P = 0.05$). The error bars reflect the SEM is associated with the interaction of DGS type × CaO addition × time.

Figure 3.2



Effects of supplementing 0% calcium oxide (CaO) or 1.2% CaO (DM basis) to beef steers fed dry (DDGS) or modified wet (MDGS) distillers grains with solubles-based diets on ruminal methane concentration at 3 h post-feeding. Diets were either 48.8% DDGS with 1.2% supplemental CaO, 50% DDGS with 0% CaO,48.8% MDGS with 1.2% supplemental CaO, or 50% MDGS with 0% CaO. Methane concentration is reported as a percent of the total gas. There were no treatment effects ($P \geq 0.48$) on methane concentration. Error bars reflect the SEM associated with the interaction of distillers grains type × CaO addition.

CHAPTER 4: CONCLUSIONS

Distillers grains with solubles can be an effective energy source in beef cattle feedlot rations. Although we had hypothesized that CaO addition would increase ruminal pH, altering rumen fermentation kinetics, and subsequently increasing performance with DDGS eliciting the greatest response; no interaction on animal performance or rumen parameters were realized. Alkaline agents, CaO in particular, may reduce ruminal acidosis; however, the current research suggests their efficacy is limited to the first 3 h after feeding. While CaO addition may provide an improved rumen environment shortly after feeding, perhaps diet palatability and subsequent eating behavior can explain the improved efficiency realized when adding CaO; however, more research in this area is necessary.

Previous research has shown that WDGS and MDGS can offer improved feedlot profitability and increased animal performance when compared to DDGS. While DDGS has advantages when feedlots are located great distances from an ethanol plant, these experiments agreed with previous research which explains that partially drying DGS to approximately 50% DM provided improved cost of gain when compared to cattle fed DGS dried to approximately 90% DM.

In conclusion, although CaO addition improved G:F and decreased cost of gain, added labor involved in treating DGS must be taken into consideration. While MDGS reduced cost of gain in this project, distance of the feedlot from the ethanol plant and ability to store and handle the wet product must also be considered.