EFFECTS OF FEEDING CAO TREATED MODIFIED WET DISTILLERS GRAINS WITH SOLUBLES OR CORN STOVER TO CATTLE ON PERFORMANCE, CARCASS CHARACTERISTICS, AND RUMINAL METABOLISM

BY

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ABSTRACT

Traditionally, feedlot cattle have been fed corn grain; however, recent competition for corn grain for fuel has made it an expensive feed option for cattle producers. Therefore, alternative feeds, like corn co-products, are being considered as energy sources for cattle. Two such co-products are corn stover (**CS**) and modified wet distillers grains with solubles (**MWDG**S). These co-products are less expensive and less digestible than corn grain. Chemically treating corn co-products may increase their feeding value for feedlot cattle by increasing fiber digestibility. This may occur through two mechanisms: 1) altering the composition and structure of the cell wall component of forages through delignification, and 2) buffering ruminal acidity. It is currently not known if these mechanisms can be accomplished simultaneously with the use of calcium oxide (**CaO**) in CS and MWDGS-based diets, nor has the magnitude of the response of CaO in these types of diets been investigated. Therefore, three experiments were conducted. The objective of these experiments was to determine the effects of feeding CaO-treated MWDGS or CS, and corn silage to cattle during the finishing phase on growth, feed efficiency, and carcass characteristics; and on ruminal metabolism and in situ dry matter disappearance using fistulated cattle. *Exp. 1*: Steers (n = 162) were fed for ad libitum intakes one of three treatments: (1) 20% corn stover, untreated (**UCS**), (2) 20% corn stover, treated with 5% CaO (**TCS**), and (3) 40% MWDGS, treated with 2.5% CaO (**TDG**). Calcium oxide treatment of both MWDGS and CS reduced ($P \leq$ 0.03) DMI and final BW when compared to feeding UCS. Steers fed TCS had slower ($P = 0.03$) ADG than steers fed UCS; steers fed TDG were intermediate. Backfat (**BF**) was decreased ($P <$ 0.01) in steers fed TCS and TDG compared to those fed UCS. *Exp. 2*: Heifers (n = 138) were fed for ad libitum intakes one of three treatments: (1) UCS, 2) TCS, and (3) 40% corn silage (**SIL**). Feeding TCS to heifers reduced ($P < 0.01$) DMI, final BW, yield grade, and BF when compared to feeding UCS and SIL. Heifers fed UCS had the same ($P \leq 0.02$) ADG, DMI, marbling score, and BF as heifers fed SIL, although final BW and G:F were decreased. *Exp. 3*: Fistulated steers (n = 5) were fed for ad libitum intakes in a 5 x 5 Latin square design. Diets were: (1) UCS, (2) TCS, (3) TDG, (4) SIL, and (5) control, 50% cracked corn (**CON**). Ruminal pH tended to be reduced ($P = 0.06$) when steers were fed TCS compared to UCS. Steers fed TCS had the greatest ($P \leq 0.05$) concentrations of acetate and total VFA. Apparent dry matter digestibility was affected ($P = 0.02$) by treatment. When steers were fed UCS, dry matter digestibility was reduced, but it did not differ when steers were fed TCS, CON, and SIL diets; those fed TDG were intermediate. Neutral detergent fiber digestibility tended ($P = 0.06$) to follow apparent digestibility. Feeding TCS increased ($P = 0.01$) apparent ADF digestibility in steers compared to feeding UCS and TDG, and was similar to feeding SIL and CON. In situ DM and NDF disappearance increased over time with treated corn stover compared to untreated corn stover, and disappearance tended to plateau around 48h. Feeding cattle TCS decreased DMI and reduced ADG although it increased DM and ADF apparent total tract digestibility when compared to feeding UCS. However, cattle fed TDG had decreased DMI and reduced ADG and no improvement in digestibility. Contrary to our hypothesis, feeding cattle CaO-treated corn stover tended to reduce, rather than increase, ruminal pH ($P = 0.06$). This was most likely caused by increased ruminal fermentation of fiber that increased VFA concentrations ($P < 0.01$). Cattle fed UCS had better performance than those fed TCS or TDG, and performed similarly to cattle fed SIL, even though the UCS was not as digestible. These data suggest that treating CS and MWDGS with CaO prior to feeding was not effective in enhancing growth performance.

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CHAPTER 1: LITERATURE REVIEW

INTRODUCTION

Rising ethanol production in the U.S. has resulted in an increased demand for corn. In 2012, U.S. bio-refineries consumed 121 billion kg of corn yielding 50 billion liters of ethanol and 33.3 million metric tons of distillers grains (Renewable Fuels Association, 2013). As a result of this demand, corn prices will continue to remain elevated for the foreseeable future. This has economic implications for traditional, corn-based feedlot diets and creates incentive to develop corn replacement diets for finishing beef cattle.

Corn stover is one reduced cost option for corn replacement that may be able to partially replace corn without significantly reducing ADG and carcass traits (Bartle et al., 1994). Corn stover is the biomass residue left on the field after the corn harvest and is one of the most abundant crop residues in the U.S. (Glassner et al., 1998). Because corn stover is only the fibrous portion of the corn plant after the corn grain harvest, it does not compete with ethanol production from corn grain.

Feeding corn stover does present some challenges. Corn stover contains little protein or energy in comparison to corn or even other better quality roughages, such as alfalfa haylage or corn silage (NRC, 1996). This means that feeding corn stover may necessitate protein supplementation as well as methods to increase its energy availability for the animal. One technique that has been used is the alkaline treatment of corn stover to increase its digestibility. The first methodology for treating poor quality forages was developed by Beckmann (1921) and improved by Wilson and Pigden (1964). This involved a NaOH application to moistened roughages prior to feeding. Other studies have found that $Ca(OH)_2$ or CaO is nearly as effective as NaOH, is lower in cost, and is safer to apply in comparison (Rounds and Klopfenstein, 1974; Chaudhry, 1999).

Increased corn prices and the abundance of corn stover have renewed interest in the alkaline treatment of corn stover to improve its feeding value. Recent work has been focused on evaluating feeding CaO-treated corn stover with distillers grains with solubles (**DGS**) as a replacement for corn in feedlot diets (Russell et al., 2011; Shreck et al., 2011; Shreck et al., 2012a; Shreck et al., 2012b). Distillers grains are a co-product of the ethanol industry (Stock et al., 2000). They are nutrient-dense when compared to corn, with a nearly 3-fold increase in fat, fiber, and protein (Stock et al., 2000), *and* have an increased energy value (Larson et al., 1993).

Distillers grains with solubles have traditionally been fed at approximately 6 to 15% of diet DM as a protein supplement due to their increased concentration of CP (NRC, 1996). However, when fed at greater dietary inclusions, DGS can be an energy source replacing corn (Klopfenstein, 2001). Several studies have established 40% (DM basis) as the optimal dietary inclusion rate for DGS as a corn replacement (Ham et al., 1994; Vander Pol et al., 2006; Bremer et al., 2011).

Increasing DGS inclusion in diets has some drawbacks. One is the increased S concentration (Vanness et al., 2009) and reduced ruminal pH (Leupp et al., 2009; Felix et al., 2012), both of which can lead to an increased risk of polioencephalomalacia (**PEM**; Gould, 1998). Furthermore, reduced ruminal pH impedes fiber digestibility (Mould and Orskov, 1983; Hoover, 1986). One potential strategy to mitigate this decrease in ruminal pH when feeding increasing inclusion rates of DGS is to treat the DGS with alkaline compounds in an attempt to buffer acidity in the rumen. Felix et al. (2012) found that feeding cattle DDGS that had been treated with 2% NaOH prior to feeding increased ruminal pH compared to cattle fed untreated

DDGS. Work still remains to be done to determine the optimal type and inclusion of alkaline treatment to mitigate the inherent acidity of DGS-based diets.

CORN STOVER

Approximately 35 million ha of corn were harvested in 2012 in the United States (USDA, 2013). Corn stover is the residue left on the field after the corn grain has been harvested and consists of the stalks, leaves, and residual cobs. It is the largest single source of biomass residue in the United States (Glassner et al., 1998). One report estimated that between 170 and 232 million metric tons are produced annually depending on yield and tillage (Perlack et al., 2005). With increasing amounts of corn grain being used to produce ethanol, the residual bio-mass of the corn plant is a co-product, rather than competitor, of ethanol production. This is in contrast to other forages such as corn silage that compete with corn grain for acreage. This is because making silage uses the whole corn plant, while making corn stover uses only the residue after the grain has been harvested. The same plant provides grain for ethanol production and residue for corn stover production.

Corn Stover as a Corn Replacement

With rising corn prices, replacing corn with a roughage equivalent becomes more of an attractive option. The availability and abundance of corn stover suggests that it may have tremendous potential as a cost effective corn replacement ingredient as ethanol production from corn continues to expand. However, there are challenges associated with feeding corn stover in beef feedlot diets. According to the NRC (1996), corn stover has a net energy value for maintenance of 1.50 Mcal/kg and corn grain, 2.18 Mcal/kg. The decreased energy value of corn stover compared to some other common roughages like corn silage (1.79 Mcal/kg; NRC, 1996) could reduce animal performance. Bartle et al. (1994) found that alfalfa and soybean hulls could replace concentrates in beef cattle diets at 20% DM inclusion rates without negatively affecting ADG or carcass characteristics, despite the reduced energy density of 20% roughage diets. However, Russell et al. (2011) replaced corn with corn stover at 20% of the diet DM and reported a reduction in cattle weight gain when compared to cattle fed the control diets containing only 5% corn stover. Cattle intakes in that trial were reduced; therefore, cattle fed stover had the same feed efficiency as cattle fed corn. Another challenge is the protein content of corn stover (6.5% CP) in comparison to other roughages such as ryegrass or timothy grass hay (8.6% and 9.7% CP, respectively; NRC, 1996). Feedlot cattle require approximately 14% CP in their diet; therefore, replacing corn (9.8% CP) with corn stover will increase the need for protein supplementation in the diet to meet the animal's requirements.

The primary challenge of feeding corn stover, however, is the maturity of the corn plant at time of harvest. Stage of maturity at time of harvest affects the feeding value of forages. As plants mature, the feeding value decreases (Moxon et al., 1951). Russell (1986) reported that IVDMD decreased as fiber concentration increased with maturity of corn silage. This is due to a 5% increased portion of lignin in the NDF component of the mature corn plant compared to a less mature corn plant like corn silage (NRC, 1996). Kamstra et al. (1958) determined that increasing lignin content correlated directly with decreased cellulose digestibility. They concluded that lignin had an inhibitory effect on cellulose digestion and, therefore, fiber digestibility. As the plant matures, not only does the NDF portion of total DM increase, but the cellulose and lignin increase while the hemicellulose proportion decreases, causing the greater quantity of NDF to be even less digestible. Jung and Vogel (1986) reported that lignin had a curvilinear inhibitory effect on cellulose and hemicellulose digestibility with increasing concentrations in the plant cell wall. Furthermore, they concluded that this would reduce corn stover DM and fiber digestibility when compared to corn silage, which is harvested at an earlier stage of maturity than stover, and as a result, has reduced lignin content (Jung and Vogel, 1986). According to the NRC (1996), corn silage contains just 41% NDF with 7% lignin, whereas corn stover contains 65% NDF with 10% lignin.

As a result of its poor digestibility, corn stover has traditionally been used as bedding for animals or left in the field to decompose and has not been extensively used as livestock feed (Glassner et al., 1998). With rising corn prices, including corn stover in beef cattle diets may be an economically feasible option for beef producers. However, there is a critical need to improve the feeding value of corn stover. One approach to increase feeding value is to improve digestibility of poor quality forage by chemical treatment.

Alkaline Treatment of Corn Stover

Poor quality forages can be defined as roughages that are less than 55% digestible and deficient in protein (< 8% CP; Leng, 1990). Much work has been done to improve the digestibility and, therefore, feeding value of poor quality forages such as corn stover (Beckmann, 1921; Wilson and Pigden, 1964; Chaudhry, 1999; Russell et al., 2011). Studies have reported that treating poor quality forages with a combination of NaOH and $Ca(OH)_2$ improved production performance when compared to NaOH alone (Kormishchikov, 1969; Rounds and Klopfenstein, 1974). Substituting $Ca(OH)_2$ for NaOH reduces the cost of treatment while reducing Na intake and increasing Ca intake, thereby potentially reducing the need for further Ca supplementation (Rounds and Klopfenstein, 1974). Waller and Klopfenstein (1975) reported that a combination of $Ca(OH)_2$ and NaOH treatment resulted in equal or improved ADG and efficiency compared to either $Ca(OH)_2$ or NaOH alone. A 1978 review of chemical treatment of poor quality forages found that 3 to 5% inclusion levels on a DM basis seemed to be the optimum chemical treatment to improve digestibility and growth performance (Klopfenstein, 1978).

Research has shown that one way lignin acts is as a natural protective barrier to microbial attack, enclosing the largely crystalline cellulose microfibrils and amorphous hemicellulose polymers, and preventing microbial access for enzymatic hydrolysis of the cellulose (Mansfield et al., 1999). Chemical treatment is thought to remove the lignin crust, allowing for dissolution of hydrogen bonds and swelling of cellulose microfibrils, which serves to partially break off and solubilize the hemicellulose polymers. This increases the surface area of cellulose and the accessibility to hemicelluloses for increased hydrolysis of both by rumen microbial cellulases (Kahar, 2013). Lignin is reported to inhibit cellulose hydrolysis by irreversibly adsorbing the cellulase enzymes. As a result, separation of the lignin from the cellulose/hemicellulose complex not only increases substrate availability, but also increases cellulase enzymatic activity (Lee, 1994). It has been reported that chemical treatment may remove acetyl groups on lignin that may have a structurally inhibitory effect on hemicellulose digestion and, therefore, may increase the potential rate or extent of digestion of the hemicellulose component (Bacon and Gordon, 1980).

Beckmann (1921) developed a method for treating wheat straw with NaOH to remove the lignin barrier from the cellulose and hemicelluloses to reduce the inhibitory effect of lignin on digestibility. This methodology, however, required large amounts of water to wash out unreacted alkali, which also had the effect of washing out soluble nutrients, *including* hemicelluloses. Wilson and Pigden (1964) developed a “dry” method that involved grinding wheat straw and then mixing up to 15 g of NaOH in 30 ml of H_2O per 100 g of wheat straw. NaOH is sprayed on and the moist forage is fed to animals without being washed. This study reported that alkali treatments of up to 9% NaOH resulted in significant increases in IVDMD, with further additions of NaOH having little or no significant effect. This method was more pratical than Beckmann's (1921) method because it did not wash out the soluble nutrients. Klopfenstein et al. (1967) studied the effects of treating alfalfa stems and corn cobs wetted to 50% moisture with NaOH or Na_2O_2. They reported that treatment of corn cobs resulted in a greater magnitude of increase than did treatment of alfalfa stems. This increased response to the treatment of corn cobs was attributed to delignification having a greater impact on digestibility due to treatment reducing the lignin content of the cobs and not affecting the lignin content of the alfalfa. It was concluded that since the differing chemical treatments produced little variation in growth performance, the NaOH had greater practical implications, due to its relative cost, than Na_2O_2.

Ololade et al. (1975) investigated the combined effects of duration, temperature, and concentration of NaOH treatment of poor quality forages on IVDMD. Klopfenstein et al. (1976) corroborated these findings in showing an increase in IVDMD for all treated diets, with the greatest increase affecting barley straw and the least increase for alfalfa stems. Like Ololade et al. (1975), Klopfenstein et al. (1976) reported a diminishment of returns at inclusionary levels greater than 8%. They also reported that temperature seemed to speed up the rate of treatment effect on digestibility, but only resulted in significant gains at the uppermost NaOH concentrations. Ololade et al. (1975) reported no net decrease in lignin, suggesting that the lignin may not be solubilized by treatment, but rather physically separated from the cellulose and hemicelluloses without being dissolved. Other studies have reported a large variation in actual solubilization of lignin based on substrate, type of chemical used, intensity of chemical treatment, and other physical factors such as washing of treated forage (Chandra and Jackson

1971; Fernandez and Greenhalgh, 1972). It appears that alkaline treatment solubilizes hemicelluloses, can solubilize lignin, and presumably does solubilize cellulose.

CALCIUM OXIDE AS A FORAGE TREATMENT

One alkaline treatment that has not been extensiviely researched but that is gaining popularity is calcium oxide, CaO. Chaudhry (1999) compared the effects of CaO, NaOH, and alkaline hydrogen peroxide (AHP) treatments on the rate and extent of disappearance of wheat straw in sheep. Calcium oxide is the dehydrated, powdered form of $Ca(OH)_2$ and was used to treat the wheat straw in the dry form rather than as a wet solution Although AHP was the most effective treatment for improving ruminal degradation of wheat straw, it was the most costly and least practical. Chaudhry (1999) ultimately found that CaO was effective in modifying NDF composition of wheat straw to improve ruminal digestion of wheat straw. While CaO was slightly less effective at improving ruminal digestion of wheat straw than NaOH, CaO was the more desirable treatment option to these authors due to it's reduced cost, ease of handling, relative ease of storage and application, as well as fewer safety concerns when compared to NaOH (Chaudhry, 1999).

Calcium oxide, or quicklime, is an efficient means of alkaline treatment in terms of cost and labor. It is cheaper and safer than NaOH. It is also easier to apply than eiter NaOH or $Ca(OH)_2$ since it can be added dry to moistened corn stover in a mixer wagon and does not require a special apparatus for application. Additionally, it may provide a supplemental source of calcium in the diet (Rounds and Klopfenstein, 1974; Waller and Klopfenstein, 1975). Thus, more recent research has evaluated the effects of CaO treatment of corn stover on ADG, feed efficiency, carcass characteristics, and ruminal metabolism.

Effects on growth performance and mode of action

Russell et al. (2011) conducted studies during the growing and finishing phases of feedlot cattle production, along with a lamb metabolism trial, to evaluate the effects of CaO-treated MWDGS and CaO-treated corn stover silage (wetted to 50% DM) fed as corn replacement diets on production characteristics, ruminal metabolism, and profitability. They concluded that CaO-treated stover can be fed at 20% of the diet in combination with MWDGS without adversely affecting ADG or feed efficiency. However, marbling scores were decreased in cattle fed CaO-treated corn stover when compared to cattle fed a corn-based control diet. Russell et al. (2011) also concluded that feeding the CaO-treated corn stover diets could be economically competitive with the traditional corn-based diets if the price of corn is above $4.00 per bushel.

Shreck et al. (2011) concluded that feeding cattle 5% CaO-treated corn stover at 20% of the diet DM improved IVDMD when compared with feeding an untreated corn stover control. Furthermore, they stated that the optimal means of storing treated corn stover was by wetting to 50% moisture prior to treatment, and storing anaerobically for 7 d. A follow-up study compared 5% CaO treatment of corn stover to that of 5% CaO-treated corn cobs and wheat straw (Shreck et al., 2012a). They reported that feeding CaO-treated corn stover and straw to cattle resulted in increased final BW, ADG, and feed efficiency when compared to feeding untreated corn stover and straw, while treating corn cobs was not effective. Furthermore, in a follow-up study, Shreck et al. (2012b) reported that reducing the particle size of ground corn stover from 7.62 to 2.54 cm prior to feeding increased feed efficiency.

One possible mechanism to explain the aforementioned improvement in feed efficiency may be increased microbial attachment, due to a greater surface area, and increased digestibility. Shreck et al. (2013) compared the effects of feeding of CaO-treated corn cobs, corn stover, and wheat straw at 25% of the diet DM, to replace corn, on ruminal metabolism and digestibility. They reported that no differences were found in DM or OM digestibility between cattle fed the treated corn stover diets or those fed a corn-based control when feeding 40% WDGS on a DM basis; however, feeding treated corn stover increased NDF digestibility by cattle when compared to feeding corn. They also noted ruminal that pH increased when feeding treated stover but decreased when feeding treated straw, compared to their respective untreated counterparts, while pH remained the same when treated corn cobs were fed. Feeding corn stover, regardless of whether it was treated or untreated, did not affect ruminal pH when compared to cattle fed the control diet. No difference was observed in acetate to propionate ratios when feeding the treated stover compared to the control. They concluded that due to the increased fiber solubility and NDF digestibility with chemical treatment, the treated forages resulted in a similar nutrient supply to the animal when substituted for grain. Most of the aforementioned digestibility work was done comparing corn-based diets to corn stover and DGS diets. A direct comparison of wetted, untreated corn stover and wetted, CaO-treated corn stover has not yet been done. Furthermore, most of the work with treating poor quality forages has been done with the premise of improving digestibility similar to increased quality, immature forages. However, it is currently not known whether feeding CaO-treatment of corn stover will result in the same production and digestibility increases as feeding immature corn silage.

MODIFIED WET DISTILLERS GRAINS AS A PROTEIN AND ENERGY SOURCE

Distilllers grains with solubles are one dietary ingredient that has become common in recent years (Lardy, 2007). Distillers grains with solubles are a co-product derived from the fermentation and distillation process to convert cornstarch to ethanol. The coarse grains from the stillage are separated from the liquid fraction and the liquid fraction is condensed and added back to the grains to produce wet distillers grains with solubles (**WDGS**). This combination can also be dried to produce dried to distillers grains with solubles (**DDGS**; Stock et al., 2000).

Distillers grains are easier to use in the dry form due to transportation and storage options. However, drying WDGS to DDGS may account for a large increase in energy cost for the plant (Perrin et al., 2009), which increases the cost of DDGS for producers and may reduce nutritional quality (Van Soest, 1989; Weis et al., 1989). Wet distillers grains with solubles are approximately 30 to 35% DM. However, due to increased spoilage in the wet product, WDGS have a shelf life of approximately one week (Dooley et al., 2008). Therefore, shipping is limited by distance and must be fed rapidly, making them feasible, typically, only for large production operations within an average radius of 100 km from the co-product source (Dooley et al., 2008). Dried distillers grains with solubles are dried to approximately 90% DM, greatly increasing shipping radius and increasing storage options for the producer which comes at greater cost (Dooley et al., 2008). Modified wet distillers grains with solubles (**MWDGS**) are WDGS dried to approximately 42 to 50% DM as a compromise between transportability, storage convenience, and cost (Dooley et al., 2008). A study comparing MWDGS to WDGS and DDGS found that moisture level of DGS did not affect ADG or carcass characteristics (Nuttelman et al., 2011). However, they reported that feeding cattle MWDGS and DDGS tended to increase feed intake, resulting in reduced efficiency when compared to cattle fed WDGS.

Because the ethanol fermentation process consumes the starch that makes up approximately two-thirds of the original grain, the remaining fat, protein, and fiber are concentrated nearly 3 times (Stock et al., 2000). Traditionally, DGS have been used as a supplementary protein source due to their increased protein content (NRC, 1996), but have become attractive as an energy source for cattle producers due to rising corn prices. Larson et al. (1993) reported that wet distillers byproducts contained on average 1.3 to 1.6 times more energy for gain ($NE_{g,}$ Mcal/kg) than corn at different stages of growth. This was partially attributed to a 3-fold increase in fat and an increased concentration of highly digestible corn fiber (DeHaan, 1983). According to the NRC (1996), DGS contain 46% NDF, 29.5% CP, and 10.3% fat on a DM basis.. Distillers grains with solubles become a more attractive option as a corn replacement as corn prices increase. They are nutrient dense and are increasing in availability as ethanol production continues to increase.

Dietary inclusion of MWDGS

Traditionally, DGS have been fed at 6 to 15% DM inclusion rates as a source of supplemental protein. This is largely because they are an excellent source of bypass protein with approximately 70% of the CP fraction being rumen undegradable intake protein (**UIP**; NRC, 1996). However, due to their high nutrient density, when fed at greater dietary inclusion rates, they can be used as an energy source to replace corn in the diet (Klopfenstein, 2001). Ham et al. (1994) reported that cattle fed WDGS that were fed at a 40% DM inclusion rate resulted in an average of 39% more NE_g than dry rolled corn. Also, cattle fed WDG had decreased DMI and increased feed efficiency compared to cattle fed DDGS. This study also reported that WDG contained approximately 4 times the NDF and 3 times the protein and fat when compared to dry rolled corn. Vander Pol et al. (2006a) reported that WDGS fed from 10 to 50% of the diet DM resulted in a greater energy value relative to corn. However, ADG and DMI increased quadratically as dietary WDGS inclusion increased. Therefore, they concluded that 40% inclusion was optimal since ADG and G:F were the greatest when WDGS was fed at 40% of the diet DM. Furthermore, they reported that replacing corn with WDGS did not alter carcass characteristics.

Leupp et al. (2009) studied the effects of increasing inclusion of DDGS from 0 to 60% DM basis on DMI and ruminal metabolism. They reported an increase in OM intake from 0 to 15% followed by a linear decrease as the dietary inclusion of DDGS increased to 60%. This is in contrast to other studies that found that feeding 30% was the optimum inclusion to maximize DMI in WDGS (Vander Pol et al., 2006a) and DDGS (Buckner et al., 2007). Leupp et al. (2009) also reported decreased ruminal digestibility as DDGS inclusion increased to 60% of the diet DM; however, this resulted in increased post-ruminal digestibility with little net effect on total tract digestibility. Ultimately, they concluded that 45% inclusion of DDGS on a DM basis would maximize digestibility and ruminal fermentation when fed to growing steers. Rich et al. (2011) evaluated feeding WDGS at levels ranging from 40 to 85% DM basis with varying ranges of forage inclusion. They concluded that WDGS could be fed at up to 85% dietary DM inclusion when at least 8% forage was fed in the diet, but production performance and profitability were optimized at the 40% inclusion level. Furthermore, Vander Pol (2006b) determined that the optimal profitability resulted from feeding WDGS at the 40% inclusion level.

Bremer et al. (2011) conducted a DGS meta-analysis of 28 finishing studies that evaluated feeding increasing levels of WDGS, MWDGS, and DDGS as a corn replacement in diets. The DM inclusions analyzed were 0 to 40% replacement of corn in the diet with DGS. When WDGS and MWDGS were fed, feeding value compared to corn was greatest at the 10% inclusion level (150 and 128%, respectively) and decreased linearly up to the 40% inclusion level (to 130 and 117%, respectively). The feeding value of DDGS compared to corn remained at a steady 112% with no change seen with increasing dietary inclusion rates. Nuttelman et al.

(2011) compared feeding WDGS, MWDGS, and DDGS in the same trial at 3 dietary levels of corn replacement (20, 30, and 40%, DM basis) to determine the effects of moisture level and inclusion rate on feeding value. They reported that moisture did not have an effect on ADG, although feeding WDGS decreased DMI. Cattle fed MWDGS were less efficient than those fed WDGS but more efficient than those fed DDGS. To summarize, all types of DGS at all levels of inclusion resulted in a feeding value greater than corn. The optimal dietary inclusion to feed MWDGS were reported as 30% for ADG and 40% for G:F. For WDGS, feeding at 30% inclusion was reported as optimal for ADG and 40% for G:F; and for DDGS, feeding 40% inclusion was optimal for ADG, with G:F remaining the same across inclusion levels.

Klopfenstein et al. (2008) asserted that due to the protein content of DGS, cheaper, poorer quality forages with less digestibility and less protein could be fed in combination with increasing dietary inclusions of WDGS. Benton et al. (2007) demonstrated that cattle fed corn stover performed as well as cattle fed alfalfa and corn silage when fed diets containing 30% WDGS on a DMB. Feeding poor quality forages with DGS based diets may be optimal given the potentially cheaper cost compared to good quality forage.

Problems with increased DGS inclusion

Increasing dietary inclusions of DGS is not without some drawbacks. Issues with feeding greater amounts of DGS include fat (Zinn, 1993; Zinn et al., 2000; Vander Pol, 2009), protein (Klopfenstein et al., 2008; Gunn et al., 2009), and S (Gould, 1998, Felix et al., 2012). Fat and protein issues are discussed at length in the previously mentioned reports; therefore, the focus in this report will be the S and resulting acid present in DGS.

Sulfuric acid (H_2SO_4) is used during ethanol production for cleaning and pH regulation during fermentation (Snider, 2004). Residual H_2SO_4 can remain in DGS (Vanness et al., 2009).

This may increase S concentration (Vanness et al., 2009) *and* increase acidity of the DGS (Felix and Loerch, 2011). Increasing dietary S concentrations can decrease DMI and increase the incidence and risk of Polioencephalomalacia (**PEM**) in cattle (Gould, 1998). Sulfur-induced PEM results from the reduction of dietary sulfates to hydrogen sulfide gas (H_2S) that then builds up in the rumen. This H_2S is eructated and then inhaled by the animal (Gould, 1998), disrupting metabolic pathways in the brain and inducing PEM symptoms. Feeding increasing concentrations of DGS also reduces ruminal pH (Vander Pol et al., 2009; Leupp et al., 2009; Felix and Loerch, 2011, Felix et al., 2012). Therefore, PEM is exacerbated in cattle fed DGS-based diets because they provide available hydrogen ions to reduce the sulfates to H_2S. As a result, greater inclusions of DGS may result in a synergistic increase in PEM risk from elevated S concentrations and decreased ruminal pH combined.

Several studies have reported a decrease in ruminal pH as a result of feeding DGS (Vander Pol et al., 2009; Leupp et al., 2009; Felix and Loerch, 2011, Felix et al., 2012). Reductions in ruminal pH decrease DMI (Owens, 1998) and have an inhibitory effect on the growth of ruminal cellulolytic microbial populations and fiber digestibility (Mould and Orskov, 1983). Traditionally, the most common cause of acidic ruminal pH is increased intake of starch, or other rapidly fermentable carbohydrate sources, which rapidly increases lactic acid concentrations resulting in an acidic pH (Allen and Mertens, 1987). Reduced ruminal pH can lead to ruminal acidosis. Historically, ruminal acidosis was caused by lactic acid (Owens, 1998) Lactic acid is a stronger acid ($pK_a = 3.9$) than the VFA ($pK_a = 4.8$) and, therefore, has a greater effect on reducing ruminal pH (Van Soest, 1994). Lactic acid accumulation in the rumen is determined by a balance of lactic acid “producers” and lactic acid “users”. Lactic acid users tend to be less sensitive to acidic pH than lactic acid producers. When ruminal pH decreases, lactic acid users decrease and results in lactic acid accumulation (Owens et al., 1998). Similarly, VFA are typically readily absorbed from the rumen and do not accumulate at sufficient concentrations to affect pH significantly, but when the rate of acid accumulation outpaces the rate of acid absorption, VFAs accumulate and can decrease pH as well (Owens et al., 1998). In comparison, the pKa of H_2SO_4 is 1.9. Therefore, H_2SO_4 is an even stronger acid than lactic acid with the potential to impact ruminal pH even more. Additionally, diets with more concentrates, like DGS, and less roughages can decrease rumination, thereby decreasing saliva production and potential buffering in the rumen (Church, 1988; Felix and Loerch, 2011).

According to Stock et al. (2000), most of the starch in corn is converted to ethanol through microbial fermentation. Therefore, there is little starch left in DGS and the acidic ruminal pH from feeding distillers grains is more likely a result of residual H_2SO_4 in the grain rather than lactic acid production in the rumen (Felix et al., 2012). Felix and Loerch (2011) measured the pH of DDGS at 3.76 compared to 5.8 for corn. They hypothesized that DDGS may actually increase the acid load in the rumen due to residual H_2SO_4 rather than decreasing the acid load by replacing rapidly fermentable starch with NDF as previously believed (Klopfenstein et al., 2008).

It is well documented that reduced ruminal pH has a major inhibitory impact on fiber digestion (Hoover, 1986). According to Mould and Orskov (1983), fiber digestibility by sheep was reduced as ruminal pH decreased from 6.6 to 6.2 and below pH 6.0 it was almost completely inhibited. Mould and Orskov (1983) concluded that this was because cellulolytic microbes necessary for fiber digestion were inhibited and eventually destroyed when ruminal pH was less than 6.1. The moderate decreases in fiber digestion associated with a pH of around 6.0 may also be partially due to inhibition of the ability of cellulolytic bacteria to tightly adhere to plant cell walls at decreased pH (Cheng et al., 1984; Shriver et al., 1986). As stated previously, DGS contain nearly 46% NDF (NRC, 1996); therefore, a decrease in fiber fermentation in the rumen could have detrimental impacts on DGS digestibility. Strategies, then, are necessary to control pH when greater inclusions of DGS are fed to cattle. One such strategy is to increase roughage inclusion in the diet to stimulate salivary buffering (Owens et al., 1998; Church, 1988), Felix and Loerch (2011) evaluated feeding of additional forage to manage ruminal pH in 60% DDGS-based diets by supplementing diets with up to 10% alfalfa haylage. They reported that 10% haylage supplementation increased DMI by 19% and ADG by 9%, and increased ruminal pH as expected. However, reduced acetate concentrations, despite elevated dietary NDF and ADF concentrations, suggest that fiber fermentation was still negatively affected at 60% DDGS inclusion. This study concluded that inclusion of 60% DDGS may result in substantial decreases in ruminal pH but that increased roughage supplementation could mitigate the effects of reduced pH. However, Felix and Loerch (2011) noted that increasing dietary roughage alone was not sufficient to buffer all of the increased acidity from DDGS.

Another approach to controlling ruminal pH is to buffer the acidity of the rumen using alkali treatment. However, results have been highly variable as regards the effects of chemical treatment on ruminal pH. Coombe (1979) reported no change in ruminal pH when barley straw was treated with NaOH and fed to steers. Some studies found a decrease in pH with NaOH treatment (Koers et al., 1970; Ololade and Mowat, 1975), and in the case of Ololade and Mowat (1975), pH decrease corresponded with an increase in total VFA concentration, suggesting VFA as weak organic acids were reducing ruminal pH. Shreck et al. (2013) reported a decrease in ruminal pH when treating wheat straw with 5% CaO and an increase when treating corn stover. It is noteworthy that the decrease reported with treated wheat straw corresponded with a numerical increase in total VFA, and the increase reported with treated corn stover corresponded with a decrease in total VFA.

All of the previous reports have been based on treated forages. Little research has been done to determine the effects of buffering the acidity from DGS on growth performance or ruminal metabolism. Felix et al. (2012) studied the effects of treating DDGS with 2% NaOH on ruminal metabolism. They determined that neutralizing the acidity in DDGS with NaOH prior to feeding increased ruminal pH when compared to feeding untreated DDGS. Currently, the use of CaO to mitigate the effects of acidity from DGS has not been investigated.

CONCLUSION

The rising price of corn may be mitigated by substituting DGS and treated crop residues as partial corn replacements in diets. Distillers grains with solubles are energy dense ingredients with greater feeding value than whole corn that are becoming more available as ethanol production increases. Although challenges exist to feeding DGS at elevated dietary inclusions, these challenges may be countered by increasing the proportion of forages in the diet, in tandem with DGS, as a replacement for corn. Corn stover is the most abundant crop residue in the United States, and treating it with CaO has been demonstrated to be a safe and effective method of increasing its digestibility and, thus, feeding value to the ruminant animal. Additionally, the increase of roughage in the diet to approximately 20% DM, along with alkali treatment, may increase ruminal buffering, thereby mitigating the inherent acidity of DGS and its effects on fiber digestion and ruminal metabolism. Therefore, the potential limitations of including DGS as a corn replacement, the abundance of corn crop residual biomass, and the capability to increase the digestibility of this crop residue has resulted in renewed interest in corn replacement diets that are composed of DGS and CaO-treated corn stover. While initial investigations on treated corn stover show positive results on animal growth performance, effects on ruminal metabolism are lacking. It is currently unknown if the treatment of corn stover works in the DGS-based corn replacement diets solely by improving forage digestibility, or if there is ruminal buffering occurring that improves the DGS digestibility as well. These areas need to be investigated to fully understand the effects of a corn stover and DGS-based corn replacement feed on animal growth performance, carcass characteristics, and ruminal metabolism.

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CHAPTER 2: EFFECTS OF FEEDING CAO TREATED MODIFIED WET DISTILLERS GRAINS WITH SOLUBLES OR TREATED CORN STOVER TO CATTLE ON PERFORMANCE, CARCASS CHARACTERISTICS, AND RUMINAL METABOLISM

ABSTRACT

Chemically treating corn alternatives, corn stover and modified wet distillers grains with solubles (MWDGS) may increase feeding value for feedlot cattle. The objectives of this study were to determine effects of feeding CaO treated MWDGS or treated corn stover to cattle during the finishing phase on growth, efficiency, and carcass characteristics, and on ruminal metabolism and in situ dry matter disappearance in fistulated cattle. *Exp. 1*: Steers (n = 162) were fed 1 of 3 treatments: (1) 20% corn stover, untreated (**UCS**), (2) 20% corn stover treated with 5% CaO (**TCS**), or (3) 40% MWDGS, treated with 2.5% CaO (**TDG**). *Exp. 2*: Heifers (n = 138) were fed 1 of 3 treatments: (1) UCS, (2) TCS, or (3) 40% corn silage (**SIL**). *Exp. 3*: fistulated steers (n = 5) were fed in a 5x5 Latin square design. Diet treatments were: (1) UCS, (2) TCS, (3) TDG, (4) SIL, and (5) control, 50% cracked corn (**CON**). *Exp 1*: Feeding CaO-treated MWDGS or corn stover reduced ($P \leq 0.02$) DMI, final BW, HCW, and back fat (**BF**) when compared to feeding UCS. Steers fed TCS had reduced ($P = 0.03$) ADG and yield grade (**YG**) when compared to steers fed UCS; steers fed TDG were intermediate. Marbling score (**MS**), LM area, and G:F did not differ ($P \geq 0.08$) by treatment. *Exp 2*: Feeding TCS to heifers reduced ($P < 0.01$) DMI, final BW, YG, and BF when compared to feeding UCS and SIL. Heifers fed UCS had similar ($P \leq 0.02$) ADG, DMI, and MS, as heifers fed SIL; however final BW and G:F were reduced ($P \leq 0.04$). *Exp 3:* Ruminal pH tended to decrease ($P = 0.06$) when steers were fed TCS compared to UCS. Steers fed TCS had the greatest ($P \leq 0.05$) mean concentrations of acetate and total VFA. When steers were fed UCS, dry matter digestibility was reduced ($P = 0.02$), but it did not differ

when steers were fed TCS, CON, or SIL diets; those fed TDG were intermediate. Feeding TCS increased ($P < 0.01$) ADF digestibility compared to feeding UCS and TDG, and similar to feeding SIL and CON. After 48 h of ruminal fermentation, DM digestibility was increased by 15.9% and NDF digestibility was increased by 16.7% in calves fed treated stover compared to those fed untreated. Treating corn stover with CaO was an effective means to increase digestibility; however, it did not improve cattle performance due to reduced DMI. Feeding untreated, ensiled corn stover resulted in performance comparable to corn silage.
Key words: corn stover, distillers grains, calcium oxide, cattle

INTRODUCTION

Ethanol production has increased corn prices over the last decade. Therefore, alternatives to corn-based cattle diets are needed that will alleviate rising costs without reducing animal growth performance. Recently, corn stover (**CS**), in combination with modified wet distillers grains with solubles (**MWDGS**), has been suggested as a corn replacement feed (Lardy, 2007). However, dietary DM inclusion levels of MWDGS above 20 to 40% may negatively affect animal performance because of dietary S concentration and reduced pH caused by H_2SO_4 used in the ethanol production process (McAloon et al., 2000). Felix and Loerch (2011) discovered that cattle consuming dry distillers grains with solubles (**DDGS**)-based diets have reduced ruminal pH compared to cattle fed corn diets. Mould and Orskov (1983) found that reduced ruminal pH may inhibit cellulolytic bacteria necessary for fiber digestion. Inhibition of cellulolytic bacteria could be problematic for corn replacement feeds containing high fiber co-products like CS and MWDGS (NRC, 1996).

Calcium oxide increases the digestibility of poor quality forages, like CS (Kamstra, et al., 1958; Rounds and Klopfenstein, 1974). Shreck et al. (2012a) found that treating CS with 5% CaO at 50% moisture improved digestibility. Felix et al. (2012) reported that neutralizing the acidity in DDGS could increase in situ fiber digestibility. There are currently no data on treating MWDGS with CaO. It is also unknown if CaO can improve digestibility of CS to that of an immature forage like corn silage.

The objectives of this study were to determine the effects of feeding CaO-treated MWDGS or CS, and corn silage, to cattle during the finishing phase on growth, feed efficiency, and carcass characteristics, and on ruminal metabolism and in situ dry matter disappearance in fistulated cattle. We hypothesized that CaO would increase fiber digestibility and increase rumen pH similarly whether applied to CS or MWDGS, with improvements being most similar to a corn silage diet.

MATERIALS AND METHODS

All animals used in these trials were managed according to guidelines recommended in the *Guide for the Care and Use of Agriculture Animals in Agriculture Research and Teaching* (FASS, 2010). All experimental procedures were approved by the University of Illinois Institutional Animal Care and Use Committee.

Experiment 1

Animals and Diets:

Angus × Simmental steers (n = 162; initial BW = 436 ± 2.0 kg) were placed on trial at the Beef and Sheep Field Laboratory in Urbana, IL. Feedlot barns are constructed of wood frames with ribbed metal roofs, and siding on the north, west, and east sides. The south sides are covered with 1.27 cm × 1.27 cm wire mesh bird screen and have retractable curtains. Each pen has rubber-coated, slatted concrete floors and measures 4.9 m × 4.9 m. Steers were blocked by BW, stratified by sire, and allotted to 12 heavy block pens and 9 light block pens.

Pens within block were randomly assigned to one of three treatments (Table 1): (1) untreated corn stover (**UCS**), (2) corn stover treated with 5% CaO (**TCS**), or (3) MWDGS with 1% CaO added to the diet (**TDG**). All UCS diets contained 20% corn stover and 40% MWDGS. The CaO treated diets, TCS and TDG**,** were formulated to include 1% CaO on a DM basis. The remainder of the diets was corn and a vitamin/mineral supplement. Steers were adjusted to their feedlot diets over the course of 14 d. Diets were mixed in a mixer wagon (Knight Reel Auggie 3130; Kuhn Agricultural Machinery, Brodhead, WI) and delivered to pens once daily. Steers were fed for once daily *ad libitum* intakes. Samples of each dietary ingredient were collected every 21 d and were composited at the end the trial for nutrient analysis.

CaO Treatment for TCS and TDG diets:

Corn stover was ground through a 2.5 cm screen using a tub grinder (Haybuster Big Bite H-1000 series; Agricultural Products DuraTech Industries International, Inc., Jamestown, ND) . It was then added to the mixer (Knight Reel Auggie 3130; Kuhn Agricultural Machinery, Brodhead, WI) and wetted to 50% moisture. Untreated corn stover was bagged in an Ag-Bag (A. Miller-St. Nazianz, Inc. Company, St. Nazianz, WI). Treated corn stover underwent the same aforementioned process; however, after wetting, CaO was added at 5% (DM basis) total inclusion and allowed to mix in the wagon for 10 min. 907 kg of Treated corn stover was made at a time and placed in a covered feed bay and allowed to react for 7 d prior to feeding. For the TDG diet, CaO was added to corn for a 1% total dietary inclusion (DM basis). This corn was added to the remainder of the ingredients in the mixer. This process was followed to facilitate complete mixing of the CaO in the diet. Therefore, CaO in the TDG diet was simply part of the total ration and not a pretreatment.

Growth Performance and Carcass Data Collection:

Steers were weighed on two consecutive days at the beginning and end of the trial to determine initial and final BW, respectively. The d 0 BW was used for allotment, and cattle were implanted with Component TE-S® (Elanco, Greenfield, IN) and allotted to trial pens on d 1. Interim BW were taken every 28 d. Individual BW was recorded using a Flying W hydraulic® squeeze chute system (Flying W Livestock Equipment, Watonga, OK). Individual intake data were recorded using the GrowSafe® feed intake measurement system (GrowSafe Systems Ltd., Airdrie, AB Canada). Steers were weighed off of trial by BW block upon reaching an average final BW of approximately 590 kg, 56 and 96 d for the heavy and light blocks, respectively.

Steers were slaughtered at a commercial abattoir in Joslin, IL. Steer HCW was recorded at slaughter and carcasses were chilled for 24 h at -4^{o} C. At approximately 24 h post-slaughter, the carcasses were ribbed between the 12th and 13th ribs and carcass data were collected via cameras including: 12th rib back fat thickness (**BF**), kidney pelvic and heart fat (**KPH**), marbling score (**MS**), and LM area. USDA Yield Grade (**YG**) was calculated using the equation:

$$YG = 2.5 + (6.35 \times BF(cm)) + (0.2 \times \%KPH) + (0.0017 \times HCW(kg)) - (2.06 \times LM\ area(cm^2)).$$

Quality Grade was provided by USDA personnel at the plant.

Sample Analysis:

Composited feed samples were freeze-dried (Labconco; FreeZone^{12},Kansas City, MO), and ground to 1 mm particle size using a Wiley mill (Arthur H. Thomas; Philadelphia, PA). Chemical composition was individually analyzed and used to calculate nutrient composition of diets. All samples were analyzed for DM (105^{o} C). All freeze dried samples were analyzed for ash (500^{o} C for 18 h, HotPack Muffle Oven Model; 770750, HotPack Corp., Philadelphia, PA), NDF and ADF (Ankom Technology method 6 and 5 respectively; Ankom^{200} Fiber Analyzer, Ankom Technology, Macedon, NY), fat (ether extract method; Ankom Technology), CP (Leco TruMac; LECO Corporation, St. Joseph, MI), and complete minerals by inductively couple plasma electrophoresis (ICP; OARDC STAR lab; Wooster, OH). Corn stover was analyzed for ADL using the method described by Van Soest et al. (1991)

Statistical Analysis:

The experimental design was a randomized complete block design. Treatments were randomly assigned to pens within blocks. Pen was the experimental unit. The MIXED procedure of SAS (SAS Institute; Cary, NC) was used for analysis of all production and carcass data. Differences were declared significant at $P \leq 0.05$ and trends were discussed at $0.05 < P < 0.10$.

Experiment 2

Animals and Diets:

Angus × Simmental heifers (n = 138; initial BW = 406 ± 2 kg) were placed on trial at the Beef and Sheep Field Laboratory in Urbana, IL. Barn construction, floor space, and cattle management were identical to conditions used Experiment 1. Heifers were blocked by BW, stratified by sire, and allotted to 9 heavy block pens and 9 light block pens. Heifers were assigned to one of three treatments (Table 2): (1) untreated corn stover (**UCS**), (2) corn stover treated with 5% CaO (**TCS**), or (3) corn silage (**SIL**). The corn stover diets contained 20% corn stover and 40% WDGS. The SIL diet consisted of 40% MWDGS and 40% corn silage. Silage was assumed to have 50% grain and was added at 40% to match the roughage inclusion from the corn stover. The remainder of the diets was corn and a vitamin/mineral supplement. Heifers were adjusted to their feedlot diets over the course of 14 d. Diets were mixed in a mixer wagon (Knight Reel Auggie 3130; Kuhn Agricultural Machinery, Brodhead, WI) and delivered to pens once daily. Heifers were fed once daily for ad libitum intakes. The same corn stover, treated and untreated, was used as was used in Experiment 1.

Growth Performance and Carcass Data Collection:

Heifers were implanted on d 1 of the trial with Component TE-H® (Elanco; Greenfield, Indiana). All other data collection, management procedures, and sample analysis were the same as for Experiment 1.

Statistical Analysis:

The experimental design was a randomized complete block design. Treatments were randomly assigned to pens within blocks. Pen was the experimental unit. The MIXED procedure of SAS (SAS Institute; Cary, NC) was used for analysis of all production and carcass data. Differences were declared significant at $P \leq 0.05$ and trends were discussed at $0.05 < P < 0.10$.

Experiment 3

Animals and Diets:

Angus × Simmental steers (n = 5; initial BW = 524 ± 69 kg) fitted with a rumen cannulae were used in a metabolism trial at the Beef and Sheep Field Laboratory in Urbana, IL. Steers were randomly allotted to one of five dietary treatments (Table 3): (1) untreated corn stover (**UCS**), (2) corn stover treated with 5% CaO (**TCS**), (3) MWDGS with 1% CaO added to the diet (**TDG**), (4) corn silage (**SIL**), or (5) corn control (**CON**). Diets 1 through 4 were described in the previous 2 experiments. Diet 5, CON, was added as a positive control to reflect a more typical feedlot diet and contained 15% corn silage, 25% MWDGS, 50% dry rolled corn, and 10% vitamin/mineral supplement. The aforementioned diets were fed for ad libitum intakes in a 5×5 Latin square design. Diets were individually mixed daily and fed once daily at 0900. Dietary treatment sequences were assigned according to procedures described by Patterson and Lucas (1962) in order to ensure complete randomization of animal, treatment, and period.

Steers were housed in individual 1.5 m × 2.4 m metabolism stalls with rubber mat flooring. Stalls and mats were cleaned twice daily, once after the morning feeding and once in the afternoon.

Sampling and Analysis:

Each period consisted of a dietary adaptation phase (14 d), a fecal collection phase to determine apparent digestibility (5 d), and a ruminal collection phase (1 d) for determination of VFA concentrations and ruminal pH.

To determine total tract apparent digestibility, 5 aluminum pans were weighed empty and placed behind stalls for total fecal collection. Pans were placed immediately after feeding on d 14 for a 120 h fecal collection. Pans and feces were weighed back every 24h and 10% total fecal weight was sub-sampled and composited for later analysis. Individual intakes were recorded and averaged over this time period. Individual feed ingredients were sampled daily (50 g) and composited for later analysis. Orts were weighed back and a 10% sub-sample was saved each day of collection and composited for later analysis.

Feed, fecal samples, and orts composite samples were freeze-dried (Labconco; FreeZone[12] Kansas City, MO) and ground to 1 mm particle size using a Wiley mill (Arthur H. Thomas; Philadelphia, PA). Methods of proximate analysis were as described in Experiment 1. Orts and feces were analyzed for NDF, ADF, fat, and ash only.

Ruminal fluid was collected at 0, 1.5, 3, 6, 9, 12, and 18 h post-feeding and strained through two layers of cheesecloth. Ruminal pH measurements were immediately recorded (Metler Toledo FE20; Metler Toledo Inc., Columbus, OH). At 0, 3, and 6 h post-feeding, 75 mL of ruminal fluid were acidified with 75 mL of a 2N HCl solution to be analyzed for VFA concentrations via gas chromatography (Model 5890A, Hewlett Packard). The acidified ruminal fluid was refrigerated overnight and then centrifuged for 20 min at 20,000 × g. The supernatant was filtered through a 0.45 µ filter, then transferred to an intermediate tube to freeze overnight. The following day, the filtered sample was thawed and 1.0 mL of the filtered sample was pipetted into a GC vial with 0.1 mL of internal 2 ethyl-butyrate standard. The GC vials were stored at -20^{0}C until analyzed by gas chromatography (Model 5890A, Hewlett Packard) for VFA.

Statistical Analysis:

The experimental design was 5 × 5 Latin square. Repeated measures were used to analyze ruminal pH and VFA concentrations using the covariate structure for compound symmetry. Steer was the experimental unit. Data were analyzed via the MIXED procedure of SAS (SAS Institute; Cary, NC). Significance was declared at $P \leq 0.05$. Trends were discussed at $0.05 < P < 0.10$.

In Situ Collection:

Upon completion of all periods, an in situ trial was conducted to evaluate in situ digestibility of untreated, ensiled corn stover compared to CaO treated (5% DM basis) corn stover. The procedures cited by Felix et al. (2012) were followed. Bags were removed at 12, 24, 36, and 48 h post-incubation. Bags were composited by animal and hour, analyzed for DM and NDF, and corrected for wash-out of these components.

RESULTS AND DISCUSSION

Experiments 1 and 2:

In Exp. 1, steers fed TCS gained 0.26 kg/day less ($P < 0.03$) than steers fed UCS; steers fed TDG had intermediate gains (Table 4). This caused steers fed TCS and TDG to finish at a lighter final BW (*P* = 0.02) than steers fed UCS at the same number of days on feed. Similar results were observed in Exp. 2. Heifers fed TCS had reduced (*P* < 0.03) ADG when compared to heifers fed SIL, although there was no difference when compared to heifers fed UCS. Feeding heifers TCS resulted in a reduced (*P* < 0.01) final BW (Table 5) compared to heifers fed UCS and SIL. However, CaO treatment of corn stover or WDGS did not affect G:F in either trial. Decreased DMI caused decreased ADG in cattle fed CaO treated feed, without a reduction in G:F . Steers fed TCS and TDG in Exp. 1 had decreased (*P* < 0.01) DMI (8.78 kg/day and 8.59 kg/day, respectively) compared to steers fed UCS. Likewise, in Exp. 2 heifers fed TCS had a 1.56 kg/day reduction (*P* < 0.01) in DMI compared to heifers fed UCS. This decrease in ADG and final BW is contradictory to previous work that reported increased ADG and final BW in cattle fed treated corn stover (Russell et al., 2011; Shreck et al., 2012a; Shreck et al., 2012b). These studies (Russell et al., 2011; Shreck et al., 2012b) reported improvements in performance despite their decreased DMI when stover was treated with CaO compared to untreated stover that *was* similar to our results.

In Exp. 2, heifers fed TCS had the decreased (*P* < 0.01) DMI while those fed SIL and UCS were similar. However, heifers fed SIL had the greatest (*P* < 0.01) ADG, while those fed TCS had the decreased ADG; heifers fed UCS were intermediate. These difference in DMI and ADG caused heifers fed SIL to have increased (*P* ≤ 0.04) final BW and G:F compared to those fed either TCS or UCS. The similar ADG and DMI between UCS and SIL is surprising as increasing maturity of the corn plant increases lignin content (NRC, 1996) and decreases digestibility and feeding value (Moxon et al., 1951; Kamstra et al., 1958). Therefore, we had hypothesized that TCS would result in similar production performance as SIL due to delignification of corn stover by modifying cell wall composition to increase ruminal degradation (Chaudhry, 1999). Benton et al. (2007) reported that, despite the greater maturity, steers fed corn stover were comparable in production performance with those fed silage in diets consisting of 30% WDGS at an 8% roughage inclusion. The results of our study and those of Benton et al. (2007) imply that the elevated energy density and high protein of DGS may be compensating for the reduced feeding value and protein content of poor quality, mature forages. Previous studies reported that feeding untreated corn stover compared to treated corn stover *reduced* animal growth performance (Shreck 2012 a, b). However, in this study, cattle fed untreated corn stover received dry, ground stover. In the current study, the UCS was ground, wetted, and bagged to maintain similar consistency to the TCS. In fact, the UCS in the current study was ensiled in the bag (pH = 4.91), which may have increased its palatability as seen by the increased DMI by calves fed UCS diets compared to those fed TCS. Steers fed TCS and TDG had a lighter ($P = 0.05$) HCW and reduced ($P \leq 0.01$) backfat (**BF**) when compared to steers fed UCS in Exp. 1. Similarly, heifers fed TCS had a lighter ($P < 0.01$) HCW and reduced ($P < 0.01$) BF and YG when compared to those fed either UCS or SIL in Exp. 2. There were no differences ($P \geq 0.08$) in Longissimus dorsi muscle (**LM**) area or marbling score (**MS**) for steers in Exp. 1. Due to the changes in HCW and BF, steers fed TCS had the decreased ($P < 0.01$) yield grade (**YG**), those fed UCS had the greatest, and those fed TDG were intermediate. Heifers had reduced MS ($P = 0.02$) when fed UCS compared to TCS; feeding SIL was intermediate for MS. LM area was unaffected by treatment ($P = 0.54$) in Exp 2.

Carcass results from CaO treatment of corn stover in other studies correlated with their growth performance. Shreck et al. (2012a,b) reported an increase in HCW consistent with increased final BW. Russell et al. (2011) reported an increase in BF corresponding with an increased YG. The previously mentioned studies reported no change in LM area and MS. Benton et al. (2007) reported that feeding 8% corn stover in place of 8% silage in a diet consisting of 30% WDGS did not impact carcass characteristics. The difference noted in our results compared to the studies above are likely a reflection of the decreased performance we observed when TCS was fed at the increased level of corn stover included when compared to the Benton et al. (2007) study.

Experiment 3:

Apparent DM digestibility increased ($P = 0.02$) when steers were fed TCS and SIL diets compared to when they were fed UCS, and they did not differ from the CON fed steers; apparent DM digestibility by steers fed TDG was intermediate (Table 6). NDF digestibility patterns tended to ($P = 0.06$) follow DM digestibility. Steers fed TCS diets had the greatest ($P = 0.01$) ADF digestibility, while steers fed UCS had the least; steers fed CON, SIL and TDG were intermediate.

Russell et al. (2011) reported an increase in apparent DM digestibility when feeding CaO-treated stover compared to untreated stover, similar to the current finding. They also observed a trend for increased NDF and ADF digestibility. Shreck et al. (2013) reported a very similar increase in both apparent NDF and DM digestibility as well. We hypothesized that feeding TDG would also increase fiber digestibility. Felix et al. (2012) reported a 50% increase in in situ fiber digestibility when cattle were fed dry distillers grains with solubles (DDGS) that had been treated with 2% NaOH. They theorized that this was due to increased ruminal pH improving cellulolytic activity because cellulolytic microbial activity necessary for the digestion of roughages begins to decline when ruminal pH drops below 6.1 (Mould and Orskov, 1983).

To test this theory of improved ruminal digestibility, corn stover, treated and untreated, was placed in in situ bags to measure ruminal degradation of each source. In situ digestibility of corn stover and CaO-treated corn stover was measured at 12, 24, 36, and 48 h (Table 7). Treating corn stover with CaO increased in situ DM disappearance at 12, 24, 36, and 48 h when compared to untreated stover. Similarly, treating corn stover increased in situ NDF disappearance at all but 12h time points as well. These data support our findings that treating corn stover with 5% CaO increases both DM and fiber digestibility, and the increase in apparent total tract fiber digestibility is likely driven by increased ruminal fiber fermentation.

Surprisingly, ruminal pH did not increase with the increase in fiber digestibility as expected. There were no pH differences ($P = 0.22$) among treatments in the current study (Table 8). In fact, there was a trend for *decreased* ($P = 0.06$) ruminal pH in steers fed TCS compared to those fed UCS. This is contrary to the increase in pH expected from the CaO treatment neutralizing the acidity in the rumen, as was reported in NaOH treatment of DDGS (Felix et al., 2012) and CaO treatment of corn stover (Shreck et al., 2013). However, feeding steers TCS had increased ($P \leq 0.05$) ruminal concentration of VFA (Table 9) which may explain the decrease in pH. The VFA are weak acids ($pK_a = 4.8$) and can reduce ruminal pH after rapid and increased intake (Van Soest, 1994). In the current study, it was observed that the fiber mat of cattle fed TCS was frequently lacking during ruminal collections, suggesting a decreased rate of degradation of the TCS and increased rates of passage when compared to cattle fed UCS or SIL. Reduction in the fiber mat can decrease the stimulation of rumination, which decreases salivary buffering resulting in a more acidic rumen (Ruckebusch, 1988).

There were no diet × hour interactions ($P \geq 0.08$) for any of the VFA measured in this experiment (Table 9). There was an effect of diet ($P = 0.05$) on acetate concentration. Steers fed TCS had the greatest mean acetate concentrations. Acetate concentrations are indicative of fiber fermentation (Van Soest, 1994) and suggest increased fiber fermentation. As previously mentioned, fiber digestibility was increased in steers fed TCS compared to those fed UCS; therefore, the acetate response corroborates this evidence, further supporting increased ruminal fiber digestibility. The concentration of acetate in the rumen of steers fed TCS at the 0 h (52.84 m*M*) versus 6 h (53.71 m*M*) time point is unusual as they did not greatly differ. Animals were collected at 0 h prior to feeding where VFA production is expected to be least and 6 h to represent peak fermentation and, therefore, peak VFA production. The reason for the lack of distinction between the 0 h and 6 h concentrations with acetate is unknown at this time. One possibility is that the CaO treatment is affecting intake patterns. These steers were fed for ad libitum intakes; therefore, they had access to feed all day and could have eaten directly prior to ruminal sampling at 0 h.

No dietary effect was observed for propionate ($P = 0.43$) or butyrate ($P = 0.33$); therefore, the total VFA concentrations mirrored the acetate response. Steers fed TCS had the greatest ($P = 0.03$) concentration of total VFA and steers fed UCS had the least. This increase in total VFA was largely driven by the increased acetate. However, this increase in acetate did not affect the acetate to propionate ratio ($P \geq 0.08$) , due to the lack of change in propionate concentrations.

Contrary to our results, a recent ruminal metabolism study reported a *decrease* in propionate and no change in acetate or total VFA concentrations when cattle were fed 5% CaO-treated stover compared to untreated stover (Shreck et al., 2013). They also reported an increase in ruminal pH when cattle were fed treated corn stover. These data support our theory that, in the current study, increased VFA production is counteracting any potential increase in ruminal pH resulting from the alkali treatment.

CONCLUSIONS

Although treating corn stover with 5% CaO increased ruminal fiber fermentation, it did not increase production performance as would be expected with increased digestibility of a diet. This is largely due to decreased DMI. The decrease in intake may be due to decreased ruminal pH (Owens et al., 1998) or decreased palatability, which requires further study to confirm. However, treating corn stover did increase apparent total tract DM digestibility, fiber digestibility or resulted in greater acetate production. Treating corn stover reduced ruminal pH, even though this did not seem to affect fiber fermentation.

The impact of adding CaO to an acidic diet, i.e. the TDG diets, had little impact on ruminal pH and fiber digestibility at the 1% inclusion level. Further studies at greater inclusion levels may be warranted. although feeding cattle TCS improved ruminal metabolism similar to that of SIL and CON diets, feeding ensiled UCS was comparable to feeding SIL as regards production performance. In the current study, bagging and ensiling corn stover prior to feeding improved animal performance when compared to feeding 5% CaO-treated corn stover.

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TABLES

Table 1. Composition of diets fed in Experiment 1.

	Dietary treatment[1]		
Item, % DM basis	UCS	TCS	TDG
Corn stover	20.00	-	20.00
Treated corn stover[2]	-	20.00	-
Corn silage	-	-	-
MWDGS[3]	40.00	40.00	40.00
Dry rolled corn	30.00	35.00	34.00
High Ca supplement[4]	10.00	-	-
Low Ca supplement[5]	-	5.00	5.00
CaO[6]	-	-	1.00
Analyzed composition			
NDF	30.29	28.65	30.22
ADF	19.31	17.93	19.25
CP	15.69	16.19	15.78
Fat	6.39	6.35	6.47
Ca	0.99	0.83	1.10
P	0.37	0.38	0.38
S	0.29	0.29	0.27

[1] UCS = Untreated corn stover, TCS = Treated corn stover, TDG = Treated distillers grains.

[2] Corn stover brought to 50% moisture and treated with 5% CaO ([71% Ca, MicroCal OF 200], Mississippi Lime Company [St. Louis, MO])

[3] MWDGS = Modified wet distillers grains with solubles.

[4] High Calcium supplement included: 75% corn, 23% limestone, 0.91% TMS (20% $CaCo_3$, 15.43% 4 ZINPRO, 14.17% KCl, 8.75% MgO, 8% $MnSo_4$, 6.74% $FeSO_4$, 6.54 Rice hulls mineral oil, 6.21% $ZnSO_4$, 5.95% S prilled, 4.41% VIT E 50%, 1.50% Se, 1.03% $MgSO_4$, 0.88% $CuSO_4$, 0.22% Vit A 1000, 0.13% Vit D3 500 MS, 0.04% $Ca(IO_3)_2$ 63.5% to yield 5% Mg, 10% S, 7.5% K, 2% Fe, 3% Zn, 3% Mn, 5,000 mg/kg Cu, 250 mg/kg I, 40 mg/kg Co, 150 mg/kg Se, 2,204,634 IU/kg Vitamin A, 7,275,293 IU/kg Vitamin D_3, 22,046 IU/lb Vitamin E), 0.15% Rumensin 90, (Elanco; Greenfield, IN) 0.10% Tylan 40, (Elanco; Greenfield, IN), 0.77% fat.

[5] Low Calcium supplement included: 87% corn, 9% limestone, 1.8% TMS (20% $CaCo_3$, 15.43% 4 ZINPRO, 14.17% KCl, 8.75% MgO, 8% $MnSo_4$, 6.74% $FeSO_4$, 6.54 Rice hulls mineral oil, 6.21% $ZnSO_4$, 5.95% S prilled, 4.41% VIT E 50%, 1.50% Se, 1.03% $MgSO_4$, 0.88% $CuSO_4$, 0.22% Vit A 1000, 0.13% Vit D3 500 MS, 0.04% $Ca(IO_3)_2$ 63.5% to yield5% Mg, 10% S, 7.5% K, 2% Fe, 3% Zn, 3% Mn, 5,000 mg/kg Cu, 250 mg/kg I, 40 mg/kg Co, 150 mg/kg Se, 2,404,634 IU/lb Vitamin A, 7,275,293 IU/lb Vitamin D_3, 22,046 IU/lb Vitamin E) 0.304% Rumensin 90, (Elanco; Greenfield, IN), 0.197% Tylan 40, (Elanco; Greenfield, IN), 1.51% fat.

[6] CaO = Calcium Oxide

Table 2. Composition of diets fed in Experiment 2.

	Dietary treatment[1]		
Item, % DM basis	UCS	TCS	SIL
Corn stover	20.00	-	-
Treated corn stover[2]	-	20.00	-
Corn silage	-	-	40.00
MWDGS[3]	40.00	40.00	40.00
Dry rolled corn	30.00	35.00	10.00
High Ca supplement[4]	10.00	-	10.00
Low Ca supplement[5]	-	5.00	-
Analyzed composition			
NDF	30.29	28.65	33.40
ADF	19.31	17.93	20.16
CP	15.69	16.19	15.68
Fat	6.39	6.35	7.20
Ca	0.99	0.83	0.95
P	0.37	0.38	0.36
S	0.29	0.29	0.29

[1] UCS = Untreated corn stover, TCS = Treated corn stover, SIL = Silage.
[2] Corn stover brought to 50% moisture and treated with 5% CaO ([71% Ca, MicroCal OF 200], Mississippi Lime Company [St. Louis, MO]).
[3] MWDGS = Modified wet distillers grains with solubles.
[4] High Calcium supplement included: 75% corn, 23% limestone, 0.91% TMS (20% $CaCo_3$, 15.43% 4 ZINPRO, 14.17% KCl, 8.75% MgO, 8% $MnSo_4$, 6.74% $FeSO_4$, 6.54 Rice hulls mineral oil, 6.21% $ZnSO_4$, 5.95% S prilled, 4.41% VIT E 50%, 1.50% Se, 1.03% $MgSO_4$, 0.88% $CuSO_4$, 0.22% Vit A 1000, 0.13% Vit D3 500 MS, 0.04% $Ca(IO_3)_2$ 63.5% to yield5% Mg, 10% S, 7.5% K, 2% Fe, 3% Zn, 3% Mn, 5,000 mg/kg Cu, 250 mg/kg I, 40 mg/kg Co, 150 mg/kg Se, 2,204,634 IU/kg Vitamin A, 7,275,293 IU/kg Vitamin D_3, 22,046 IU/lb Vitamin E), 0.15% Rumensin 90, (Elanco; Greenfield, IN). 0.10% Tylan 40, (Elanco; Greenfield, IN), 0.77% fat.
[5] Low Calcium supplement included: 87% corn, 9% limestone, 1.8% TMS (20% $CaCo_3$, 15.43% 4 ZINPRO, 14.17% KCl, 8.75% MgO, 8% $MnSo_4$, 6.74% $FeSO_4$, 6.54 Rice hulls mineral oil, 6.21% $ZnSO_4$, 5.95% S prilled, 4.41% VIT E 50%, 1.50% Se, 1.03% $MgSO_4$, 0.88% $CuSO_4$, 0.22% Vit A 1000, 0.13% Vit D3 500 MS, 0.04% $Ca(IO_3)_2$ 63.5% to yield 5% Mg, 10% S, 7.5% K, 2% Fe, 3% Zn, 3% Mn, 5,000 mg/kg Cu, 250 mg/kg I, 40 mg/kg Co, 150 mg/kg Se, 2,404,634 IU/lb Vitamin A, 7,275,293 IU/lb Vitamin D_3, 22,046 IU/lb Vitamin E) 0.304% Rumensin 90, (Elanco; Greenfield, IN), 0.197% Tylan 40, (Elanco; Greenfield, IN), 1.51% fat.

Table 3. Composition of diets fed in Experiment 3.

	Dietary treatment[1]				
Item, % DM basis	UCS	TCS	TDG	SIL	CON
Corn stover	20.00	-	20.00	-	
Treated corn stover[2]	-	20.00	-	-	
Corn silage	-	-	-	40.00	15.00
MWDGS[3]	40.00	40.00	40.00	40.00	25.00
Dry rolled corn	30.00	35.00	34.00	10.00	50.00
High Ca supplement[4]	10.00	-	-	10.00	10.00
Low Ca supplement[5]	-	5.00	5.00	-	-
CaO[6]	-	-	1.00	-	-
Analyzed composition					
NDF	31.27	28.86	31.42	32.57	21.55
ADF	18.92	19.75	18.96	20.50	11.50
CP	16.02	16.47	16.13	16.09	13.38
Fat	4.59	4.75	4.75	4.82	4.47
Ca	1.02	0.91	1.03	1.11	0.99
P	0.38	0.38	0.39	0.39	0.33
S	0.29	0.28	0.27	0.30	0.23

[1] UCS = Untreated corn stover, TCS = Treated corn stover, TDG = Treated WDGS, SIL = Silage, CON = Control.

[2] Corn Stover wetted to 50% moisture and treated with 5% CaO ([71% Ca, MicroCal OF 200], Mississippi Lime Company [St. Louis, MO]).

[3] MWDGS = modified wet distillers grains with solubles.

[4] High Calcium supplement included: 75% corn, 23% limestone, 0.91% trace mineral salt (20% $CaCo_3$, 15.43% 4 ZINPRO, 14.17% KCl, 8.75% MgO, 8% $MnSo_4$, 6.74% $FeSO_4$, 6.54 Rice hulls mineral oil, 6.21% $ZnSO_4$, 5.95% S prilled, 4.41% VIT E 50%, 1.50% Se, 1.03% $MgSO_4$, 0.88% $CuSO_4$, 0.22% Vit A 1000, 0.13% Vit D3 500 MS, 0.04% $Ca(IO_3)_2$ 63.5% to yield 5% Mg, 10% S, 7.5% K, 2% Fe, 3% Zn, 3% Mn, 5,000 mg/kg Cu, 250 mg/kg I, 40 mg/kg Co, 150 mg/kg Se, 2,204,634 IU/kg Vitamin A, 7,275,293 IU/kg Vitamin D_3, 22,046 IU/lb Vitamin E), 0.15% Rumensin 90, (200g Rumensin/kg; Elanco; Greenfield, IN) 0.10% Tylan 40, (80g Tylosin/kg; Elanco; Greenfield, IN), 0.77% fat.

[5] Low Calcium supplement included: 87% corn, 9% limestone, 1.8% trace mineral salt (20% $CaCo_3$, 15.43% 4 ZINPRO, 14.17% KCl, 8.75% MgO, 8% $MnSo_4$, 6.74% $FeSO_4$, 6.54 Rice hulls mineral oil, 6.21% $ZnSO_4$, 5.95% S prilled, 4.41% VIT E 50%, 1.50% Se, 1.03% $MgSO_4$, 0.88% $CuSO_4$, 0.22% Vit A 1000, 0.13% Vit D3 500 MS, 0.04% $Ca(IO_3)_2$ 63.5% to yield 5% Mg, 10% S, 7.5% K, 2% Fe, 3% Zn, 3% Mn, 5,000 mg/kg Cu, 250 mg/kg I, 40 mg/kg Co, 150 mg/kg Se, 2,404,634 IU/kg Vitamin A, 7,275,293 IU/kg Vitamin D_3, 22,046 IU/kg Vitamin E) 0.304% Rumensin 90, (200g Rumensin/kg; Elanco; Greenfield, IN), 0.197% Tylan 40, (80g Tylosin/kg; Elanco; Greenfield, IN), 1.51% fat.

Table 4. Feedlot growth performance and carcass characteristics for steers fed in Experiment 1.

	Dietary treatment[1]				
Item	UCS	TCS	TDG	SEM	*P*-value[2]
n, pen (animal)	7(53)	7(55)	7(54)	-	-
Initial BW, kg	438	436	435	1	0.30
Final BW, kg	558[a]	542[b]	545[b]	4	0.02
ADG, kg	1.61[a]	1.35[b]	1.42[ab]	0.07	0.03
DMI, kg	10.62[a]	8.78[b]	8.59[b]	0.17	<0.01
G:F	0.1519	0.1532	0.1661	0.0064	0.24
HCW, kg	338[a]	327[b]	330[b]	2	0.01
Calculated yield grade[3], kg	3.06[a]	2.65[b]	2.86[ab]	0.08	<0.01
LM area, cm^2	79.67	80.43	78.63	0.94	0.37
Marbling score[4]	434	396	412	12.3	0.08
Backfat, cm	1.20[a]	0.94[b]	1.02[b]	0.05	<0.01

[1]UCS = Untreated corn stover, TCS = Treated corn stover, TDG = Treated distillers grain.

[2]Means in the same row with different superscript letters differ ($P \leq 0.05$).

[3]Yield grade calculation:[2.5 + (6.35 × cm. back fat) + (0.20 × %KPH) + (0.0017 × kg. HCW) – (2.06 × LM area $cm.^2$)].

[4]Marbling score: 300-399 – Slight; 400-499 – Small; 500-599 – Modest.

Table 5. Feedlot growth performance and carcass characteristics of heifers fed in Experiment 2.

	Dietary treatment[1]				
Item	UCS	TCS	SIL	SEM	*P*-value[2]
n, pen (animal)	6(47)	6(45)	6(46)	-	-
Initial BW, kg	406	406	406	1	0.96
Final BW, kg	504[b]	490[c]	516[a]	4	<0.01
ADG, kg	1.31[ab]	1.10[b]	1.48[a]	0.08	<0.01
DMI, kg	8.98[a]	7.42[b]	8.55[a]	0.22	<0.01
G:F	0.1472[b]	0.1467[b]	0.1731[a]	0.0082	0.04
HCW, kg	308[a]	292[b]	313[a]	2	<0.01
Calculated yield grade[3], kg	2.91[a]	2.37[b]	2.88[a]	0.08	<0.01
LM area, cm^2	79.03	79.52	80.54	1.04	0.54
Marbling score[2]	470[a]	408[b]	440[ab]	12	0.02
Backfat, cm	1.23[a]	0.88[b]	1.23[a]	0.04	<0.01

[1]UCS = Untreated corn stover, TCS = Treated corn stover, SIL = Silage.

[2]Means in the same row with different superscript letters differ ($P \leq 0.05$).

[3]Yield grade calculation:[2.5 + (6.35 × cm. back fat) + (0.20 × %KPH) + (0.0017 × kg HCW) – (2.06 × LM area cm^2)].

[4]Marbling score: 300-399 – Slight; 400-499 – Small; 500-599 – Modest.

Table 6. Effect of dietary treatment on total tract apparent digestibility by steers fed in Experiment 3.

	Dietary treatment[1]						
Item	UCS	TCS	TDG	SIL	CON	SEM	*P*-value[2]
n	5	5	5	5	5	-	-
Apparent Digestibility, % DM basis							
DM	62.6[c]	70.0[ab]	66.4[bc]	70.2[ab]	75.0[a]	2.4	0.02
ADF	49.1[c]	68.3[a]	57.1[bc]	64.3[ab]	63.9[ab]	3.5	0.01

[1]UCS = Untreated corn stover, TCS = Treated corn stover, TDG = Treated distillers grains, SIL = Silage, CON = Control.
[2]Means in the same row with different superscript letters differ ($P \leq 0.05$).

Table 7. Composition and in situ digestibility of untreated corn stover and treated corn stover composited across Experiments 1, 2, and 3.

	Corn stover	
Item, % DM basis	Untreated[2]	Treated[1,2]
NDF	70.1	58.1
ADF	48.8	51.0
Hemicelluloses	21.3	7.1
Cellulose	38.8	36.8
ADL	6.8	6.4
Total dietary fiber	76.8	66.7
Insoluble dietary fiber	72.8	64.1
Soluble dietary fiber	4.0	2.5
In situ disappearance		
DM		
12[3]	9.53	9.96
24	13.90	24.22
36	15.80	34.65
48	25.46	41.36
NDF		
12	5.78	4.80
24	6.09	17.93
36	16.89	33.22
48	25.66	42.35

[1] Treated with 5% CaO (71% Ca, MicroCal OF 200, Mississippi Lime Company St. Louis, MO).

[2]Corn stover wetted to 50% DM and ensiled in AG-BAG (AG-BAG, St. Nazianz, WI).

[3]Values reflect hours within the rumen, corrected for washout (0 h) of DM and NDF.

Table 8. Effect of dietary treatment on ruminal pH change over time in Experiment 3.

	Dietary Treatment[1]						*P*-values[2]		
	UCS	TCS	TDG	SIL	CON	SEM	D	D × H	T vs. U[3]
n	5	5	5	5	5				
Ruminal pH						0.1	0.22	0.65	0.06
0[4]	6.91	6.36	6.75	6.87	6.7				
1.5	6.28	5.99	6.38	6.33	6.14				
3	6.21	5.89	6.22	6.13	6.14				
6	5.94	5.84	6.24	6.06	6.04				
9	6.20	5.83	5.98	6.06	5.94				
12	6.10	5.92	6.06	6.08	5.91				
18	6.40	6.05	6.27	6.37	6.07				

[1]UCS = Untreated corn stover, TCS = Treated corn stover, TDG = Treated distillers grain, SIL = Silage, CON = Control.

[2]D = Main effect of dietary treatment; D × H = interaction of dietary treatment × hour.

[3]Contrast of TCS vs. UCS.

[4]Time post-feeding (h).

Table 9. Effect of dietary treatment on ruminal VFA concentrations over time from steers fed in Experiment 3.

	Dietary treatment[1]						*P*-values[2, 3]		
Item	UCS	TCS	TDG	SIL	CON	SEM	D	D × H	T vs. U[4]
n	5	5	5	5	5	-	-	-	-
Acetate, m*M*						3.1	0.05	0.40	<0.01
0[5]	38.0	52.8	42.0	41.3	39.5				
6	49.66	53.71	55.06	47.92	51.29				
Propionate, m*M*						3.5	0.43	0.87	0.27
0	11.6	18.9	13.1	11.1	17.6				
6	23.5	26.4	21.4	21.2	27.8				
Butyrate, m*M*						1.8	0.33	0.56	0.06
0	6.6	12.0	8.3	6.8	7.9				
6	11.4	13.7	12.7	12.3	11.4				
Total VFA, m*M*						6.3	0.03	0.71	<0.01
0	58.8	86.7	66.7	62.0	68.2				
6	84.8	97.1	92.6	84.6	93.9				
A:P[6]						0.4	0.65	0.08	0.89
0	3.4	3.0	3.5	3.7	2.7				
6	2.2	2.3	3.0	2.3	2.2				

[1]UCS = Untreated corn stover, TCS = Treated corn stover, TDG = Treated distillers grain, SIL = Silage, CON = Control.

[2]D = Main effect of dietary treatment; D × H = interaction of treatment by hour.

[3]Means in the same row with different superscript letters differ ($P \leq 0.05$).

[4]Contrast of TCS vs. UCS.

[5]Time post-feeding (h).

[6]A:P = ratio of Acetate to Propionate.

CHAPTER 3: CONCLUSION

As long as corn prices remain high as a result of ethanol production, feeding co-products like modified wet distillers grains with solubles (**MWDGS**) and corn stover (**CS**) as partial or complete corn replacement feeds will be necessary. However, feeding DGS to cattle presents challenges. Recently it has been suggested that the greatest issue with feeding DGS is its negative effects on ruminal pH, and that this may be overcome through the use of alkaline agents. Furthermore, recent research has suggested that treatment of corn stover with alkalizing agents, namely calcium oxide (**CaO**), prior to feeding will improve its digestibility and, ultimately, cattle growth performance. However, the combined effects of ruminal buffering and potentially increasing digestibility with corn stover and DGS diets have not been investigated. Therefore, in an effort to determine the combination of the effects of alkaline agents on MWDGS and CS, three experiments were designed and tested.

In experiment 1, our objective was to determine the effects of feeding CaO-treated MWDGS or CS to cattle during the finishing phase on growth, feed efficiency, and carcass characteristics. We found that feeding CaO-treated CS to cattle decreased final body weight (**BW**), average daily gain (**ADG**), and dry matter intake (**DMI**) compared to feeding CS that had not been treated. Feeding treated MWDGS to cattle decreased final BW and DMI when compared to untreated CS, but was intermediate for ADG with respect to treated CS and untreated CS. Feeding treated CS resulted in decreased backfat and yield grade (**YG**); but, marbling score (**MS**) and longissimus muscle (**LM**) area were unaffected. Therefore, simply wetting and bagging CS was a more effective feeding strategy than treating either MWDGS or CS with CaO.

In Experiment 2, our objective was to determine the effects of feeding CaO-treated CS or corn silage to cattle during the finishing phase on growth, feed efficiency, and carcass characteristics. We found that, once again, cattle fed treated CS had the lightest final BW and lowest DMI. Cattle fed corn silage had similar ADG and DMI, and improved feed efficiency and final BW when compared to cattle fed untreated CS. Although we had hypothesized that feeding treated CS would result in growth performance more similar to the cattle fed immature forage, corn silage, the cattle fed untreated CS actually performed more similarly to those fed corn silage. Cattle fed treated CS had decreased YG, MS, and BF when compared to those fed corn silage or untreated CS. These data, again, suggest that simply wetting and bagging CS may be an effective strategy for its use in beef cattle diets. Furthermore, they suggest that cattle fed this bagged, untreated CS product and MWDGS can achieve similar feedlot performance as cattle fed corn silage with MWDGS.

In Experiment 3, our objectives were to determine the effects of feeding CaO-treated MWDGS or treated CS, and corn silage, on ruminal metabolism and in situ dry matter disappearance in fistulated cattle. Feeding treated CS and corn silage resulted in increased dry matter (**DM**) and ADF digestibility compared to feeding untreated CS. Contrary to our hypothesis, feeding cattle treated CS tended to decrease ruminal pH compared to the other diets. This reduction in ruminal pH may have been because feeding treated CS increased both mean acetate and total VFA concentrations when compared to all other treatments. Therefore, treating CS with CaO increased digestibility of fiber, and was comparable to feeding corn silage or corn-based diets with regards to ruminal metabolism.

Although treating CS with 5% CaO (DMB) improved ruminal fiber digestibility, effects on growth performance were not realized. Therefore, a more practical strategy for feeding CaO, based on this study's results, may be harvesting and anaerobically storing wetted, untreated CS. Treatment of MWDGS with CaO at 2.5% (DMB) did not affect ruminal pH, nor did it improve digestibility and, therefore, does not appear to be a viable management practice for producers feeding DGS-based diets. Research at greater dietary inclusion levels of CaO in the diet may be warranted.