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USE OF ALKALINE TREATED CROP RESIDUES AS PARTIAL GRAIN
REPLACEMENTS FOR FINISHING CATTLE

By

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A DISSERTATION

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

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USE OF ALKALINE TREATED CROP RESIDUES AS PARTIAL GRAIN
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University of Nebraska, 2013

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Recently, corn has become expensive and this has led to high feed costs and decreased profitability. High priced corn has allowed for the consideration of other ingredients as replacements to reduce diet cost. In much of the Corn Belt, supplies of wet or modified distillers grains and crop residues are abundant. These ingredients were investigated as corn replacements. Studies were conducted to identify methods for treating crop residues to improve digestibility and value in finishing diets based on corn grain and corn wet distillers grain with solubles (WDGS). Digestibility and value of crop residues were improved by mild chemical treatment. Moisture and temperature affected treatment response and extending reaction times beyond 7 days did not improve digestibility. The magnitude of response to chemical treatment depends on the type of residue (i.e., straw vs. stover) and plant part within corn residue (i.e., husk vs. stalk). Treating crop residues at 50% DM with 5% calcium oxide fed in conjunction with wet or modified distillers grains can replace up to 15 percentage units of corn without hindering performance. It appears that moisture, storage time, and plant part affect response to chemical treatment. Feeding chemically treated crop residues and wet or modified distillers grains is an effective strategy for replacing a portion of corn grain in feedlot

diets. Replacing 15% units of corn and all of the untreated roughage with treated crop residue resulted similar nutrient supply to the animal. Reducing grind size, feeding a maximum of 20% treated crop residue, and maintaining at least 25% corn in the diet are strategies for optimizing cattle performance for replacing corn with treated crop residues and distillers grains. Collectively, these studies demonstrate corn replacement options which should reduce diet costs, maintain performance and ultimately increase profitability.

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DEDICATION

I dedicate this work to my wife, Karen. Who washed dishes while I filtered, listened when I complained, built me up when I was down, and always made life better. You're my rock and without you I wouldn't be half of what I am.

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INTRODUCTION

Of the animal kingdom, the suborder of *ruminantia* is the most efficient converter of fibrous materials into edible protein. To be competitive with other species however, both dairy and beef cattle are commonly fed diets that are rich in grain, to increase production efficiency and growth rate. Currently, demand for corn is increasing. Some of this increase in corn price can be explained by ethanol production. As the price of corn and crude oil are linked, high energy prices may dictate that ethanol is the best use of corn. In the future, demand for corn will only become more competitive. Livestock will be less competitive for corn compared to humans. Relative to fish, swine, and poultry, ruminants are the least efficient at converting starch into protein.

The increase in worldwide population has put pressure on technology to supply the needed increase in food production to meet global protein demand. Rapid economic growth of developing nations has led to increases in needs for energy and food. As these developing nations gain affluence, consumption of protein generally switches from plant to animal sources.

Therefore, it is important to consider alternative feedstuffs to corn grain in cattle feeding, in order to help meet protein needs of the world. While corn grain has increased demand, the United States has consistently grown more and more corn over the past 50 years (Cassman et al., 2006). As corn production increases, residue from that crop also increases. A review of the literature was conducted to understand the history of enhancing digestibility of poor quality crop residues by chemical treatment.

CHAPTER I. REVIEW OF LITERATURE

Corn based beef industry. Since the 1940s and 1950s, the U.S. beef feedlot industry has used corn grain to finish cattle (Corah, 2008). Still today, corn is the primary grain used in finishing diets. Vasconcelos and Galyean., (2007) reported that 100% of feedlot consultants (whose clients accounted for 70% of cattle on feed at the time of survey) used corn as the primary grain source. However, recent supplies of byproducts from corn wet and dry milling industries have increased in popularity and replaced some corn. Since 1980, the proportion of the U.S. corn crop used for alcohol fuel has increased from 0.7% to 49.4%, while corn designated for feed use has declined from 86.5% to 41.1% (ERS, 2012). Correspondingly, the cattle feeding industry has undergone a “paradigm shift” (Hersom et al., 2009). Paradigm shift can be characterized as the replacement of corn grain, the long standing inexpensive energy source, with byproduct feeds from corn milling that are usually higher in fiber and lower in starch. Thompson (1980) noted, “reduced grain feeding seems inevitable” regarding the future of cattle feeding. Regionally, opinions vary what the future of cattle feeding will be. In areas with less access to byproducts and forages, the use of grain processing should increase as higher feed prices encourage greater energy capture from grain (Galyean, 2010). Others suggest that corn replacement strategies, such as corn milling byproducts and crop residues which are in abundance in the northern plains and Midwest, could serve as a direct solution that will reduce feed costs while maintaining adequate performance (Sewell et al., 2008; Berger and Singh, 2010; Donkin et al., 2013; Burken et al., 2013).

Undeniably, crop residue is abundant. A reported 96.4 million acres were planted for corn in U.S. during 2012 (NASS). Based on residue estimates from Burken et al. (2013) of 10.25 tons of DM yield per acre, an estimated 988 million DM ton of corn residue would be produced. In 2011, 48.8 million acres of wheat were harvested, which yielded 43.7 bu/acre (NASS). An estimated 1500 DM pounds of straw is produced for every DM ton of wheat (T.J. Klopfenstein, personal communication). Correspondingly, an estimated 47.9 million DM ton of wheat straw was produced as well. Unfortunately, these crop residues do not have energy similar to corn grain. As noted in Sunstøl and Owen (1984): “In folk-lore and metaphor, straw is regarded as an inferior substance.” Tabular values for wheat or oat straw are below 50 TDN (NRC, 1996). Burken et al. (2012) suggested that the energy value of corn stover was 41 TDN.

Pond et al. (1980) noted that crop residues’ inherent poor digestibility is a constraint that would limit animal protein production. Increasing digestibility of poor quality crop residues by chemical treatment could be an avenue to replace corn and increase overall production (Anderson, 1978). Indeed, many efforts have focused on improving digestibility crop residues by a variety of chemical treatment methods (Goering et al., 1973; Kerley, 1987; Klopfenstein, 1978; Ben-Ghedalia, et al., 1983). However, commercial application of treated crop residues never gained foothold in the feedlot industry as this resulting feedstuff’s competitiveness was either reduced during low priced corn, had sustainability concerns due to sodium excretion (Berger, 1979ab), or lacked economically priced protein to complement unlocked energy (Cecava et al., 1990; Willms et al., 1991;).

Distillers grains. In today's feed market, an inverse of the historical paradigm exists: inexpensive protein sources with expensive starch and energy sources. This demand for energy has been driven partly by the rise in ethanol production. Ethanol production has partially increased due to the Volumetric Ethanol Excise Tax Credit (VEETC). The VEETC, created as part of American Jobs Creation Act of 2004, provided subsidies to the ethanol industry as blenders credits to gasoline at \$0.45 per gallon. Additionally, recent legislation promoted the increase in ethanol production, which has increased the amount of distillers grains (DG). Ethanol mandates of 7.5 billion gallons by the Energy Policy Act of 2005 and further increases to the Renewable Fuels Standard of 15 billion gallons from grain ethanol by Energy Independence and Security Act of 2007 have led to increases of byproduct.

Distillers grains now provide relatively inexpensive protein as protein content is increased 3-fold compared to corn grain (Buckner et al., 2011). However, as distillers grains are priced relative to corn (Waterbury et al., 2009), this allows for feeding as an energy source. Greater energy utilization by feedlot cattle for increasing moisture content of DG has been observed (Klopfenstein et al., 2008; Nuttelman et al., 2010), even though nutrient content is unchanged. Dry matter intake appears to increase as moisture content of DG decreases, indicating a response to decreased energy density of the diet. Research to date has suggested a small improvement in NDF digestibility of wet compared to dry DG, but the differences contributing to observed performance largely remain an enigma (Nuttelman et al., 2012). However, whatever factors contribute to this difference must be primarily related to energy utilization, rather than supply of nutrients. A meta-analysis by Klopfenstein et al. (2008) found that 30 to 40% inclusion (DM basis)

of wet DG optimized G:F in dry rolled and high moisture corn based diets. Mechanisms behind the improvement in energy value of DG, regardless of moisture content, relative to corn are unexplained. In a review, Stock et al. (2000) stressed that digestibility of DG was not a factor related to increased performance compared to the corn which it replaced. Several studies have found lower DM or OM digestibility in distillers grain based diets compared to corn based (Corrigan et al., 2009; Vander Pol et al., 2009;). Vander Pol et al. (2009) speculated that the improvements were related to greater propionate production, greater fat digestibility, or greater amounts of unsaturated fatty acids being supplied post-rationally.

Protein. Distillers grains contain appreciable amounts of crude protein (31.7%; Buckner et al. 2011), the majority (50-75%) of which is resistant to degradation by rumen microbes (NRC, 1996; Akayezu et al., 1996; Kleinschmidt et al., 2007) but is very digestible post-rationally (Corrigan et al., 2009). As the protein in DG is mostly undegraded, some have questioned if DIP requirements are met through urea recycling. The NRC (1996) model would predict a DIP deficiency, with excesses in MP supply (requiring nearly all N to be recycled), when 20% DDGS is fed in a corn based diet. Lack of response to urea (Vander Pol, et al., 2005; Jenkins et al., 2012), however, suggested that adequate urea recycling ability existed to meet N needs of rumen microbes. Correspondingly, feeding a diet containing 40% WDGS would likely meet protein requirements for finishing cattle, as wet DG tends to have lower UIP content (Kleinschmidt et al., 2007) and less N would need to be recycled compared to DDGS. Willms et al. (1991ab) identified that protein supplementation stood as the biggest obstacle for the commercial application of feeding alkaline hydrogen peroxide treated

wheat straw. Today, this obstacle would be easily overcome with the supply of DG and corn gluten feed.

Lipid. Distillers grains are also high in lipid (11.8%; Buckner et al., 2011). Some have speculated that the majority of improvement in feeding value relative to corn is distillers grains' fat content. The relative increase in fat content of distillers grains compared to corn (2.8 fold) is similar to the NE_g difference (2.4 fold) for fat compared to corn (Zinn, 1988; Benton, 2010). One could expect that the fat in corn distillers grains would be of similar composition to corn oil and be metabolized similarly. Duckett et al. (2002) found that corn oil was composed of 82.2 to 83.2% unsaturated fatty acids and 69.2 to 73.2% of dietary fat supplied by corn oil was bihydrogenated. However, the observations of Vander Pol et al. (2009) suggested that corn oil is biohydrogenated to a much greater extent than the lipid in DG, based on duodenal fatty acid composition. This is supported by others who have observed increased polyunsaturated fatty acid composition of meat from cattle fed distillers grains (Roeber et al., 2005; Mello et al., 2012). In contrast to most fat sources, depressions in NDF digestion are not commonly observed when distillers grains or condensed distillers solubles is included in growing (Loy et al., 2007) or finishing diets (Bremer et al., 2010; Pesta et al., 2012). Collectively, greater lipid intake and supplying unsaturated fatty acids to the duodenum, which are preferentially digested compared to saturated fatty acids (Zinn et al., 2000), may explain some of the performance responses observed with distillers grains relative to corn.

However, recent findings by Jolly et al. (2013ab) questions the influence of fat as an explanation for increased energy value of distillers grains compared to corn. Jolly et al. (2013a) observed no difference in feed efficiency between conventional condensed

distillers solubles and modified distillers grains or condensed distillers solubles and modified distillers grains that had oil partially removed from condensed distillers solubles by centrifugation. This research implied that fat addition from either byproduct had limited value. However, it is unlikely that fat digestibility is enhanced by this centrifugation process. Working from the hypothesis that high lipid intakes could comprise fat digestibility (Plascencia et al., 2003), Bremer et al., (2010) tested several fat sources (corn oil, tallow, CDS, and WDGS) in a finishing diet containing 8.5% dietary fat. The authors noted subtle differences in fatty acid digestibility (fatty acid digestibility ranged 94-97% among treatments) but concluded that fat adsorption was not decreased with high lipid feedlot diets. Similarly, Pesta et al. (2012) observed no difference in fat digestibility among finishing diets (dietary fat ranged 5.3 to 7.4%) with WDGS and CDS as single ingredients and in combination. Research with a pre-fractionation process (which removes a greater amount of lipid compared to centrifugation) found no difference in feed efficiency when steers were fed (35% of diet DM) normal DDGS compared to DDGS which had fat removal by a pre-fractionation process (Kelzer et al., 2011). In that study, however, no difference was observed compared to a DRC based control diet.

Sulfur. Sulfur is exogenously added to the fermentation control pH. Sulfur effects have been characterized as mainly detrimental to both animal health (Gould, 1998) and performance (Sarturi et al., 2013a). Indeed, high ruminal sulfide (H_2S) production may induce polioencephalomalacia (PEM) by absorption of re-inhaled ruminal gases. Lower DMI and ADG are commonly observed with high levels of sulfur, while G:F is not impacted (Sarturi et al., 2013a). However, PEM is manageable and risk of

PEM is low (Nichols et al., 2011) assuming recommended levels of S do not exceed safe limits and adequate roughage is provided. Increasing roughage has shown to effectively reduce H₂S concentration (Vanness et al., 2009; Morine et al., 2012).

Not considered, however, are the potential benefits of additional sulfur. Sulfur may improve production of propionate from lactate through the acrylate pathway (Russell, 2002). Sarturi et al. (2013b) found that addition of a more rumen degradable inorganic (CaSO₄) sulfur source resulted in a 16% increase in propionate concentration compared to organic (corn gluten meal) sulfur sources. However, others (Zinn et al., 1997; Drewnoski et al., 2012) have reported no difference in lactate concentration, suggesting acrylate pathway to convert lactate to propionate was not overwhelmed. Still, the addition of sulfur from ammonium sulfate or sulfuric acid decreased acetate to propionate (A:P) ratio in some studies (Thompson et al., 1972; Rumsey, 1978; Zinn et al., 1997; Vander Pol et al., 2009; Leupp et al., 2009; Drewnoski et al., 2012) but not in diets based on steam flaked corn (May et al., 2009; Smith et al., 2010; Uwituze et al., 2011). Factors such as sulfur source, grain processing method, as well as roughage level may influence results. It stands to reason that the addition of sulfur could enhance feeding strategies that have more fiber and lower fermentation rate by promoting fermentations that favor propionate.

Propionate. Ruminants rely heavily on VFA production to support maintenance and growth. Siciliano-Jones and Murphy (1989) reported that ruminal VFA contributed 51.0 to 71.9% of ME supplied in a diet that contained 80% concentrate. Of the VFAs that are produced in the rumen, propionate captures the greatest amount of energy from fermentation by avoiding losses associated with methane and CO₂ production. Per mole

of glucose fermented, acetate formation yields 1.0 mole of CO₂ and 1.0 mole of CH₄ whereas butyrate yields 1.5 moles of CO₂ and 0.5 moles of CH₄. Proportionally, the energy retained as fermented glucose in acetate, propionate, and butyrate are 0.62, 1.09, and 0.78 respectively (Ungerfeld and Kohn, 2006). Propionate can be produced from two pathways (Russell, 2002), (1) the randomizing pathway or (2) the acrylate pathway. The randomizing pathway primarily uses succinate as an intermediate whereas the acrylate pathway uses lactate. From culture based methods, *Megasphaera elsdenii* and *Bacteriodes ruminicola* are ruminal bacteria presumed to be most commonly associated with the acrylate pathway (Russell, 2002). Propionate is the only VFA that leads to a net production of glucose. However, other substrates can be used for gluconeogenesis. Huntington et al. (2006) summarized several studies and found that propionate (43-77%), L-lactate (13-36%), and amino acids (11-30%) accounted for the maximum theoretical contribution to liver glucose production for beef steers. Increasing propionate may lead to greater fat deposition due greater glucose availability. Smith and Crouse (1984) reported that while acetate provided 70 to 80 percent of the acetyl units for lipogenesis in subcutaneous adipocytes, it only supplied 10 to 25 percent in intramuscular adipocytes. However, the majority (50 to 60%) of the acetyl units for lipogenesis in intramuscular adipocytes came from glucose.

The lipid in DG could have an effect on protozoal numbers. Protozoa are the predominate producers of hydrogen, which has several fates: methane by archea or biohydrogenation of unsaturated fatty acids (Russell, 2002). For finishing cattle, the presumed hypothesis was that most high grain diets and resultant low ruminal pH, caused most to be defaunated. Towne et al. (1990) found no relationship between ruminal pH

and protozoal counts, but the addition of tallow or soybean soap stock reduced protozoal counts. However, no difference was observed when yellow grease was the fat source in diets containing steam flaked sorghum or corn. Oldrick and Firkins (2000) found reduced protozoa counts from the addition of tallow or animal-vegetable fat blends. Van Soest (1994) speculated that loss of ciliated protozoa was a factor contributing to milk fat depression and the resulting loss would promote fermentation towards propionate fermentation.

While emphasis is placed on corn (i.e., starch) substitutes, perhaps more consideration should be placed on the production of propionate from non-starch polysaccharides and fiber. Murphy et al. (1982) identified rumen fermentation characteristics based on substrate and inoculum as influenced by diet (concentrate vs roughage based). For a starch substrate, roughage based diets yielded greater proportions of acetate (59.0 vs 40.0), compared to concentrate based diets, and acetate was the predominate VFA. However, concentrate based diets had higher molar proportion of propionate (30.0 vs 14.0) than roughage based. Similar amounts of acetate for either diets were noted when hemicellulose (57.0 vs 56.0) was the substrate. However, a greater proportion of hemicellulose was fermented to propionate (26.0 vs 18.0) under concentrate based diets than roughage. DiLorenzo and Galvayan (2009) speculated that decreased acetate:propionate ratio observed in several studies (Corrigan et al., 2008; Vander Pol et al., 2009) which compared DG to corn based diets, could be due to hemicellulose fermentation to propionate as DG diets contained more NDF and potentially more hemicellulose. While distillers grains inclusion generally promotes a propionate fermentation, be it replacing corn or roughage, what remains unclear is

whether the carbohydrate source, sulfur content, rumen pH, or fat content contribute to this.

Plant Cell Wall Structure. The plant cell wall is the primary structural component of the plant, lending both protection and strength to the plant. The middle lamella is synthesized first and is composed of pectic substances, primarily galacturonate and rhamnogalacturonate (Selvendran and O'Neill, 1987). Primary cell wall is formed next by cellulose, hemicellulose, and pectin. The primary cell wall is composed of microfibrils that are arranged in a sheet-like manner. The primary cell wall is laid down while cells are dividing and expanding. The microfibrils are parallel linear chains of cellulose that are connected by hydrogen bonds. Some have defined a microfibril as an aggregate of glucose polymers consisting of 60-70 chains (Clovin, 1981; Dey and Brinson, 1984). In some plants that are more lignified and as maturity progresses, a secondary cell wall may take shape. A secondary cell wall is characterized as a thickening of the primary cell wall (Jung and Allen, 1995). This thickening causes the space between the primary cell wall and the middle lamella to become more ordered and less hydrated.

Cell wall carbohydrates. Cellulose is found in both primary and secondary cell walls. The monomeric unit is glucose, which is linked by β 1-4 glycosidic bonds in a linear polymer. Degree of polymerization, or the measure of number of glucose units that make up one polymer molecule, ranges from 2,000 to 6,000 in the primary cell wall and can increase to greater than 10,000 in secondary cell walls (Delmer, 1987). As a plant matures, the increase in polymerization leads to greater strength and lower digestibility. In contrast to cellulose, xylans are more heterogeneous. In a forage cell wall, polymers

of linked β 1-4 xylose are found, as well as arabinose, glucuronic acid, and galactose residues (Wilkie, 1979). Bailey (1973) defined hemicelluloses as structural carbohydrates that are not pectin or cellulose based. Determination of xylans and cellulose can be determined by gravimetric, enzymatic-gravimetric, and enzymatic-chemical methods. The detergent fiber system, originally proposed by Van Soest (1963), is a gravimetric based analysis that is the standard for fiber quantification for ruminants. Neutral detergent fiber solution solublizes non structural plant polysaccharides, leaving hemicellulose, cellulose, and lignin. The disadvantages of NDF system include: all that is solublized is not structural carbohydrate, as well as interference from starch, fat (Buckner et al., 2013), or protein. Acid detergent fiber solution solublizes hemicellulose and the remaining residue is composed of lignin and cellulose.

Limitations to cell wall digestibility. Van Soest (1982) characterized polysaccharides in the plant cell wall as belonging to two classes based on biological associations and nutrient availability: (1) polysaccharides covalently bonded to core lignin and partially fermented (2) those that are not bond, soluble, and completely fermentable. The association of polysaccharides with lignin was also considered by Kerley (1987) as the primary factor limiting cell wall digestibility. Additionally, Kerley (1987) proposed that the crystalline nature of cellulose and low surface area for cellulose attachment as other impairments to fiber utilization.

Core and non-core lignin. Lignin and its associated phenolic monomers reduce microbial carbohydrate degradation dramatically (Van Soest, 1965; Jung and Deetz, 1993; Jung and Allen, 1995). Both concentration and composition of lignin appear to affect digestibility. Lignin has often been classified into two fractions known as core and

non-core lignin. Core lignin is described as a three-dimensional structure composed of condensed phenylpropanoid units that limits digestibility by encrustation (Kerley, 1988). This plant cell wall is further shielded by the hydrophobic nature of core lignin, which reduces microbial ability to attach and hydrolyze cell wall polysaccharides. Crude lignin can be isolated following acid detergent fiber analysis, using 72% H₂SO₄ (acid detergent lignin, ADL; Goering and Van Soest, 1970.). If Maillard products or silica are present in a sample, permanganate oxidation can be conducted on acid detergent residue to estimate core lignin content. While core lignin is focused on the most when evaluating lignin content, some have argued that total phenolic content, which would include non-core lignin should be considered (Jung and Deetz, 1993; Van Soest, 1993). Non-core lignin is readily soluble in alkali and the majority of recovered phenolic acids are generally ferulic and *p*-coumaric. These phenolics are covalently bonded to hemicellulose (Van Soest, 1982; Jung and Fahey, 1983). Some have thought that non-core lignin reduces cell wall polysaccharide digestibility by inhibiting microbial growth or enzyme activity as the addition of phenolic acids to *in vitro* incubations has inhibited fiber digestion (Zemek et al., 1979; Chesson, 1982; Martin and Blake, 1989). Lowry (1990) reported no difference in intake or *in situ* and *in vivo* digestibility when *p*-coumaric or ferulic acid were ruminally infused or fed to sheep. Chemical treatment by hydrolytic or oxidative means often solubilizes lignin monomers which may depress digestibility of cell solubles (Atwell et al., 1990; Cameron et al., 1990; Fahey et al., 1993).

A more likely factor reducing fiber degradability is the steric hindrance caused by lignin and polysaccharide linkages, which limit access of fibrolytic enzymes (Jung and Deetz, 1993). Jung and Fahey (1983) reported that corn stalkage had numerically higher

amounts of *p*-coumaric and ferulic acid (9.85 and 2.85 mg/g DM, respectively) compared to wheat straw (4.90 and 2.90 mg/g DM, *p*-coumaric and ferulic acid, respectively).

Hartely and Keene (1984) reported that mature corn stems contained (mg/g DM) 33.05 of esterified *p*-coumaric and 3.78 ferulic acid, whereas wheat straw contained 3.20 and 3.50 mg/g DM *p*-coumaric and ferulic acid, respectively. As, non-core lignin is readily soluble in alkali, the success of chemical treatment by hydrolytic agents could be partially attributed to reducing polysaccharide-lignin associations. As monocots have a greater amount of ferulic and *p*-coumaric acids than dicots, it stands to reason that they are good candidates for milder hydrolytic treatments (as opposed to oxidative) such as NaOH, Ca(OH)₂, or NH₃. Little thought is given to the consumption of phenolics by many nutritionists but extensive metabolism does occur. Phenolic acids, such as ferulic and *p*-coumaric are liberated in the rumen, reduced, and absorbed into the portal blood (Bourquin et al., 1990). Increasing level of reduced phenolics showed impairment (*in vitro*) to both conversion of propionate to glucose and oxidation of palmitate using liver tissue collected from heifers (Cremin et al., 1994).

Consumption of phenolics may alter gut microbial community and environment. Diaz-Gonzalez et al. (1998) initially identified a reduction in the prevalence *E. Coli* O157:H7 by feeding alfalfa hay to finishing cattle. In that study, the authors speculated the reduction in O157:H7 was a result of the phenolic consumption supplied in the alfalfa. Further work by Wells et al. (2005) confirmed that phenolics common to forages, were effective in decreasing counts of O157:H7. However, considering that finishing cattle consume small amounts of roughage (Vasconcelos and Galvayan, 2007) and an even

smaller amount of phenolics, other strategies targeting reducing O157:H7 prevalence may have more impact.

Crystallinity and hydrogen bonding. Crystallinity of plant walls is defined by increasing structural order and number of intermolecular (between cellulose chains) and intramolecular (between glucose residues) hydrogen bonds. Determination of crystallinity is performed using the X-ray diffraction technique (Franks, 1955; Kerley et al., 1988). As hydrogen bonding increases, water may be excluded from penetrating the inner structure. Conceptually, rate of hydration of a fiber has been identified as an important factor influencing lag time associated with microbial attachment to fiber, as microbes travel and are transferred through water (Allen and Mertens, 1988; Fahey et al., 1993). However, direct comparisons of hydration rate and fractional digestion suggest otherwise. Researchers have found no relationship between hydration rate and lag time (Bhatti and Firkins, 1995) or that hydration of feed was not a major factor limiting fractional digestion rate of DM (Van Milgen et al., 1993). Rate of hydration is related to cation exchange capacity of a plant cell wall (McBurney et al., 1981). However, while chemical treatment decreases hydrogen bonding and crystallinity and increases hydration rate, removal of lignin and hemicellulose by harsh chemical treatment may lower CEC (Fahey et al., 1993). Yet, hydration rate is largely unaffected as disruption to the cell wall matrix allows for water penetration.

Space is at a premium inside a cell wall. Capillaries between microfibrils and other parts of the cell are quite small, and only expand to 200 Å in diameter, when fully hydrated (Cowling, 1975). In comparison, rumen bacteria are much larger (approximately 200 fold), ranging from 0.3 to 2.0 µm in diameter and 1.0 to 6.0 µm in

length (Church, 1976). Initial studies on cellulase size suggested that it is approximately 40 Å (Stone, 1969) to 51 Å (Grethelin, 1984) in diameter. Bacterial species, such as *Fibrobacter succinogenes*, *Ruminococcus albus*, and *Ruminococcus flavefaciens* are regarded as the major cellulolytic organisms within the rumen (Russel, 2002). These ruminal cellulolytic bacteria must be attached to feed particles as their cellulolytic enzymes are retained in the cell surface (Wiemer, 1996). Other bacteria (*Butyrivibrio fibrisolvens*, *Eubacterium cellulosolvens*) have been identified as having extracellular cellulase, but these are generally considered to have a minor importance within the rumen. Wiemer (1996) noted that attachment to feed particles by bacteria covered up available sites for adsorption of extracellular cellulase. Forsberg et al. (2000) described the production of cellulosomes that are involved in adhesion of bacteria to cellulose. In a review by Miron et al. (2001), it was suggested that pH, temperature, and cations (Na^+ , Ca^{2+} , Mg^+) could affect adhesion of major cellulolytic bacteria. Fungi (*Neocallimastix*, *Caecomyces*, *Piromyces* genus) appear to enhance the attachment of bacteria to feed particles. During the life cycle of the fungi, rhizoid development grows root-like structures that penetrate the feed particle and allow for greater space (Russell, 2002). As attachment of rumen bacteria appears to be requirement for the majority of carbohydrate degradation, reducing particle size should improve surface area for bacterial attachment. This hypothesis was confirmed by Dehority (1961) as well as Dehority and Johnson (1961), both of which noted that decreasing particle size by ball milling increased digestibility due to the increased enzyme accessible space.

Chesson (1982) suggested a holistic approach to the study of cell wall chemistry and degradation. This idea proposed that the cell wall is a complete entity, not a complex

of factors. This hypothesis was based on the findings that rumen bacteria were indiscriminate as to the degradation of specific cell wall fractions, as the composition of undigested residue and starting material were similar (Beveridge and Richards, 1973; Chesson et al., 1982; Bacon et al., 1983; Chesson and Orskov, 1984). This suggested that identification of individual components which affect digestibility may not be representative of the realistic factors that constrain degradation of plant cell walls.

Types of chemical treatment. Technology for the chemical treatment of crop residues likely stems from paper making techniques, which were in place as early as the 12th century. Chemical treatment of straw with NaOH began in Germany in the 1880s with the development of the Beckmann method (Homb, 1984). This process, while effective in increasing OM digestibility (45.7% in untreated to 71.2% treated with 1.5% NaOH), led to losses of approximately 20% of the DM (due to washing off excess NaOH) and produced significant amount of environmental pollution (Fingerling and Schmidt, 1919). Since that time, a variety of methods have been developed to improve the treatment of fiber. These methods can be grouped by their mode of action. Mostly, chemical treatment occurs by hydrolytic or oxidative means. Physically treatments such as particle size reduction (Thomas et al., 1980), steam treatment (Garrett et al., 1980), or irradiation (Pritchard et al., 1962; Yu et al., 1975) have also been used. Combinations of chemical and physical treatment are possible as well.

Owen et al. (1984) identified that an ideal chemical would: 1) be effective in increasing intake or digestibility, 2) benefits that outweigh the costs associated with treatment, 3) have non-toxic effects on animals or the environment, 4) provide an essential nutrient to the animal or as fertilizer, 5) be non-hazardous to handle.

Hydrolytic treatment. Hydrolytic agents improve digestibility by action of OH^- groups disrupting cell wall structure and increased swelling resulting increased microbial attachment (Fahey et al., 1993). Core lignin is usually not affected by hydrolytic treatment but bonds between lignin and hemicellulose are broken. Klopfenstein (1976) postulated that the mode of action of hydrolytic agents were primarily related to (1) solubilization of hemicellulose, (2) increased rate and (3) increased extent of digestion of hemicullose and cellulose. Sodium hydroxide has been the principal base produced by the chemical industry. As a chemical treatment agent, it is often the standard by which other treatments are compared to. Fahey et al. (1993) reviewed 24 studies which fed cattle or sheep crop residues (included at $\geq 60\%$ of diet DM) treated with NaOH and found an average improvement in DMI of 22%. In the same review, chemical treatment with NaOH led to an average of 30% improvement in DM digestibility from 32 studies by lambs or cattle.

Sodium content of treated feeds is largely the biggest drawback of NaOH treatment. Effects of high sodium intakes on rumen fermentation have been studied (Berger et al., 1979b). The notion that sodium might be influencing digestion was conceived by the difference in digestibility between in vitro and in vivo techniques (Klopfenstein et al., 1972; Berger et al., 1979b). Rexen and Thompson (1976) noted that the difference between in vivo and in vitro OM digestibility became apparent at 4% NaOH and above. Sodium intake, from NaOH treated corn stover, increased liquid passage rate, shifted site of digestion of fiber to a greater proportion digested in the lower gut (Berger et al. 1979b). Willms et al. (1991b) noted that steers fed NaOH- H_2O_2 treated wheat straw had decreased ADG compared to steers fed corn silage based diets. The

authors attributed the differences in ADG partially to increased sodium intakes (2.04% dietary sodium, DM basis) from treated wheat straw which caused the steers to urinate more, leading to wetter pens. They speculated that greater maintenance energy requirements, caused by greater urinary energy and adverse environmental conditions caused by wetter pens, may explain the differences in performance. In the same study, the authors also noted that high Na and K intakes due to consumption of treated wheat straw could have comprised the efficacy of lasalocid (Rumpler et al, 1986; Spears and Harvey, 1987).

Ammoniation has also been evaluated as a hydrolytic agent. The utility of NH_3 is sometimes greater than NaOH, even though the improvement in digestibility is not often as great as observed with NaOH. Fahey et al. (1993) reported that the average study response to NH_3 treatment was an 22% increase in DMI, while DM digestibility was increased by 15%. Being a gas, anhydrous ammonia eliminates the need to mix and handle material. To treat stacks of straw or corn residue, the only equipment needed is a tarp fitted around the bales that is air tight. Residual NH_3 compliments the diet as a protein supplement, allowing for the production of, essentially, a complete feed. Ammonia treated crop residues can be fed free choice and are well accepted by cattle compared to NaOH treated residues (Fahey et al., 1993). Success with ammoniation treatment is dependent on several factors including: temperature, time, moisture, as well as quality and type of substrate to be treated (Ward et al., 1982; Sundstøl and Coxworth, 1984; Fahey et al., 1993). Paterson et al. (1980b) conducted two trials with anhydrous ammonia treatment. In trial 1, corn stalks were treated with varying levels of NH_3 (0, 2, 3, 4%; DM basis) and stored for 21 days. Dry matter digestibility by lambs offered

treated corn stalks increased by 25.9% compared to untreated. Increasing level of ammonia led to increased DMI but within treated stalks, DM digestibility was similar. In trial 2, growing steers were offered corn stalks collected at two different harvest dates, with and without ammonia treatment. Dehydrated alfalfa was included in both diets at 20.0% of the DM. Harvest date had a greater effect on steer performance than did treatment. No difference in DMI was observed between untreated and treated stalks from early harvest, however treated stalks had greater DMI compared to untreated with late harvest date.

Research with treating wheat straw with ammonia also has been conducted. Zorrilla-Rios et al. (1985) treated wheat straw with 3.5% ammonia and found that crude protein was increased to 9.8% compared untreated which was 4.6%. However, no difference in NDF, ADF, or hemicellulose was noted between treated and untreated. Still, IVDMD was increased for treated wheat straw (47.6%) compared to untreated straw (37.3%). Interestingly, the authors noted increased fragility of treated wheat straw compared to untreated; suggesting that part of the response to treatment may be related to increased ease of mastication. Saenger et al. (1982) treated baled corn stover with anhydrous ammonia (2.0% of DM) and observed increases in DMI (22.0%) and DM digestibility (9.8%) with NH_3 treatment compared to corn stover supplemented with protein from soybean meal or urea. No difference in DM digestibility was observed for treatments containing soybean meal or urea compared to no protein supplementation, but not supplemented steers consumed less DM. Saenger et al. (1983) treated baled wheat straw stored in a large piles. In that research, crude protein increased from 3.6% in untreated straw to 11.2% in treated straw (treated with 3.0% anhydrous ammonia). In

in vitro DM digestibility also increased by 26.1% for treated compared to untreated. The authors also observed crude protein to migrate slightly to the top of the stack, which they attributed to the gaseous nature of ammonia. An estimated 49.6% of N applied to the straw was retained. Treatment also decreased recoverable NDF from 74.8% in untreated to 66.9% in treated. Ward et al. (1982) noted improved in vitro NDF digestibility for ammonia treated wheat straw at 35% moisture compared to 10%. Additionally, increasing moisture led to increased capture of residue N, as crude protein levels were greater for 35% compared to 10% moisture.

Use of ammonia fiber expansion (AFEX) treatment has increased in popularity, particularly in preparation of biomass for cellulosic ethanol production (Lau and Dale, 2009). Currently, there is renewed interest in using AFEX treated crop residues as feed. Invented by Bruce Dale and colleagues, AFEX treatment causes tremendous disruption of plant cell walls (Dale and Moreira, 1982). The AFEX treatment process includes subjecting biomass with aqueous ammonia under high pressure (200-400 psi) and temperature (80-150°C) for 5-30 minutes, after which pressure is explosively released. Similar to other hydrolytic treatments, hydrogen bonding is disrupted, as well as solubilizing some carbohydrate. Ultimately, AFEX treatment results in greater accessible space for microbial attachment allowing for greater digestibility. As stated above, its primary use has been intended as a preparation for enzymatic hydrolysis for ethanol, however, this technology could be used to treat residues for ruminants.

Urea has also been considered as a source NH_3 treatment, as historically it was inexpensive. Urea needs to be hydrolyzed to ammonia and a source of urease is usually required unless the roughage has sufficient urease. Jackbean meal is often used as a

urease source (Fahey et al., 1993). Moisture content is a major factor related to breakdown of urea to ammonia (Ward et al., 1982). As with other chemical treatments, there are pitfalls to ammonia treatment. Ammonia can react with soluble carbohydrate, present in high quality forages and those that would be able to be ensiled, forming imidazole compounds, which are carried in cow's milk. Known by the moniker "crazy calf syndrome", calves nursing dams that consume ammonia treated forages are most at risk. Afflicted calves can have convulsions, hyperactivity, and death. Currently, estimated cost of ammonia treatment is \$20 to 30 per ton. Even though supplies of feedstuffs high in protein are readily available, ammoniation of crop residues is still a viable option for many producers.

Historically, calcium hydroxide was quickly dismissed as a lesser chemical if used solely as the principal hydrolytic agent (Fahey et al., 1993). Its primary use for treatment was to partially substitute for NaOH and eliminate negative effects of Na on digestion and excretion of Na (Rounds et al., 1976; Waller and Klopfenstein, 1975). Waller (1976) noted (as cited by Klopfenstein, 1978) 14.4% of hemicellulose was solubilized and 51.0% (17.2% increase compared to control) was digested by addition of 4% $\text{Ca}(\text{OH})_2$ to corn cobs. However, when 4% or 3% NaOH was used, hemicellulose digestibility was increased by 80.2 and 52.6%, respectively, compared to control corn cobs. In that research, digestibility was measured using *in vitro* methods, which consistently has yielded higher values for NaOH treated feedstuffs compared to *in vivo* methods. Correspondingly, this likely led to the idea that calcium hydroxide was not as effective for treating. Rounds et al. (1976) tested various combinations of NaOH and $\text{Ca}(\text{OH})_2$ treatments on corn cobs. *In vitro* DM disappearance appeared to increase

linearly as $\text{Ca}(\text{OH})_2$ decreased and NaOH increased. However in feeding trials, DMI, ADG, and F:G favored lambs fed corn cobs with 1 or 2% $\text{Ca}(\text{OH})_2$ compared to NaOH alone. Lesoing et al. (1980) tested 6 combinations of NaOH and $\text{Ca}(\text{OH})_2$ as treatments for wheat straw. Combinations of 3 or 4% NaOH with 0, 1, or 2% $\text{Ca}(\text{OH})_2$ had higher IVDMD (average 81.2% improvement compared to control) than 3:1 $\text{Ca}(\text{OH})_2$: NaOH. Compared to untreated wheat straw, 3:1 $\text{Ca}(\text{OH})_2$: NaOH increased IVDMD by 29.2%. However, when the same treatments were applied to wheat straw and offered to lambs at 75% of the diet (DM basis), the control (untreated) was significantly lower for DM digestibility compared to the other six treatments but no difference was noted among NaOH or $\text{Ca}(\text{OH})_2$ treatment combinations. Numerically, DMI and ADG appeared to increase as NaOH increased, and similar relationships were observed on lamb OM and DM digestibility. In a review, Klopfenstein and Owen (1981) report data from Asadpour (1978) where 4% or 5% $\text{Ca}(\text{OH})_2$ treated straw was fed to lambs at 80% of diet DM. Compared to an untreated control straw, DM and NDF digestibility increased by an average of 9.9% and 10.9%, respectively, for $\text{Ca}(\text{OH})_2$ treated straw. Numerically, ADG, DMI, and G:F were also improved markedly for $\text{Ca}(\text{OH})_2$ treatments compared to control straw. Waller and Klopfenstein (1975) (as cited by Klopfenstein and Owen, 1981) fed various NaOH: $\text{Ca}(\text{OH})_2$ combinations (4:0, 3:1, 2:2, 1:3, 0:4; NaOH:calcium hydroxide, DM basis) of treated corn cobs to growing steers. Ratios of 1:3 and 3:1 had greatest ($P < 0.05$) ADG, while 4:0 and 2:2 were intermediate, and 0:4 had the least ADG. As $\text{Ca}(\text{OH})_2$ increased, DMI appeared to decline.

As it became apparent that crop residues respond differently to alkaline treatment (Klopfenstein, 1978), Paterson et al. (1980a) tested crop residue response to treatment

with 5% Ca(OH)_2 (DM basis) at varying moisture levels (20, 40, or 60%). Lambs were offered diets containing 85% residue (untreated-60% moisture, treated with 5% Ca(OH)_2 at 20, 40, or 60% moisture). Dry matter intake of treated wheat straw and corn cobs was maximal at 40% moisture. However, corn stover DMI appeared to increase as moisture increased. The authors attributed this observation to decreased dustiness and increased palatability for increased moisture treatments. Lamb digestibility of wheat straw and corn cobs had numerically highest values at 40% moisture, while moisture level appeared to decrease both DM and cell wall digestibility linearly. Another experiment within the same article used lambs that were fed 5% Ca(OH)_2 treated stover with varying moisture level (25, 30, 35, 40, and 45%). In this experiment, DMI was lowest at 25% moisture, intermediate when moisture was 30 to 40%, but a large increase was observed at 45% moisture. Paterson et al. (1980a) also evaluated reaction length of 5:0, 4:1, and 3:2 (Ca(OH)_2 :NaOH, DM basis, %) treatment combinations for corn cobs. As early as 2 days post treatment, improvements in IVDMD compared to the control were apparent. For 4:1 and 3:2 treatments, IVDMD was not different from 4 days post treatments until day 22. For 5:0, alkaline treatment did not cause IVDMD to plateau until day 10, but this treatment appeared to have lower IVDMD than 3:2 and 4:1 treatments from days 10 to 22. However, they noted that treatment at 40% moisture may allow for increased molding but treatment with 60% moisture likely provided enough moisture for fermentation, as treatments applied at 60% moisture appeared to have fermented. The authors recommended a moisture level between 20 and 40% to allow for adherence of Ca(OH)_2 to the fiber but dry enough to inhibit fermentation. To address issues with mold, Oliveros et al. (1988) treated corn stalks with combinations of urea or anhydrous

ammonia and $\text{Ca}(\text{OH})_2$, but found no improvement compared to $\text{Ca}(\text{OH})_2$ alone. From this research, it became apparent that crop residues respond differently to alkaline treatment, and that reaction length as well as moisture level affect treatment success.

Sewell et al. (2008) conducted several trials with a pellet that contained various blends of crop residues that were thermo-chemically treated with a Readco processor containing 5% calcium oxide and dried distillers grains plus solubles (DDGS). In a finishing trial with Holstein steers, the corn replacement pellet replaced all the corn and was compared to a control diet which contained (DM basis): 50% DRC, 25% DDGS, 15% corn silage, and 10% supplement. Dietary NDF was higher (37.1 and 38.3%, corn bran based and wheat straw based pellets, respectively) for treatments that contained corn replacement pellets compared to the control diet which contained 19.3% NDF. Sewell et al. (2008) observed lower DMI for the control compared to two diets that contained a corn replacement pellet which contained either corn fiber or wheat straw. Additionally, they found decreased G:F for Holstein steers that were fed the corn replacement pellet compared to the control diet but no difference in ADG was observed. This work suggested that calcium oxide treated crop residues fed in conjunction with a distillers grain-based diet may be a feeding strategy to reduce diet costs while maintaining acceptable performance and ultimately lowering cost of gain.

Oxidative treatment. Oxidative agents (H_2O_2 , O_3 , Na_2O_2) are among the most caustic. However, the practicality of these treatments has never been realized. Mode of action for oxidative treatments is characterized by attack and degradation of core lignin (Fahey et al., 1993). Klopfenstein et al., (1972) evaluated treatment with H_2O_2 , Na_2O_2 and combinations of the two. Crude lignin (ADL) was not solubilized by peroxide or

NaOH treatments but peroxide and NaOH treated corn cobs had lower ADL compared to untreated. Both peroxide and NaOH treatment increased digestibility of alfalfa and corn cobs compared to untreated, but no difference was noted between oxidative and hydrolytic treatments.

Alkaline-hydrogen peroxide treatment. Alkaline- hydrogen peroxide (AHP) treatment was developed on the concept of two modes of action for fiber treatment, which had additive effects on digestibility (Streeter and Horn, 1982; Fahey et al., 1993). Oxidative (1) treatment (H_2O_2), providing direct attack against core lignin, coupled with (2) hydrolytic treatment (NaOH, NH_3), which solubilized hemicellulose-lignin complexes, were investigated as fiber treatment options by researchers from IL in the mid 1980s.

Based on the Beckman method, Kerley et al. (1985) described a wet treatment where wheat straw was soaked in dilute H_2O_2 (1% w/v) and NaOH (added to raise pH to 11.5) for several hours. Insoluble residue was then collected and washed repeatedly until filtrate was neutral pH. Washed residue was then dried in a 50°C oven, under vacuum. In trial 1, lambs were fed treated and untreated straw at at 1200 g/d, to avoid confounding effects of DMI on digestibility, at two levels of diet DM (35.7 and 72.0%). Dry matter digestibility was improved for treated straw (83.0% and 74.8%; 35.7% and 72.0% DM inclusion, respectively) compared to untreated straw (68.45 and 50.0%; 35.7% and 72.0% DM inclusion, respectively). Compared to DM, NDF (81.4% vs. 48.0%; 35.7% and 72.0% DM inclusion, respectively) and ADF (86.0% vs. 48.9%; 35.7% and 72.0% DM inclusion, respectively) digestibility were increased to a much greater degree. Fahey et al. (1993) states that this wet treatment is cost prohibitive for livestock application but is

commonly used in the manufacture of human fiber supplements. As with the Beckmann method, concerns were raised with loss of soluble carbohydrate and potential pollution due to the sodium rich effluent. This prompted research in developing a “dry” treatment that didn’t require washing. Studies (Cameron et al., 1988; Atwell et al., 1990; Cecava et al., 1990; Willms et al., 1991ab) were conducted with AHP wheat straw treated with an alkaline solution of 5.0% NaOH and 2% H₂O₂ (DM basis). Wheat straw was subjected to this dry treatment where an alkaline solution was sprayed during mixing. This DM of the treated straw was approximately 65% and was stored in upright silos.

Willms et al. (1991a) conducted two experiments with AHP wheat straw fed to growing and finishing steers. Replacing all (66% diet DM) or half (33% diet DM) of the corn silage with AHP wheat straw led to lower ADG and G:F when fed to growing steers. Dry matter intake of AHP treated wheat straw replacing half of corn silage was similar to the control but DMI was lower when AHP wheat straw replaced all of the corn silage. The authors speculated that decreased performance was related to high sodium intakes. In contrast, Cameron et al. (1991) reported similar milk production of cows fed 37.5% or 40% AHP wheat straw replacing corn silage or alfalfa haylage. In a finishing steer experiment, no difference was noted on ADG, DMI, or G:F between AHP wheat straw, alfalfa hay, or corn silage fed at similar (10 or 20% diet DM) inclusion levels. However, AHP wheat straw had lower dressing percent compared to alfalfa hay and corn silage diets.

Effect of NDF on intake and performance. In cattle, fiber concentration (NDF) can increase or decrease DMI, depending on whether intake is regulated chemostatically (Allen et al., 2009) or by gut fill. Since NDF became a measure for fiber (Van Soest et

al., 1963) it has been suggested as a measure of voluntary fill (Van Soest, 1965; Waldo, 1986; Mertens, 1994). A primary goal of cattle feeding is to maximize energy intake, which in turn drives performance. Roughage plays a key role in maximizing energy intake by promoting DMI (Galyean and Defoor, 2003; Arlovich et al., 2008). Still, roughage is viewed as a necessary evil by those associated with cattle feeding. Roughages incur high shrink losses due to processing, have much greater cost per unit energy compared to grains and other ingredients, and their bulky nature decreases mill efficiency. In recent history, research has focused on ways to reduce roughage handling for reasons stated previously. Consequently, feeding high levels of roughage has been studied less compared to low levels of roughage or diets without roughage. Vasconcelos and Galyean (2007) report that most feedlots feed approximately 8.0% (DM basis) roughage (4.1% roughage NDF% supplied). Compared to diets without roughage, increasing roughage level will increase DMI, while ADG will increase slightly, plateau, and then decrease at high levels due to gut fill (Gill et al., 1981; Stock et al., 1990; Bartle et al., 1994; Shain et al., 1999). Feed efficiency is poorer as roughage increases (Gill et al., 1981; Bartle et al., 1994). Strong empirical evidence of a relationship between roughage supplied or dietary NDF and DMI exists for both feedlot (Galyean and Defoor, 2003) and dairy cattle (Arlovich et al., 2008). In finishing beef cattle, Arlovich et al. (2008) found that for every 1% unit increase in dietary NDF, DMI was increased by 0.16 kg/d. However, the same article reports that dairy cattle DMI declined by 0.21 kg/d for 1% unit decrease in dietary NDF.

Bartle et al. (1994) evaluated roughage source (alfalfa or cottonseed hulls) and inclusion level (10, 20, 30%; DM basis) on steers fed diets based on steam flaked

sorghum. For both roughage sources, increasing roughage inclusion increased DMI. For alfalfa ADG was similar between 10% and 20% levels, but decreased at 30%. In cottonseed hull diets, ADG decreased as roughage increased. Gill et al. (1981) fed increasing levels of a roughage blend (1/3 alfalfa, 2/3 corn silage; DM basis) at 8 to 24% of diet DM in diets containing high-moisture corn, steam flaked corn, and a 50:50 (DM basis) blends of the two. As roughage level increased, ADG did not change while DMI increased. In general, this led to poorer G:F as roughage was increased, but greater amounts of roughage had less of an impact on G:F when high moisture corn or a blend was fed.

Effects of roughage with byproduct inclusion have also been studied. Loza et al. (2010) evaluated inclusion of alfalfa hay (0, 2.5, 5, 7.5%; DM basis) in diets containing increasing levels of sweet bran and WDGS. A tendency ($P = 0.06$) for increased DMI as alfalfa hay increased was observed. However, roughage level had no effect on ADG or G:F. Feeding no roughage in a diet that contained 75% byproducts (equal parts WDGS and sweet bran) and 0.45% sulfur resulted in 30% of cattle on that treatment to be removed for PEM. This, along with observations of Vanness et al. (2009) suggested that roughage may provide some protection against H_2S formation. Benton et al. (2008) evaluated roughage source (corn stalks, corn silage, alfalfa hay) and level of NDF supplied roughage (normal or 1/2 normal) in diets containing 30% WDGS. Increasing roughage level increased DMI and ADG compared to no roughage, and diets containing higher roughage amounts had greater DMI and ADG compared to lower. However, no difference was observed on G:F due to roughage level or source, but feeding no roughage tended ($P = 0.09$) tended to result in higher G:F compared to diets with roughage.

Rich et al. (2011) fed levels of WDGS in excess of 70% with and without DRC and varying roughage levels (4.7 to 25% diet DM) supplied by wheat straw. Steers fed no corn and higher roughage levels (10, 17.5, and 25% wheat straw) required 42 d longer to finish compared to steers fed diets containing 40, 70, and 77% WDGS (and 4.7%, 5.2%, and 9.1% wheat straw). From that study, it appeared that even small inclusions of DRC (17% and 9%, DM basis) improved ADG, G:F and reduced DOF dramatically. Large depressions in DMI, ADG, and HCW were observed for steers fed (DM basis) 70% WDGS, 22% DRC and 8% wheat straw compared to steers consuming 40% WDGS, 50% DRC, and 5% corn stover. In that study, high dietary sulfur content likely contributed to the poorer performance of steers consuming high levels of WDGS.

Burken et al. (2013b) fed increasing levels of corn silage (15, 30, 45, 55% of diet DM) in diets containing 40% MDGS to calf-fed steers. Dry matter intake declined linearly as corn silage increased in the diet. Daily gain and G:F decreased in a linear manner as well. Goodrich and Mieske (1976) summarized 17 research studies with corn silage levels (10 to 80% of diet DM) in diets without distillers grains. In contrast to Burken et al. (2013), DMI appeared to increase quadratically with 40 to 50% silage having the highest DMI. Brennan et al. (1987) fed steers increasing levels (0, 21.0, 40.8, 59.4, 77.1, and 93.3%) of corn silage replacing corn grain, offered at *ad libitum* intake. Intake and ADG increased in a quadratic manner, then declined as silage increased. No difference in feed efficiency was observed. The authors also concluded that diets comprised almost entirely of corn silage were most profitable.

Effect of NDF on rumen metabolism. Roughages can affect the physical nature of rumen contents (Galvan and Defoor, 2003). Most notably, roughages contribute to

the formation of a mat layer, which is essential for rumination. Rumination promotes the production of saliva which is essential for normal buffering of acids produced during fermentation. Most research devoted to studying roughage effects in finishing diets has been concerned primarily with acidosis.

Roughage can affect utilization of other ingredients. Some researchers have found decreased ruminal residence time for grain as roughage increased in the diet (Owens and Goetsch, 1986; Moore et al., 1990; Wylie et al., 1990) whereas others have noted no difference (Poore et al., 1990; Shain et al., 1999). Shifting site of digestion for starch toward the small intestine is generally viewed as counterproductive to efficient grain utilization as intestinal starch digestion is limited (Huntington, 1997), despite energy losses associated with fermentation. Owens et al. (1986) hypothesized that shifting site of digestion of starch should result in 42% greater energy capture compared to fermentation.

In general, digestibility of fiber is less compared to starch and digestibility of fiber is also poorer in feedlot diets compared to forage based. Several factors contribute to this. The high inherent rate of starch fermentation, typically abundant in feedlot rations, causes ruminal pH to decline, often below 5.6 for much of a day. Low pH is inhibitory to fiber digesting microbes (Russell, 2002). Correspondingly, negative associative effects are commonly observed when high starch based supplements are used in high fiber rations. Digestibility and intake of fiber from concentrates is usually greater than fiber from most roughage sources. Moore et al. (1990) fed 30, 60, and 90% concentrate diets based on steam flaked milo, which was replaced by a blend of alfalfa hay and wheat straw. For the 90% concentrate diet, steam flaked milo contributed 57.3% of the dietary

NDF. In the same study, observed NDF digestibility was 41.0%, 35.6%, 33.1% for 30, 60, and 90% concentrate diets, respectively. However, this observed NDF digestibility differed greatly from potentially (92.4%, 70.3%, 48.0% for 30, 60, and 90% concentrate diets, respectively) digestible NDF (estimated using *in situ* digestibility). This difference between observed and potentially digestible NDF increased as concentrate level decreased. The authors estimated that while observed NDF digestibility was unchanged as concentrate increased, steam flaked milo accounted for 54% of the total depression in NDF digestibility.

The response to distillers grain in feedlot diets on NDF digestibility has been variable. Vander Pol et al. (2008) noted a numerical increase in ruminal NDF digestibility for a WDGS diet compared to corn based control. Corrigan et al. (2008) observed no difference in NDF digestibility for 40% WDGS compared to none, across DRC, HMC, or SFC. Nuttelman et al. (2011) found increased NDF digestibility for DDGS, MDGS, or WDGS at 40% inclusion compared to a corn based control diet. However, several studies have noted no difference between a corn based diet and WDGS or CDS on NDF digestibility (Bremer et al., 2010; Pesta et al., 2012). Benton et al. (2008) conducted a digestion experiment and evaluated the effects of roughage source (alfalfa or corn stalks) and roughage level (0, 3-4%, 6-8%, DM basis; roughages were balanced to provide similar amounts of NDF at two levels) in finishing diets containing 30% WDGS. Linear decreases in DM, OM, and NDF digestibility as roughage level increased in the diet were observed however, no difference was noted due to roughage source. However, the observed decreases in digestibility with increasing roughage level did not relate to poorer feed efficiency when diets were offered to finishing steers in a

separate experiment. Feeding greater levels of roughage led to increased intake of DM, OM, and NDF, but no difference was observed on amount of DM and OM digested, while amount of NDF digested increased. These findings suggested that while digestibility was poorer with increased roughage level, nutrient supply to animal was similar, and this supports the similar feed efficiencies that were observed.

It is logical that an apparent synergy exists between distillers grains and fiber (Loy et al., Nuttelman et al., 2009; Buckner et al., 2010). While grain may depress fiber digestibility (Moore et al., 1990), this depression may not be as great when distillers grains are included in the diet. Burken et al. (2013) noted the while G:F was poorer as silage level increased in diets containing 40% MDGS, the rate at which G:F declined was approximately half that observed by research by Erickson et al. (2000), when distillers grains were not fed.

Agronomic considerations regarding corn residue removal. Soil and environmental impacts must be considered as corn residue is utilized to greater extents. As corn yields have increased over time, so has residue. The grain to residue ratio is generally considered to be 1:1, although Linden et al. (2000) found a harvest index of 0.54 and standard deviation of 0.079 over a 13 year study with continuous corn. In western NE, Musgrave et al. (2011) noted hybrid differences in ratio of grain to residue as well as proportion of grain relative to husk and leaf. Wilhelm et al. (2004) estimated (assuming a 50% harvest index) that Nebraska, Minnesota, Iowa and Illinois contribute to 54.1% of corn residue produced domestically. Many factors, such as soil type, climate, and tillage practices interact in a complex manner with residue and this can positively or negatively affect soil characteristics. Andrews (2006) outlined several primary benefits

of corn residue. Degradation of corn residue provides a source of OM for the soil. In turn, increased OM can improve the biological and chemical properties of the soil, leading to increased grain yield. Corn residue also provides physical cover to bare soil by providing protection against raindrop impact and wind shear; collectively reducing erosion. Research has focused on developing recommendations on residue removal (Nelson, 2002; Wilhelm et al., 2004). Recommended removal rates should be based on local factors (yield, soil type, climate, tillage) and not one rate or rule should apply across the country (Andrews, 2006). For example, a greater benefit of residue removal may be realized in the eastern corn belt where moisture is not limiting compared to western states where residue serves as a cover to prevent evaporative losses (Power et al., 1986). Under certain conditions, leaving residue on the field can insulate the ground and prolong the time it takes to increase soil temperature in the spring. This in turn can lead to poorer germination rate (Swan et al., 1987; Dam et al., 2005; Linden et al., 2006). Clapp et al. (2000) found that more N fertilizer is needed in fields with no residue removal as uptake of soil N by residue can occur.

Residue removal is not binary, various forms and degrees of removal occur. Corn harvested for silage leaves virtually no residue behind while baling removes more residue compared to grazing. Gigax et al. (2011) found that baling removed 82% of available OM while grazing removed 17 to 24% (depending on stocking rate). In eastern NE, removal of corn residue by grazing has been shown to have positive impacts on subsequent yield of soybeans or corn (McGee et al., 2013). Under grazing, cattle remove the most digestible residue (Fernandez-Rivera and Klopfenstein, 1989; Wilson et al., 2004) and excrete manure and urine back on the field such that nutrient balance remains

largely unchanged. Weinhold et al. (2013) looked at the effects of degree of residue removal in rainfed vs. irrigated corn. Removing 50% of residue on rainfed corn led to a slight reduction in yield (1.5 bu/ac) compared to no removal. However, when irrigated corn had 40% of the residue removed, yield was increased by 15.4 bu/ac. In the same article, the effects of tillage (disk tillage or no-till) and residue removal (0, 40, 80%) on grain yield in an irrigated field were evaluated. Disk tillage led to higher yields than no-till, however, less change in yield was noted with disk tillage as residue removal increased than with no-till. Regardless of tillage, yields were increased with 40% or 80% residue removal.

Conclusions. From the review of the literature, it appears crop residues, namely corn stalks, are in abundance. Chemical treatment can be used to treat crop residues, but a myriad of factors (chemical, substrate, temperature, moisture) affect the utility of treatment. Using NaOH or NH₃ are possible but excretion of sodium and N are concerning. Little data exists on how competitive calcium oxide (as opposed to calcium hydroxide) is as an alkaline treatment. Given the supply and acceptance of distillers grains in feedlot diets, the feeding higher roughage diets may result in similar or adequate performance to finish cattle with, as corn is expensive and replacement options are needed. These conclusions have resulted in the development of the following research objectives.

Objectives of Research

- 1) Identify optimum treatment combinations for improving DM digestibility of different crop residues for eventual on-farm treatment.

- 2) Evaluate replacing corn with treated residues in combination with WDGS on steer performance and carcass merit and characterize digestibility and rumen metabolism of treated and untreated crop residues replacing 15% units of corn in the diet.
- 3) Evaluate effect of grindsize, prior to treatment to test the hypothesis that grinding stover smaller may increase treatment success due to increased surface area.
- 4) Test maximal corn replacement with distillers grains or treated crop residues.

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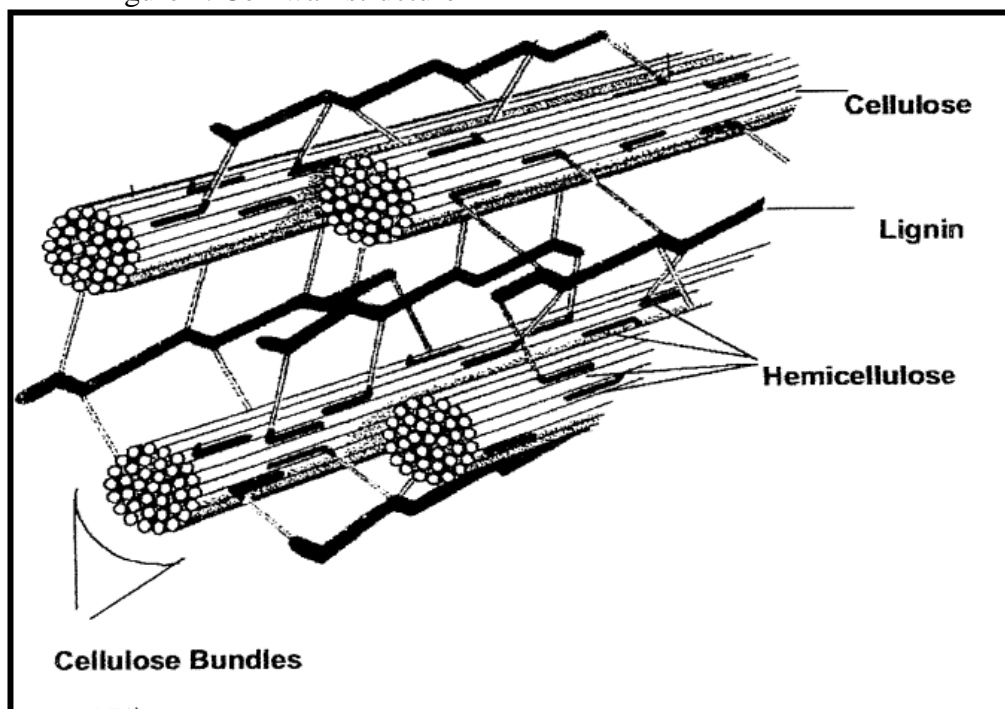
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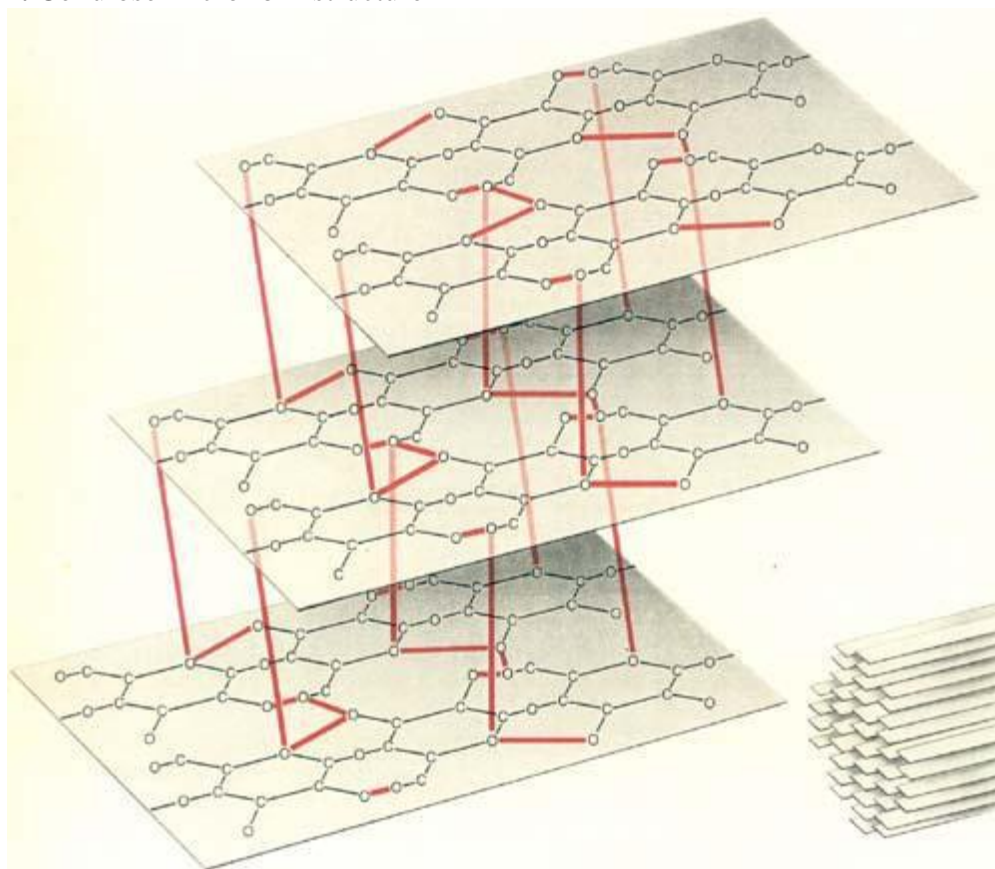
Figure 1. Cell wall structure



Adapted from:

<http://energy.mississippi.org/energycd/Report/ENERGYREPORT.htm>

Figure 2. Cellulose microfibril structure



P.J. Kononoff, personal communication

Running Head: Alkaline treatment of crop residues

CHAPTER II. Factors affecting treatment success of calcium oxide and sodium hydroxide treated crop residues¹

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ABSTRACT

Three studies were conducted to identify methods for treating crop residues to improve digestibility and value. In Exp. 1, IVOMD were slightly greater (2.27% unit increase, $P < 0.01$) if moisture was added to achieve 50% DM compared to 35%. Relative to native (control), treating with 5% CaO improved (% unit) IVOMD of cobs, wheat straw, and corn stover by 9.0, 14.3, and 10.1%, respectively. Small incremental improvements in IVOMD with 1 or 2% NaOH in addition to 5% CaO were observed ($P < 0.01$) for cobs (2.9 and 3.1% unit, respectively) and straw (0.9 and 3.5% unit, respectively) but not for corn stover. In Exp 2., samples treated and stored for 7, 14, or 28 d had similar IVDMD ($P = 0.38$). In Exp. 3., relative rankings for corn plant fractions (highest to lowest IVDMD) were husk, leaf, cob, and stem. Compared to untreated (% unit), husk (11.8%) and leaf (11.7%) had greater response to treatment than did cob (5.3%), and stem (6.7%). Digestibility and value of crop residues were improved by mild chemical treatment. Moisture and temperature affected treatment response and extending reaction times beyond 7 d did not improve digestibility. The magnitude of response to chemical treatment depends on the type of residue (i.e., straw vs. stover) and plant part within corn residue (i.e., husk vs. stalk).

Key Words: alkaline treatment, calcium oxide, crop residues

INTRODUCTION

Value of poor quality crop residues may be improved by use of alkaline treatment such as Ca(OH)_2 (Rounds et al., 1976; Waller, 1976) or NaOH (Berger et al., 1979a;

Lesoing et al., 1980; Paterson et al., 1982). Fahey et al. (1993) reviewed 32 studies where cattle or sheep were fed treated crop residues (included at $\geq 60\%$ of diet DM) with NaOH, and found a 30% improvement in DM digestibility. However, sodium intake from NaOH treated feedstuffs can increase water consumption and ruminal passage rate, thus shifting site of fiber digestion to the lower gut (Berger et al. 1979b). Thus, calcium hydroxide has been used a substitute for NaOH to limit negative effects of Na (Rounds et al, 1976; Waller, 1976; Lesoing et al., 1980; Paterson et al., 1982). Compared to NaOH, calcium oxide is less caustic, easier to handle, and provides a source of Ca. Laboratory screening of alkaline treatments should be utilized to predict how crop residues are affected by chemical treatment (Fahey et al., 1993) as variability in efficiency of treatment is a problem (Van Soest et al., 1984).

The objectives of this research were 1) to identify optimum treatment combinations for improving DM digestibility of different crop residues for eventual on-farm treatment.

MATERIALS AND METHODS

All procedures used for these experiments involving animal care were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC #517).

Exp. 1

Treatment design was a $3 \times 4 \times 2$ factorial. Factors were: three crop residue types (corn stover, corn cobs, or wheat straw), four alkaline treatments (non treated-control, 5% CaO, 4% CaO + 1% NaOH, or 3% CaO + 2% NaOH), and two DM contents (35% or 50% DM). Approximately 100 kg of corn stover, wheat straw, and corn cobs were

collected from commodity storage bays at the ARDC Research Feedlot (Mead, NE), transported to Lincoln, NE, and stored in fiberglass boxes inside until treatments were applied. Corn stover and wheat straw had been previously processed through a tub grinder equipped with a 7.62 cm i.d. screen whereas corn cobs were ground through a 1.27 cm i.d. screen (Mighty Giant, Jones Manufacturing, Beemer, NE). This supply of crop residue was used for subsequent in vitro experiments. Calcium oxide (0 to 0.098 cm granular standard quicklime; Mississippi Lime Company, Kansas City, MO) and sodium hydroxide (NaOH, reagent grade, pelleted; Fischer Scientific, Pittsburgh, PA) were partially solubilized in water to form concentrated caustic solutions, which then were applied to residues. Chemical treatments were applied to crop residues on a DM basis. Distilled water was added to a calculated amount corresponding to the targeted DM level. Approximately, 1 kg of crop residue was combined with water and hydrolytic agent and mixed (#L-100DA; Leland Detroit Manufacturing Company, Detroit, MI) then sealed anaerobically in vacuum bags (model C200; Mutivac Inc, Kansas City, MO). Each treatment combination was replicated 4 times, and bag served as experimental unit. Bags (n = 96) were stored at 20°C for 30 d then sub-sampled, frozen, lyophilized (Virtis Freezemobile 25ES, SP Industries, Warminster, PA) and ground (Wiley mill #3; Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen. Samples were assayed for IVDMD and IVOMD (Tilley and Terry, 1963). Inoculum was obtained by collecting rumen fluid (strained through four layers of cheesecloth) from two donor steers fed: 70.5% brome grass hay, 17.8% DRC, 11.3% soybean meal and 0.36% mineral supplement (DM basis). Inoculum was mixed with McDougall's buffer at a 1:1 ratio along with 1 gram of urea/L of rumen fluid. Replicate was analyzed in triplicate. A 0.5

(± 0.040 g) gram sample was added to a 200-mL test tube, and 50 mL of inoculum was added. Test tubes were placed randomly in a water bath at 39°C and incubated for 48 hours. Fermentation was ended by adding 6 mL of 20% HCl per test tube, along with 2 mL of 5% pepsin solution. Tubes were placed back in the water bath for an additional 24 h. Residue was filtered (Whatman #541, GE Healthcare, Piscataway, NJ), dried at 100°C for at least 5 h, and weighed. Blanks were used to correct for inoculum. To determine OM, incubated residue and starting sample was ashed in a muffle furnace for 6 h at 600°C. Due to size constraints, data was analyzed over two runs with treatments balanced in each run. The MIXED procedure of SAS (Version 9.2, SAS institute, Cary, NC) was used to analyze data. The MODEL statement contained main effects (crop residue, DM, chemical treatment) as well as all possible 2-way and 3-way interactions. If interactions were significant, then simple effects are presented. If interactions were not significant, then main effects are discussed. Run was included as blocking factor in the RANDOM statement. Pair-wise comparisons for treatments were determined by Fisher's LSD method when the F-test statistic was significant. A $P \leq 0.05$ was considered significant.

Exp. 2

A second experiment was conducted to evaluate the effects of temperature and storage time on IVDMD. We hypothesized that temperature may increase the rate and extent of the chemical reaction, as this has been proposed as a means to improve treatment when calcium hydroxide is used (Ørskov, 1981; Owen et al., 1984). Greater temperature may also better reflect the environment inside a bunker or plastic lined bag, as the heat resulting from the exothermic reaction of chemical treatment is retained (it is possible that these factors may interact with treatment or substrate). Thus, an experiment

was designed as a $2 \times 3 \times 2 \times 3$ factorial. Factors were chemical treatment (5% CaO, or 3% CaO + 2% NaOH), crop residue (corn stover, corn cobs, or wheat straw), temperature (40°C or ambient temperature of 20°C), and storage length (7, 14, or 28 d). Water was added during treatment to adjust all samples to 60% DM. Effects of temperature were applied by storing bags in an incubator (Model 1915; VWR Scientific, Radnor, PA) set at 40°C. The approach in this experiment was to compare a mild chemical treatment (5% CaO) versus a more aggressive treatment (3% CaO + 2% NaOH) in order to determine if NaOH would be needed for on-farm treatment (if sodium hydroxide were unnecessary, this would improve the ease of application for treating crop residues). Compared to CaO, NaOH is more caustic and poses more handling risk. The use of calcium oxide or hydroxide has generally been characterized as a less effective treatment compared to NaOH, NH₃, or oxidative treatments (Fahey et al., 1993). All other procedures (application of chemical treatment, sample preparation, and *in vitro* incubations) were the same as Exp.1. Only IVDMD was assayed in this experiment. The MIXED procedure was used to analyze data. The MODEL statement contained main effects as well as all possible 2-way, 3-way, and 4-way interactions. If interactions were significant, then simple effects are presented. If interactions were not significant, then main effects are discussed. Pair-wise comparisons for treatments were determined by Fisher's LSD method when the F-test statistic was significant.

Exp. 3.

A third experiment was conducted to understand relative response of various plant fractions to chemical treatment. Corn stover is a heterogeneous mixture of fractions which vary in digestibility and chemical composition (Gutierrez-Ornelas and

Klopfenstein, 1992), and thus may respond differently depending on chemical treatment. In November, 2009, corn residue plant parts (leaf, cob, husk, and stem) were collected from a single field near the University of Nebraska-Lincoln Agricultural Research and Development Center. The experimental design was a 6×4 factorial. Factors were plant fraction (corn leaf, husk, cob, and stem as well as corn stover and wheat straw from Exp. 1 and 2.) and chemical treatment (native not treated-control, 5% CaO, 4% CaO + 1% NaOH, or 3% CaO + 2% NaOH). Water was added during treatment to adjust all samples to 50% DM. Samples were stored for 28 d under similar conditions in an incubator as outlined in Exp 2. All other procedures (application of chemical treatment, sample preparation, and *in vitro* incubations) were the same as Exp. 1 and 2. The MIXED procedure was used to analyze data. Only IVDMD was assayed in this experiment. The MODEL statement contained main effects of plant fraction and chemical treatment as well as plant fraction x chemical treatment interaction. Pair-wise comparisons for treatments were determined by Fisher's LSD method when the F-test statistic was significant.

RESULTS

Exp 1.

The three-way interaction between crop residue type \times treatment \times DM was significant ($P < 0.01$). Of these factors, it appeared that the effect of DM contributed to relatively minor differences in IVOMD and the majority of the differences observed were due to crop residue type and chemical treatment. Therefore, we chose to report simple effects of chemical treatment and crop residue (Table 1.). Treating with 3% CaO + 2% NaOH relative to 5% CaO improved IVOMD slightly for cobs and straw; however, no

increase was observed for corn stover. Organic matter disappearance was greatest for cobs (43.5%), intermediate with straw (40.9%), and least with corn stover (43.6%; $P < 0.01$, main effect of crop residue; data not shown). Chemical treatment was effective in improving IVOMD (main effect of chemical treatment, $P < 0.01$; data not shown), as 5% CaO and treatments containing NaOH had greater disappearance (40.8%, 42.3%, and 42.8% IVOMD for 5% CaO, 4% CaO + 1% NaOH, 3% CaO + 2% NaOH, respectively) compared to control (29.6%). Treatment with 5% CaO resulted in lower IVOMD compared treatment with NaOH but no difference was observed between the addition of 1 or 2% NaOH. Organic matter disappearance was improved ($P < 0.01$) for treatments at 50% compared to 35% DM (data not shown), but this difference was small (2.27% unit improvement IVOMD). The interaction term between crop residue and DM was significant ($P < 0.01$; data not shown) with 50% DM improving IVOMD for corn cobs (46.7 vs. 40.7%), having no effect for wheat straw or corn stover compared to 35% DM . Paterson et al. (1980) treated cobs, wheat straw, and corn stover with 5% calcium hydroxide with varying moisture levels of 20, 40 and 60% and compared this to an untreated control with 60% moisture. They noted that 40% moisture resulted in the greatest digestibility for cobs and straw but treating with 20% moisture did not reduce dust or allow for even dispersion of calcium hydroxide. In the present experiment, the improvements in IVOMD by treating at 50% compared 35% DM may have allowed CaO to act as a hydrolytic agent rather than a fermentation buffer (Paterson et al. 1980). Fermentation is considered inhibitory to success of chemical treatment (Fahey et al., 1993). However, it is unknown if the crop residues used in this experiment fermented. From this experiment, it appears that magnitude of response to chemical treatment varies

between crop residues and moisture content of the mixture which may be factors to consider when on-farm treatment is implemented.

Exp 2.

The 4-way interaction term of temperature, time, crop residue and chemical was significant ($P = 0.02$; data not shown). In general, it appeared that effects of temperature, while significant with many interacting factors, were small. Therefore, to simplify interpretation, we chose to report only the three-way interaction ($P < 0.01$) of chemical treatment, crop residue, and time (Table 2.). Simple effects of the three-way interaction between crop residue \times chemical treatment \times reaction time suggest that with 5:0 treatment, corn cobs had lower IVDMD at 28 d compared to 7 or 14 d of reaction time, whereas wheat straw increased slightly at 14 d compared to 7 d. Corn stover however, exhibited little change in IVDMD with 5:0 treatment across reaction times. There appeared to be less change for crop residue IVDMD across reaction time for 3:2 compared to 5:0. Main effect of temperature was significant ($P < 0.01$) and revealed a slight improvement in IVDMD (1.02% unit increase). Interaction terms of treatment \times time ($P = 0.72$) or temperature \times time ($P = 0.14$) were not significant (data not shown). Main effect of time did not affect digestibility ($P = 0.38$; data not shown). Samples stored for 7, 14, or 28 d had IVDMD of 45.2, 45.3, and 44.8%, respectively. This is similar to Paterson et al. (1980) who noted no improvement in IVDMD for corn cobs treated with 5% calcium hydroxide after 10 days of reaction time. Shorter reaction time (7 vs. 10 d) observed in this experiment may be related to greater heat and reactivity of initial oxide form compared to hydroxide. Increasing temperature has been suggested to improve rate of reaction and efficacy of calcium hydroxide treatments as successful as

compared to NaOH (Ørskov, 1981; Owen et al., 1984). In contrast to Exp. 1, treatment with 3% CaO + 2% NaOH was greater ($P < 0.01$) than 5% CaO. The relative ranking in crop residue digestibility was similar to that observed in Exp. 1. The conclusion from this experiment is that on-farm chemical treatment of crop residues allows for feeding after 7 d of treatment. It is unclear what minimum storage length may be for CaO treated crop residues bunkered or stored in structures which may retain greater amounts of heat compared to the present experiment.

Exp 3.

A significant ($P < 0.01$) interaction between plant fraction and treatment was observed (Table 3). Similar to Exp. 1, most of the improvement in IVDMD was observed with 5% CaO and addition of NaOH did not improve IVDMD for leaf and husk. However, significant additional improvements in IVDMD of 3:2 compared to 5:0 were observed for stems and cobs. In contrast to Exp. 2, no difference between 5% CaO and 3% CaO + 2% NaOH was observed for straw and stover. It is unclear why this occurred. Relative response to chemical treatment, as viewed by percentage unit improvement, or percent increase varied by plant fraction. Compared to control, leaf, husk, stem, and cob had percent increases of 28.1%, 21.1%, 21.8%, and 12.4%, respectively, when treated with 5:0. However, leaf and husk (11.8 and 11.7, respectively) had greater percentage unit increase to 5% CaO compared to cob and stem (5.3 and 6.7, respectively). The percent improvement to alkaline treatment was lower for husk and leaf compared to cob and stem as husk and leaf have inherently greater IVOMD. Lack of response to NaOH on leaf and husk explains small overall improvement in IVDMD for stover when NaOH is added. Leaf and husk are a main component of corn stover with stems comprising the

other predominate fraction. Fernandez-Rivera and Klopfenstein (1989) found that leaf and husk made up 43.5% to 52.8% of the available corn stover prior to grazing while stem was 29.5% to 42.9%. The majority of the response to treating stems with NaOH may be related to NaOH being a stronger treatment compared to calcium oxide (Fahey et al., 1993). The relative rankings for corn plant fractions (highest to lowest IVDMD) were husk, leaf, cob, and stem, which is similar to Gutierrez-Ornelas and Klopfenstein (1992). Separation of more digestible plant fractions of corn stover has been proposed as a means to improve digestibility (Fahey et al., 1993). If it were feasible to only obtain husk and leaf, milder treatments, such as calcium oxide, may be well suited to improve the nutritive value. As stem increases in the proportion of stover, particularly in irrigated corn (Fernandez-Rivera and Klopfenstein, 1989), use of NaOH may be justified.

CONCLUSIONS

The results of these trials suggest that value of crop residues was improved by calcium oxide and under the conditions of these studies, little improvement in digestibility was observed by the addition of 1 or 2% NaOH. It appears that crop residue type, part within plant, moisture, and temperature are factors to consider when treating residues. Treatment with calcium oxide appears to be a rapid process and animal studies are warranted to understand value under commercial conditions.

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Table 1. Simple effects of chemical treatment and crop residue IVOMD¹² (Exp 1.)

Crop residue	Control ³	CaO:NaOH ³		
		5:0	4:1	3:2
Corn cobs	35.2 ^a	44.2 ^b	47.1 ^c	47.3 ^c
Wheat straw	29.1 ^a	43.4 ^b	44.3 ^{bc}	46.9 ^c
Corn stover	24.5 ^a	34.6 ^b	35.6 ^b	34.1 ^b

¹OM disappearance after 48 h of incubation.

²F-test for two-way interaction term between chemical treatment × crop residue was significant ($P < 0.01$; SEM: 2.2).

³Chemical treatments were (DM basis) Control= non-treated, 5:0= 5% CaO + 0% NaOH, 4:1= 4% CaO +1% NaOH, and 3:2= 3% CaO +2% NaOH.

^{abc}Within a row, values lacking common superscripts differ ($P < 0.05$).

Table 2. Simple effects of chemical treatment, crop residue, and reaction length on IVDMD¹ (Exp 2.)

Item	Reaction time, d ²		
	7	14	28
		5:0 ³	
Corn cobs	47.3 ^b	47.4 ^b	44.5 ^{cd}
Wheat straw	42.2 ^e	46.8 ^{cd}	44.6 ^c
Corn stover	39.8 ^f	38.5 ^g	39.6 ^{fg}
		3:2 ³	
Corn cobs	50.7 ^a	51.3 ^a	50.6 ^a
Wheat straw	47.3 ^b	47.5 ^b	47.0 ^b
Corn stover	44.0 ^{cd}	43.5 ^{cd}	42.4 ^{de}

¹DM disappearance after 48 h of incubation.

²Samples taken 7,14, or 28 d after treatments were applied

³Chemical treatments were (DM basis) , 5:0= 5% CaO + 0% NaOH, and 3:2= 3% CaO +2% NaOH. Treatments were applied at 50% DM.

^{abcd} Values lacking common superscripts differ ($P < 0.05$). Three-way interaction between chemical treatment, crop residue and time was significant (F-Test $P < 0.01$, SEM: 1.14).

Table 3. Simple effects of chemical treatment, plant part, and crop residue DM on IVDMD¹² (Exp 3.)

Item	Control ²	CaO:NaOH ³		
		5:0	4:1	3:2
Corn plant				
Husk	56.0 ^a	67.8 ^b	67.5 ^b	65.8 ^b
Leaf	41.6 ^a	53.3 ^b	53.1 ^b	54.6 ^b
Cob	42.7 ^a	48.0 ^b	48.3 ^b	50.9 ^c
Stem	30.6 ^a	37.3 ^b	38.8 ^b	43.4 ^c
Crop residue				
Wheat straw	33.9 ^a	49.3 ^b	51.3 ^b	51.5 ^b
Corn stover	34.8 ^a	42.5 ^b	41.6 ^b	41.2 ^b

¹DM disappearance after 48 h of incubation.

²F-test for two-way interaction term between chemical treatment and plant fraction was significant ($P < 0.01$; SEM:1.6).

³Chemical treatments were (DM basis) Control= non-treated, 5:0= 5% CaO + 0% NaOH, 4:1= 4% CaO +1% NaOH, and 3:2= 3% CaO +2% NaOH.

^{abc}Within a row, values lacking common superscripts differ ($P < 0.05$).

CHAPTER III. Digestibility and performance of steers fed low-quality crop residues treated with calcium oxide to partially replace corn in distillers grains finishing diets³

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ABSTRACT

Two studies were conducted to identify methods for treating crop residues to improve digestibility and value in finishing diets based on corn grain and corn wet distillers grain with solubles (WDGS). In Exp. 1, 336 yearling steers (initial BW 356 ± 11.5 kg) were used in a $2 \times 3 + 1$ factorial arrangement of treatments. Factors were three crop residues (corn cobs, wheat straw, and corn stover) and two treatments where crop residues were either fed (20% diet DM) in their native form (NT) or alkaline treated with 5% CaO (DM basis) and hydrated to 50% DM before anaerobic storage (AT). Intakes were not affected by diet (F-test; $P = 0.30$). An interaction between chemical treatment and residue ($P < 0.01$) was noted for final BW, ADG, G:F and HCW. Greater final BW was observed for treated stover (4.6%) and straw (5.6%) compared with NT residues; however treated and NT cobs were similar. Treated straw (9.7%) and stover (12.5%) had greater ADG ($P < 0.01$) and improved G:F (10.7% and 5.0%, respectively; $P < 0.01$) compared with NT forms. In Exp. 2, ruminally fistulated steers ($n = 5$) were used in an unbalanced 5×7 incomplete Latin square design with a $2 \times 3 + 1$ factorial arrangement of treatments. Factors were crop residue (corn cobs, wheat straw, and corn stover) and chemical treatment (crop residue either fed as NT or AT). Greater DM (73.7 vs 66.1%; $P < 0.01$), OM (77.0 vs 68.5%; $P < 0.01$), fat (89.2 vs 85.2; $P = 0.02$) and NDF (66.8 vs 51.5%; $P < 0.01$) digestibility were noted for AT compared to NT. However, no difference ($P > 0.10$) was found between CON and AT for DM (70.7 vs 73.7%) or OM (72.1 vs 76.9%) digestibility. Dry matter intakes were not different between treated and untreated ($P = 0.38$) but lower ($P < 0.01$) NDF intake was observed for treated diets (3.1 vs 3.5 kg/d) suggesting that CaO treatment was effective in solubilizing some carbohydrate. These

data suggest that 15% replacement of corn and 10% untreated residue with treated forage results in similar nutrient supply to the control. The improvements in fiber digestibility due to chemical treatment appear to be related to increased digestibility of recoverable NDF and not to increased ruminal pH. Feeding chemically treated crop residues and WDGS is an effective strategy for replacing a portion of corn grain in feedlot diets.

Key Words: alkaline treatment, calcium oxide, crop residues, distillers grains, roughage

INTRODUCTION

Recently, corn has become expensive and this has led to high feed costs and decreased profitability (Tonsor and Dhuyvetter, 2013). If corn could be replaced by inexpensive ingredients, this could lower feed costs and increase profitability. Wet distillers grain with solubles (WDGS), a byproduct from ethanol production, is a suitable replacement for dry rolled corn (DRC) for finishing cattle, with optimal inclusion of 30 to 40% (DM) of diet DM (Klopfenstein et al., 2008). However, as WDGS is priced relative to corn diet costs still remain high. Replacing corn with roughage, such as crop residues, may reduce diet costs but these have less NE_g than corn (NRC, 1996). In turn, substituting roughage for corn could reduce ADG and G:F (Owens, 2011).

Value of poor quality crop residues may be improved by use of alkaline treatment such as $Ca(OH)_2$ (Rounds et al., 1976; Waller, 1976) or NaOH (Berger et al., 1979a; Lesoing et al., 1980; Paterson et al., 1982). Fahey et al. (1993) reviewed 32 studies where NaOH treated crop residues were included (comprising at least 60% of diet DM) and found a 30% improvement in DM digestibility. However, NaOH treated feedstuffs can negatively shift site of fiber digestion to the lower gut (Berger et al. 1979b). Thus,

calcium hydroxide has been used a substitute for NaOH to limit negative effects of Na (Rounds et al, 1976; Waller, 1976; Lesoing et al., 1980; Paterson et al., 1982). Compared to NaOH, calcium oxide is less caustic, easier to handle, and provides a source of Ca.

The objectives of this research were 1) evaluate replacing corn with treated residues in combination with WDGS on steer performance and carcass merit and 2) characterize total tract digestibility and rumen metabolism of treated and untreated crop residues replacing 15% units of corn in the diet.

MATERIALS AND METHODS

All procedures used for these experiments involving animal care were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (IACUC #517).

Exp. 1

Three hundred sixty six yearling crossbred steers (Initial BW= 356 ± 11.6 kg) were utilized in a 140-d finishing trial. Steers were received as calves in October, 2009 and initial processing included: modified live virus vaccine for *Infectious bovine rhinotracheitis*, bovine viral diarrhea types I & II, parainfluenza₃, and bovine respiratory syncytial virus (Bovi-Shield Gold 5, Pfizer Animal Health, New York, NY), *Haemophilus somnus* bacterin (Somubac, Pfizer Animal Health), injectable anthelmintic (Dectomax, Pfizer Animal Health), and metaphylactic antibiotic (Micotil, Elanco Animal Health, Greenfield, IN). Approximately 14 d later, cattle were vaccinated for prevention of pinkeye (Piliguard Pinkeye + 7, Merck Animal Health, Desoto, KS) and given a booster against clostridial infections (Ultrabac-7 Somubac; Pfizer Animal Health). Until trial initiation, steers grazed corn residue for approximately 90 d following initial

processing, and were pen-fed a forage based diet for 120 d. Steers were limit fed (Watson et al., 2012) a diet containing 47.5% sweet bran 47.5% alfalfa hay, and 5.0% supplement (DM basis), at 2.0% of BW for 5 d, prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983). A randomized block design was used with a 2 X 3 + 1 treatment structure. Factors were crop residue (corn cobs, wheat straw, corn stover) and chemical treatment [none (**NT**) vs 5.0% CaO + 50.0% moisture (**AT**)]. The control (plus one) diet contained a greater amount of DRC (46.0 vs. 36.0%) and 10% roughage (equal parts NT cobs, wheat straw, and corn stover on a DM basis). Based on several in vitro experiments (Shreck et al., 2011), which evaluated effects of treating crop residues with calcium oxide and NaOH level, as well as moisture level, we decided to treat crop residues with 5% CaO (DM basis) at 50% DM. Supplemental calcium is needed in the diet and unlike sodium hydroxide, excretion of Ca from calcium oxide provides additional fertilizer value (Rounds et al., 1976). Crop residues replaced DRC and were fed at 20.0% diet DM (Table 1.). Crop residues were purchased approximately 2 mo before the beginning of the trial and each crop residue was secured from one source. Corn stover and wheat straw were brought to the feedlot as round bales. Corn cobs were sourced from seed corn production. Initially, crop residues were tub ground (Mighty Giant, Jones Manufacturing, Beemer NE) and stored under roof in a commodity bay. Chemical treatment consisted of water, CaO (0 to 0.098 cm granular standard quicklime, Mississippi Lime Co.), and ground residue (7.62 cm i.d. screen for corn stover and wheat straw, 1.91 cm i.d. screen for corn cobs) weighed and mixed into feed trucks (Roto-Mix, Dodge City, KS). The mixture was calculated to be 50% DM with calcium oxide added at 5.0% of the total DM (DM of treated cobs, wheat straw, and corn stover were 52.4, 51.6

and 45.6%, respectively; Table 2.). Feed trucks dispensed treated residue into a bagger (Model 2W08; Kelly-Ryan, Blair, NE) operating at approximately 1379 kPa for anaerobic storage over the duration of the trial. Treatment of crop residues was completed 30 d prior to initiation of the trial. Amounts of DM inside each bag were recorded and estimates of bulk density of treated corn cobs, wheat straw, and corn stover were 0.131, 0.130, and 0.083 kg DM/m³, respectively. Untreated residues were ground and stored under roof (no added moisture or chemical). Wet distillers grains plus solubles were obtained from a commercial ethanol plant (Abengoa Bioenergy, York, NE) and delivered as needed (approximately 1 semi-load /wk). All finishing diets contained 5% dry supplement, which was formulated to provide 33 mg/kg and 90 mg/steer daily monensin and tylosin (Elanco Animal Health, Greenfield, IN), respectively. Feedbunks were assessed at approximately 0630 h and managed so that only traces of feed were left in the bunk each morning at feeding time. Accumulated feed refusals were removed from feed bunks and were dried for 48 h at 60°C in a forced-air oven to determine DM. Ingredients were sampled weekly and DM determined similar to Orts. Orts were assessed weekly and refusals comprised 0.8% of total DM offered. Ingredient CP (method 990.06, AOAC 1990) and sulfur were analyzed using a combustion type N and S analyzer (TrueSpec N Determinator and TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI). Lipid was determined using a biphasic lipid extraction as outlined by Bremer et al. (2010). Monthly composite samples of treated and untreated crop residues were analyzed for Ca (Servi-Tech Labs, Inc. Hastings, NE), NDF (Van Soest et al., 1991), and pH. Briefly, pH was determined by taking 5.0 g (as-is, sample previous dried and ground through 1 mm) of sample and adding 100 ml of distilled water, which was

then refrigerated for 12 hr, and pH was measured (Model EN20, Mettler-Toledo, Columbus, OH) after sample was given 20 min to equilibrate to room temperature.

Calcium oxide (formulated to contain 68% Ca based on molecular ratio) replaced limestone in treated diets. Before feeding final experimental diets, a series of 4 diets containing 30, 22.5, 15, and 7.5% alfalfa hay (DM basis) were fed for 7 d per step, with corn replacing alfalfa hay in each diet. Inclusion level of crop residue was the same in the adaptation diets as in the final experimental diets for each treatment. Six steers were treated for foot rot and one steer died while on study. Steers were implanted with Revalor-XS (200 mg trenbolone acetate, 40 mg estradiol; Merck Animal Health) on d 1. Steers were pen weighed (Norac M2000, Norac Inc. Bloomington, MN) on d 140 prior to shipment and BW was shrunk 4% to calculate live BW and dressing percentage. Steer ID and HCW were recorded on the day of slaughter. After a 48 h chill, marbling score, 12th-rib fat thickness, and LM area were recorded from camera measurements. Final BW, ADG, and G:F were calculated based on HCW adjusted to a common dressing percentage of 63%. Yield grade was calculated according to Boggs et al. (1998) using the carcass measurements (assuming a common 2.5% KPH) and the following formula: $(YG = (2.50 + (0.0017 \times HCW, \text{ kg}) + (0.2 \times KPH, \%) + (6.35 \times 12^{\text{th}} \text{ rib fat, cm}) - (2.06 \times LM \text{ area, cm}^2))$.

This experiment was structured as a randomized block design, with three initial weight blocks (light, middle, and heavy; replications per block were 2, 3, and 1, respectively). Steers (8 per pen) were assigned randomly within strata and block to pens and pen was assigned randomly to treatment. Data were analyzed using the MIXED procedure of SAS. In all analyses, initial BW block was included as a random effect.

Two models were constructed to analyze data. To compare treated and untreated diets to the control, pair-wise comparisons for treatments were determined by Fisher's LSD method when the F-test statistic was significant at an alpha level of $P = 0.05$. All diets were coded such that the model statement contained the effects of each treatment combination and the control. To evaluate the main effects of crop residue type and chemical treatment, a second model was constructed. Data were analyzed as a 2 x 3 factorial treatment arrangement. This model contained main effects of chemical treatment (NT vs. AT) and crop residue (cobs, straw, and corn stover) as well as chemical treatment x crop residue interaction. A $P \leq 0.05$ was considered significant and $P \leq 0.10$ to > 0.05 were considered statistical trends.

Exp. 2

A metabolism study was conducted to evaluate rumen metabolism and digestibility of treated crop residues. Ruminally fistulated steers ($n = 5$) were assigned randomly using a row x column transformation and acclimated to each diet for seven 15-d periods, partitioned with 10 d of adaptation and 5 d of collection. This experiment was designed as a 5 x 7 incomplete Latin square with a 2 x 3 + 1 factorial arrangement of treatments. Factors were crop residue (corn cobs, wheat straw, corn stover) and chemical treatment [none (NT) vs 5.0% CaO + 50.0% moisture (AT)]. The control (plus one) diet contained a higher amount of DRC (46.0 vs. 36.0%) than AT and NT diets and 10% roughage (equal parts NT cobs, wheat straw, and corn stover on a DM basis).

Treated and untreated residues were obtained from Exp. 1 which was taking place concurrently. Wet ingredients (treated residues and WDGS) were collected from ARDC Research Feedlot (Ithaca, NE) approximately 2 times per week and transported to the

Animal Science Complex (Lincoln, NE) in 208 L steel barrels and stored in a cooler until mixing time. Diets were mixed as needed in a stationary ribbon mixer (Model S-5 Mixer; H.C. Davis Inc, Bonner Springs, KS). Finished feed and wet feed ingredients were stored at 4° C in a walk-in cooler to maintain freshness and prevent mold growth. Steers were given *ad libitum* access to feed and were fed once daily at 0800 h. The diets provided 320 to 360 mg/steer of monensin (Rumensin-90; Elanco Animal Health), 90 mg/steer of tylosin (Tylan-40; Elanco Animal Health), and 150 mg/steer of thiamine daily. Feed refusals were removed daily and from d 9 to 14, 10% (as-is) was collected and frozen. From daily feed refusal samples, a steer within period composite sample was made and then dried at 60°C to determine DM content, ground, and used for nutrient analysis in calculating digestibility.

Chromic oxide was used as an external marker to estimate fecal output. Steers were dosed intraruminally with 7.5 g of Cr₂O₃ twice daily at 0800 and 1600 hr. Approximately 300 g of feces were collected at 0800, 1200, and 1600 hr from d 11 to d 15. Within a day, fecal samples were composited on a wet basis into a daily composite, then lyophilized (Virtis Freezemobile 25ES, SP Industries, Warminster, PA). From dried daily composites, a steer within period fecal composite sample was made and analyzed for NDF (Van Soest et al., 1991), OM, and Cr percentage. Diet samples, feed refusals, and fecal samples were ground to pass through a 1-mm screen using a Wiley mill (No. 4, Thomas Scientific, Swedesboro, NJ), and composited by period. Feed, feed refusals, and fecal samples were analyzed for OM, NDF, and fat content as referenced earlier. Percent OM was determined by ashing samples at 600°C for 6 h. Fecal samples were prepared for Cr analysis according procedures outlined by Williams et al. (1962). Fecal samples

were diluted 10:1 and analyzed for Cr via atomic adsorption (Varian Spectra AA-30; Walnut Creek, GA). Approximately 45 mL of rumen fluid was collected on d 15 at 0800, 1100, 1400, 1700, 2000, and 2300 hr using the suction strainer technique (Raun and Burroughs, 1962). A composite sample of steer within period was made by taking a 5 mL aliquot of thawed rumen fluid from 3 h samples. This composite sample was prepared according to Erwin et al. (1962) and analyzed for VFA concentration, using a Series II HP 5890 (Hewlett-Packard, Avondale, MA) gas chromatograph.

Wireless, submersible pH probes (Dascor Inc, Escondido, CA) were placed into the rumen of each steer to monitor ruminal pH for the duration of the trial. Each probe was attached to a weighted enclosure designed to ensure the electrode remained in the ventral sac of the rumen. Prior to trial initiation, the calibration of each pH probe was verified by submersing probes in pH 4 and 7 standard solutions. Ruminal pH was recorded over the collection period (d 11 to 15) every min continuously for each period. On the first d of each period, prior to feeding the next diet, probes were removed from the rumen in order to download pH data and re-verify probe calibration. Ruminal pH measurements from each period were adjusted using beginning and ending calibration values to ensure accurate pH measurements.

Data for ruminal pH were analyzed within each period using the GLIMMIX procedure of SAS. Data were analyzed using a repeated measures analysis with d repeated and an unstructured (UN) covariance structure was found to provide best fit. The model included d and treatment as a fixed effects and steer was considered a random effect. Time and area of ruminal pH < 5.6 as well as magnitude of pH change were calculated as described by Cooper et al. (1999).

Digestibility and VFA data were analyzed using the MIXED procedure with steer as a random effect and period as a fixed effect. For all variables, two models were constructed to analyze data. To compare treated and untreated diets to the control, pairwise comparisons for treatments were determined by Fisher's LSD method when the F-test statistic was significant at an alpha level of $P = 0.10$. All diets were coded such that the model statement contained the effects of each treatment combination and the control. To evaluate the main effects of crop residue type and chemical treatment, a second model was constructed. Data were analyzed as a 2 x 3 factorial treatment arrangement. This model contained main effects of chemical treatment (NT vs. AT) and crop residue (cobs, straw, and corn stover) as well as chemical treatment x crop residue interaction. An alpha of $P \leq 0.10$ was considered significant.

RESULTS

Exp 1.

The 2 x 3 portion of the finishing experiment detected an interaction between chemical treatment and residue ($P < 0.01$; Table 3.) for carcass adjusted final BW, ADG, G:F, and HCW. Steers fed AT straw and corn stover had 9.7% and 12.5% greater ADG, respectively, compared to NT straw and stover. Greater final BW was observed for steers fed AT corn stover (4.6%) and wheat straw (5.6%) compared to NT corn stover and wheat straw. A tendency ($P = 0.07$) for an interaction were observed where steers fed AT straw and corn stover had greater live BW compared to NT straw and stover but NT cobs had similar live BW as AT cobs. No difference was observed between AT and NT cobs on ADG, G:F, and final BW. Steers fed AT wheat straw and corn stover had G:F

improvements of 10.7% and 5.0%, respectively, compared to NT wheat straw and corn stover. No interaction between crop residue and chemical treatment was noted for G:F ($P = 0.16$) and AT had greater ($P < 0.01$) G:F than NT forms. No interaction between chemical treatment and crop residue was observed on DMI or DMI as % of BW. Similar to performance, an interaction for chemical treatment and residue ($P < 0.01$) was noted for HCW and 12th rib fat. Greater ($P < 0.01$) HCW and 12th rib fat for AT wheat straw and corn stover were observed compared to NT wheat straw and corn stover but AT and NT cobs were similar. Greater ($P < 0.01$) HCW and 12th rib fat were observed for steers fed AT compared to NT. Treated diets tended ($P = 0.08$) to have greater calculated yield grade than untreated. No difference was observed on dressing percent due to crop residue ($P = 0.34$) or chemical treatment ($P = 0.69$).

Comparing the 2×3 set of treatments to the + 1 CON diet, no difference (F-test; $P = 0.30$) in DMI or DMI % of BW (F-test; $P = 0.93$) was observed. For the control, 9.0% NDF from roughage was calculated compared to an average of 16.5% for diets containing 20% treated or untreated roughage (Table 2.). Wheat straw had 21.0% of NDF solubilized due to AT whereas corn cobs and corn stover had 16.5% and 15.0%, respectively. Compared to the control, AT wheat straw had greater ($P < 0.01$) final BW, but AT cobs, AT corn stover, and NT straw were similar. For ADG, AT crop residues as well as NT cobs and NT straw were similar compared to the control ($P \geq 0.05$). The control did have greater ADG than NT stover. For G:F, a tendency ($P = 0.06$) for differences among all diets was observed. The control ranked intermediate in G:F compared to all treatments.

Compared to control, steers fed AT wheat straw had greater HCW. No difference was observed on HCW for AT corn stover, AT cobs, NT cobs and NT straw compared to the control. Numerically, steers fed AT corn stover had greater HCW than control. Control had greater 12th rib fat than AT cobs and NT treatments. No differences were observed for marbling score across all treatments (F-test, $P = 0.12$). No differences were observed for dressing percent across all treatments (F-test, $P = 0.36$).

Exp. 2

An interaction for DM ($P = 0.01$), OM ($P < 0.01$), and lipid ($P < 0.01$) intake was observed where NT cobs and corn stover were greater compared to AT cobs and corn stover whereas NT straw was lower compared to AT straw (Table 6.). Amount of lipid intake by NT stover was slightly greater than other treatment which suggests that steers consuming that diet were able to sort for WDGS more than steers consuming wheat straw and corn cob diets. Lower ($P < 0.01$) NDF intake was observed for treated diets (3.1 vs 3.5 kg/d), reflecting CaO treatment which partially solubilized NDF, thereby decreasing measurable NDF intake. Treatment with CaO solubilized (relative to untreated) 16.6, 21.0, and 15.6% of the NDF for treated cobs, wheat straw, and corn stover, respectively (Table 5.). Steers fed wheat straw diets had lower NDF intake ($P < 0.01$) than did corn cobs or corn stover diets. No differences were noted ($P \geq 0.10$) for DM or OM intake of AT or NT diets compared to CON. Lower NDF intake ($P < 0.01$) was observed for CON compared AT and NT diets.

No interaction between chemical treatment \times crop residue was noted for digestibility ($P > 0.10$; Table 6.). Greater DM (73.7 vs 66.1%; $P < 0.01$) and OM (77.0 vs 68.5%; $P < 0.01$) digestibility was noted for AT compared to NT. The differences in

DM and OM digestibility were the result of greater NDF (66.8 vs 51.5%; $P < 0.01$) digestibility by AT compared to NT. Digestibility of lipid was also greater for AT compared to NT. Steers fed CON numerically lower DM (70.7 vs 73.7%) and OM (72.1 vs 76.9%) digestibility compared to steers fed AT diets, although these differences were not different statistically ($P > 0.10$). The similar DM and OM digestibilities were due to dramatically greater NDF digestibility of steers fed AT diets compared to CON. Greater NDF digestibility was noted for NT cobs and straw compared to CON but NT stover was similar.

In general, AT appeared to increase pH compared to NT for cobs and stover but not for straw (Table 7.). An interaction was noted for average ruminal pH ($P = 0.08$) and minimum pH ($P = 0.03$) as steers fed AT cobs and stover had greater pH compared to NT forms but steers fed AT straw had lower rumen pH compared to NT (Table 11). Time of pH < 5.6 was decreased ($P = 0.10$) for AT cobs and stover compared to NT forms but no difference between AT and NT straw was observed. AT and NT diets were not different for average and minimum pH compared to CON. Time of pH < 5.6 was not different between CON and AT diets. Crop residue pH was numerically greater for AT compared to NT residues. However, there appears to be no relationship between crop residue pH and ruminal pH. We would submit that crop residue pH could serve as a potential quality control measure rather than an indicator of ruminal pH.

No difference ($P = 0.48$; Table 7.) was observed for molar proportion of acetate between steers fed AT and NT. Steers fed wheat straw diets had lower acetate compared to cobs and stover. A tendency ($P = 0.15$) for an interaction between chemical treatment and crop residue on propionate concentration was observed. Lower propionate

concentration was observed for AT cobs and corn stover compared to NT, but propionate was similar for straw diets. As a main effect of chemical treatment, AT had lower propionate than NT ($P = 0.05$). Wheat straw diets tended ($P = 0.15$) to have greater propionate than cobs or stover. Butyrate concentration was greater ($P = 0.03$) for AT compared to NT. An interaction ($P = 0.06$) was observed for acetate:propionate (A:P) ratio. Similar to pH, AT cobs and corn stover produced greater A:P compared to NT, but AT wheat straw produced lower A:P compared to NT straw. When CON was analyzed with AT and NT diets, a tendency for a difference in acetate was observed (F-test $P = 0.12$). No difference was observed for CON compared to AT and NT diets for propionate. No difference ($P > 0.10$) was observed between steers fed AT straw or stover compared to control (2.6) for A:P. Compared to CON, AT cobs produced higher C2:C3. Results suggest that treated crop residues can substitute for a portion of grain and roughage needed in feedlot diets and result in similar nutrient supply to the animal. The improvements in digestibility when treated residues are fed compared with untreated residues are related to fiber solubilization and improved fiber digestibility of remaining residue.

DISCUSSION

It is unclear why no response was observed with treating cobs. Based on the amount of NDF solubilized for AT cobs (16.5%) compared to NT, chemical treatment appeared to have taken place. Klopfenstein (1978) postulated that the mode of action of hydrolytic agents were primarily related to (1) solubilization of hemicellulose, (2) increased rate and (3) increased extent of digestion of hemicellulose and cellulose. Others (Chandra and Jackson, 1971; Rexen and Thompson, 1976) have found that response to

chemical treatment varies with crop residue type. Physical form of cobs, which presumably had smaller particle size due to the smaller screen used during initial processing, may have had shorter residence time within the rumen, negating any possible response to treatment (Welch, 1982).

It could also be expected that DMI of the control would be lower compared to the other diets tested, as the addition of roughage generally increases DMI (NRC, 1996). Galyean and Defoor (2003) reported that dietary NDF from roughage accounted for 92% to 93% of the variation in DMI as a % of BW for finishing cattle fed grain based diets. Presumably, energy consumption is limiting intake for control steers. However whether gut fill or energy is regulating intake in steers consuming treated and untreated diets is unknown. The control in this study supplied 9.0% NDF from roughage which is approximately double what is traditionally fed (Vasconcelos and Galyean, 2007). Benton et al. (2007) fed 0, low (2.30 to 2.65%), or normal (4.60 to 5.83%) amounts of NDF from roughage from various sources (balanced to provide similar amounts of NDF) and found that the addition of roughage increased DMI and ADG but did not depress or improve G:F in diets containing 30% WDGS. They noted ($P = 0.04$) increased DMI, ADG, and final BW of steers fed normal amounts of roughage compared to low. The authors concluded addition of roughage in diets containing WDGS appears to have effects similar to those observed in grain based diets.

Sewell et al. (2008) fed treated (processed similar to described above with 5% CaO, DM basis) pellets to lambs composed of wheat straw or corn stover, fed at 30% of diet DM. They noted improvements in diet DM and NDF digestibilities of 9.7% and 48.3%, respectively, of treated wheat straw compared to native forms. For corn stover,

diet DM and NDF digestibilities were increased by 9.0% and 46.4%, respectively, compared to native form. However, compared to a control diet that contained 60% DRC (30% DRC in wheat straw and corn stover diets, DM basis) DM digestibility was reduced for both wheat straw and corn stover diets. In the present study, diet DM digestibility was increased by 4.3%, 12.8%, and 17.8% for treated cobs, wheat straw, and corn stover, respectively, compared to untreated diets. However, we did not observe any difference on DM or OM digestibility of the treated diets compared to the control. Differences between the results in the present study and that of Sewell et al. (2008) could be related to the amount of corn replaced and that both corn and roughage were replaced in this work.

To date, few studies have focused on corn replacement strategies as historically, corn was inexpensive and the most economical source of energy. Sewell et al. (2009) replaced all of the corn in a finishing diet with a pellet (included at 50% of diet DM) that contained various blends of crop residues that were thermo-chemically treated with a Readco processor (Readco Kurimoto Continuous Processor, York, PA) containing 5% calcium oxide and dried distillers grains plus solubles (DDGS). In that study, the corn replacement pellet was compared to a control diet which contained (DM basis): 50% DRC, 25% DDGS, 15% corn silage, and 10% supplement. Dietary NDF was higher (37.1 and 38.3%) for treatments that contained corn replacement compared to the control diet which contained 19.3%. They observed lower DMI for the control compared to two diets that contained a corn replacement pellet which contained either corn fiber or wheat straw. They found decreased G:F for Holstein steers that were fed the corn replacement pellet compared to the control diet but no difference in ADG was observed. This work suggested that calcium oxide treated crop residues fed in conjunction with a distillers

grain-based diet may be a feeding strategy to reduce diet costs while maintaining acceptable performance.

It is unclear why similar efficiency was observed between treated diets and the control. However, steers in this study were fed a higher amount of roughage in the control diet than typically fed (Vasconcelos and Galyean, 2007), which may have diluted some of the response. Additionally, treated crop residue diets are replacing not only corn but also the roughage in the control diet. It is unlikely that treated residue has similar energy content to corn grain it replaces based on previous *in vitro* studies. Using tabular values (NRC, 1996), DRC has 78% and 115% greater TDN than corn cobs and wheat straw, respectively. Greater utilization of WDGS or corn may some of the explain response. Others have found decreased ruminal residence time for grain as roughage increased in the diet (Owens and Goetsch, 1986; Moore et al., 1990; Wylie et al., 1990) whereas others have noted no difference (Poore et al., 1990; Shain et al., 1999). Shifting site of digestion for starch toward the small intestine is generally viewed as counterproductive to efficient grain utilization as intestinal starch digestion is limited (Huntington, 1996), despite energy losses associated with fermentation. Owens et al. (1986) hypothesized that shifting site of digestion of starch would result in 42% greater energy capture compared to fermentation. Under the conditions of this study, grain inclusion is much lower than typically observed (Vasconcelos and Galyean, 2007) for finishing cattle and intestinal starch digestion may not be overwhelmed. Greater stratification of rumen contents, due to inclusion of crop residues, namely wheat straw and corn stover, may increase residence time of small particles such as WDGS thereby increasing digestibility (Welch, 1982).

Increasing roughage has shown to effectively reduce H₂S concentration (Vanness et al., 2009; Morine et al., 2012). Excess sulfur (> 0.46% diet DM, Nichols et al., 2011) has been characterized as detrimental to both animal health (Gould, 1998), DMI, and ADG (Sarturi et al., 2013). Indeed, high ruminal sulfide (H₂S) production may induce polioencephalomalacia (PEM) by absorption of re-inhaled ruminal gases. Lower DMI and ADG are commonly observed with high levels of sulfur (Sarturi et al., 2013; Uwituze et al., 2011). However, Sarturi et al. (2013) observed no impact on G:F due to sulfur level. It could be expected that steers fed crop residues had lower H₂S production compared to the control. Lower H₂S production would not help explain why efficiency was similar between treated diets and the control but DMI and ADG could be expected to increase which was not observed in the feedlot experiment.

Under the conditions of this study, feeding steers 20% wheat straw or corn stover, previously treated with 5% calcium oxide at 50% DM, in a wet distillers grain plus solubles based diet, was able to support similar ADG, DMI, and G:F compared to a diet that contained 10 DM percentage units less dry rolled corn. The differences in observed performance are related increased fiber digestibility by treated residues, resulting in similar nutrient supply and fermentation characteristics to the animal.

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Table 1. Composition of diets (% of diet DM) fed to finishing steers (Exp. 1).

Item	Corn Cobs			Wheat Straw		Corn Stover	
	Control	AT ¹	NT ¹	AT ¹	NT ¹	AT ¹	NT ¹
Dry-rolled corn	46.0	36.0	36.0	36.0	36.0	36.0	36.0
Wet distillers grains plus solubles	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Cobs-treated ²	–	20.0	–	–	–	–	–
Straw-treated ²	–	–	–	20.0	–	–	–
Stover-treated ²	–	–	–	–	–	20.0	–
Cobs-not treated	3.33	–	20.0	–	–	–	–
Straw-not treated	3.34	–	–	–	20.0	–	–
Stover-not treated	3.33	–	–	–	–	–	20.0
Dry Supplement ³							
Fine ground corn	2.008	3.488	2.008	3.488	2.008	3.488	2.008
Limestone	1.479	–	1.479	–	1.479	–	1.479
Salt	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Tallow	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Trace mineral ⁴	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Thiamine ⁵	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Vitamin A-D-E premix ⁶	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-80 ⁷	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Tylan-40 ⁸	0.010	0.010	0.010	0.010	0.010	0.010	0.010

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

²Formulated to contain 3.15% Ca and supply 0.63% dietary Ca at 20% inclusion

³Supplement formulated to be fed at 4% of diet DM.

⁴Premix contained 6% Zn, 5% Fe, 4% Mn, 2% Cu, 0.28% Mg, 0.2% I, and 0.05% Co.

⁵Premix contained 88 g of thiamine·kg⁻¹.

⁶Premix contained 30,000 IU of vitamin A, 6,000 IU of vitamin D, 7.5 IU of vitamin E·g⁻¹.

⁷Premix contained 198 g of monensin·kg⁻¹ (Elanco Animal Health, Greenfield, IN).

⁸Premix contained 88 g of tylosin·kg⁻¹ (Elanco Animal Health).

Table 2. Nutrient composition (% of DM) fed to finishing steers (Exp. 1).

Item	Control	Corn Cobs		Wheat Straw		Corn Stover	
		AT ¹	NT ¹	AT ¹	NT ¹	AT ¹	NT ¹
Crop Residue							
DM	84.3	52.4	93.0	51.6	87.2	45.6	72.8
NDF	90.1	78.4	94.0	69.9	88.5	74.7	87.8
NDF as % of roughage	9.0	15.7	18.8	14.0	17.7	14.9	17.6
pH	6.3	8.1	5.4	7.9	7.0	7.8	6.5
Dietary							
CP	16.2	15.5	15.5	16.0	16.0	15.7	16.0
NDF	28.9	34.4	37.5	32.7	36.4	33.7	36.3
Ether Extract	6.5	6.2	6.2	6.5	6.4	6.3	6.2
Ca	0.58	0.58	0.59	0.60	0.62	0.56	0.61
P	0.42	0.50	0.41	0.41	0.40	0.42	0.41
S	0.40	0.41	0.41	0.40	0.40	0.40	0.39

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

Table 3. Performance and carcass characteristics of steers fed treated or untreated crop residues as partial grain replacements (Exp. 1).

Item	Control	Corn Cobs		Wheat Straw		Corn Stover		SEM ²	F-test	F ³	T ⁴	FxT ⁵
		AT ¹	NT ¹	AT ¹	NT ¹	AT ¹	NT ¹					
Performance												
Initial BW, kg	357	356	355	359	355	360	355	12	0.34	0.86	0.19	0.73
Final BW, kg ⁶	597 ^{bc}	593 ^{bc}	593 ^{bc}	614 ^a	581 ^{cd}	602 ^{ab}	576 ^d	11	<0.01	0.27	<0.01	<0.01
Live BW, kg ⁷	625 ^{ab}	630 ^a	642 ^a	642 ^a	586 ^b	634 ^a	623 ^{ab}	17	<0.01	0.31	0.11	0.07
ADG, kg/d	1.72 ^{abc}	1.70 ^{bcd}	1.70 ^{bc}	1.82 ^a	1.61 ^{cd}	1.74 ^{ab}	1.59 ^d	0.04	<0.01	0.30	<0.01	0.01
DMI, kg/d	11.7	11.5	11.7	11.7	11.50	11.9	11.4	0.1	0.30	0.97	0.11	0.12
DMI, % BW	2.47	2.44	2.47	2.43	2.46	2.48	2.46	0.05	0.93	0.78	0.57	0.66
G:F	0.146 ^{ab}	0.147 ^{ab}	0.146 ^{ab}	0.155 ^a	0.140 ^b	0.146 ^a	0.139 ^b	0.003	0.06	0.31	0.01	0.16
Dressing, % ⁸	60.6	59.4	59.5	60.7	62.7	59.7	59.3	0.01	0.36	0.34	0.69	0.19
Carcass Characteristics												
HCW, kg	379 ^{bc}	376 ^{bc}	377 ^{bc}	390 ^a	369 ^{cd}	382 ^{ab}	366 ^d	7	<0.01	0.28	<0.01	<0.01
12 th -rib fat, cm	1.35 ^a	1.19 ^{bc}	1.22 ^{bc}	1.27 ^{ab}	1.12 ^c	1.35 ^a	1.12 ^c	0.02	<0.01	0.79	<0.01	0.03
LM area, cm ²	83.59	84.04	86.49	87.01	85.14	84.69	82.04	1.43	0.11	0.10	0.50	0.10
Marbling score ⁹	517	507	516	508	484	501	494	9.4	0.12	0.12	0.25	0.14
Calculated YG ¹⁰	3.46	3.23	3.20	3.29	3.12	3.45	3.21	0.10	0.16	0.39	0.08	0.59

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

²Highest reported standard error of mean from F-test, model considered all diets.

³Main effect of forage fraction.

⁴Main effect of chemical treatment.

⁵Forage fraction x chemical treatment interaction.

⁶Calculated as HCW/common dress (63%).

⁷Pen weight before slaughter.

⁸Calculated as: HCW/ (Live BW*0.96).

⁹500 = Small⁰, 600 = Modest⁰.

¹⁰YG = [2.5 + (6.35*fat thickness, cm) + (0.2*2.5% KPH) + (0.0017*HCW, kg) – (2.06*LM area, cm²)]; (Boggs and Merkel, 1993).

^{abcd}From the F-test, within a row, values lacking common superscripts, differ ($P < 0.05$).

Table 4. Composition of diets (% of diet DM) fed to steers (Exp. 2).

Item	Corn Cobs			Wheat Straw		Corn Stover	
	Control	AT ¹	NT ¹	AT ¹	NT ¹	AT ¹	NT ¹
Dry-rolled corn	46.0	31.0	31.0	31.0	31.0	31.0	31.0
Wet distillers grains plus solubles	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Cobs-treated ²	–	25.0	–	–	–	–	–
Straw-treated ²	–	–	–	25.0	–	–	–
Stover-treated ²	–	–	–	–	–	25.0	–
Cobs-not treated	3.33	–	25.0	–	–	–	–
Straw-not treated	3.34	–	–	–	25.0	–	–
Stover-not treated	3.33	–	–	–	–	–	25.0
Dry Supplement ³							
Fine ground corn	2.008	3.488	2.008	3.488	2.008	3.488	2.008
Limestone	1.479	–	1.479	–	1.479	–	1.479
Salt	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Tallow	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Trace mineral ⁴	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Thiamine ⁵	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Vitamin A-D-E premix ⁶	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-80 ⁷	0.019	0.010	0.019	0.010	0.019	0.010	0.019
Tylan-40 ⁸	0.010	0.005	0.010	0.005	0.010	0.005	0.010

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

²Formulated to contain 3.15% Ca and supply 0.63% dietary Ca at 20% inclusion

³Supplement formulated to be fed at 4% of diet DM.

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

⁵Premix contained 88 g of thiamine·kg⁻¹.

⁶Premix contained 30,000 IU of vitamin A, 6,000 IU of vitamin D, 7.5 IU of vitamin E·g⁻¹.

⁷Premix contained 198 g of monensin·kg⁻¹ (Elanco Animal Health, Greenfield, IN).

⁸Premix contained 88 g of tylosin·kg⁻¹ (Elanco Animal Health).

Table 5. Nutrient composition (% of DM) fed to finishing steers (Exp. 2)

Item	Control	Corn Cobs		Wheat Straw		Corn Stover	
		AT ¹	NT ¹	AT ¹	NT ¹	AT ¹	NT ¹
Crop Residue							
DM	84.3	52.4	93.0	51.6	87.2	45.6	72.8
NDF	90.1	78.4	94.0	69.9	88.5	74.7	87.8
Roughage supplied							
NDF ²	9.0	19.6	23.5	17.5	22.1	18.7	22.0
pH	6.3	8.1	5.4	7.9	7.0	7.8	6.5
Dietary							
CP	16.2	15.5	15.5	16.0	16.0	15.7	16.0
NDF	27.7	36.9	40.6	34.8	39.3	36.0	39.1
Ether Extract	6.3	6.0	5.9	6.0	5.9	6.1	6.0
Ca	0.58	0.69	0.60	0.71	0.63	0.66	0.62
P	0.42	0.50	0.41	0.41	0.40	0.42	0.41
S	0.40	0.41	0.41	0.40	0.40	0.40	0.39

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

²Calculated as crop residue NDF * dietary DM inclusion.

Table 6. Effect of feeding treated or untreated crop residues as partial grain replacements on total tract digestibility and intake of nutrients (Exp. 2).

Item	Corn Cobs			Wheat Straw		Corn Stover		SEM ²	F-test	F ³	T ⁴	FxT ⁵
	Control	AT ¹	NT ¹	AT ¹	NT ¹	AT ¹	NT ¹					
Intake, kg/d												
DM	9.8	9.8	10.4	10.0	9.0	9.4	10.4	0.6	0.46	0.08	0.36	0.01
OM	9.4 ^{ab}	9.4 ^{ab}	9.9 ^a	9.5 ^{ab}	8.5 ^b	8.9 ^{ab}	9.9 ^a	0.6	0.02	0.01	0.06	<0.01
EE	0.71 ^b	0.69 ^b	0.72 ^b	0.66 ^{bc}	0.60 ^{cd}	0.54 ^d	0.80 ^a	0.04	<0.01	0.02	<0.01	<0.01
NDF	2.2 ^c	3.1 ^b	3.6 ^{ab}	3.1 ^b	3.3 ^{ab}	3.1 ^b	3.7 ^a	0.2	<0.01	0.21	<0.01	0.57
Apparent total tract digestibility, %												
DM	70.3 ^{abc}	71.9 ^{ab}	68.9 ^{abc}	74.7 ^a	66.2 ^{bc}	74.5 ^a	63.2 ^c	3.0	0.11	0.51	<0.01	0.29
OM	72.1 ^{abc}	74.1 ^{ab}	69.8 ^{bc}	78.4 ^a	69.3 ^{bc}	78.4 ^a	66.3 ^c	2.9	0.04	0.80	<0.01	0.33
EE	85.8 ^{bc}	88.5 ^{ab}	88.7 ^{ab}	90.2 ^a	84.7 ^{bc}	89.0 ^{ab}	82.2 ^c	1.8	0.06	0.34	0.02	0.21
NDF	43.9 ^d	63.7 ^{ab}	55.3 ^{bc}	68.7 ^a	54.5 ^{bcd}	68.1 ^a	44.8 ^d	4.6	<0.01	0.61	<0.01	0.14

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

²Highest reported standard error of mean from F-test, model considered all diets.

³Main effect of forage fraction.

⁴Main effect of chemical treatment.

⁵Forage fraction x chemical treatment interaction.

^{abcd}From the F-test, within a row, values lacking common superscripts, differ ($P < 0.05$).

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Table 7. Effect of feeding treated or untreated crop residues as partial grain replacements on ruminal pH and VFA (Exp. 2).

Item	Control	Corn Cobs		Wheat Straw		Corn Stover		SEM ²	F-test	F ³	T ⁴	FxT ⁵
		AT ¹	NT ¹	AT ¹	NT ¹	AT ¹	NT ¹					
Average pH	5.99 ^{ab}	5.98 ^b	5.84 ^b	5.81 ^b	6.05 ^{ab}	6.23 ^a	5.95 ^b	0.11	0.11	0.98	0.43	0.08
Minimum pH	5.44	5.49	5.42	5.30	5.57	5.52	5.28	0.12	0.47	0.88	0.97	0.03
Maximum pH	6.49 ^{bc}	6.52 ^b	6.38 ^c	6.56 ^b	6.60 ^b	6.85 ^a	6.76 ^a	0.07	<0.01	0.94	<0.01	0.24
pH variance	0.051 ^b	0.065 ^b	0.054 ^b	0.059 ^b	0.050 ^b	0.067 ^b	0.100 ^a	0.012	0.02	0.23	0.02	0.04
pH change	1.09 ^c	1.11 ^{bc}	1.09 ^c	1.10 ^{bc}	1.06 ^c	1.26 ^b	1.43 ^a	0.08	0.02	0.66	0.01	0.17
Time <5.6	266 ^b	213 ^b	480 ^a	284 ^b	285 ^b	182 ^b	211 ^b	99	0.10	0.66	0.09	0.10
Area <5.6	68.1 ^{ab}	21.9 ^c	105.2 ^a	51.5 ^{bc}	48.5 ^{bc}	23.8 ^{bc}	34.1 ^{bc}	22.6	0.06	0.49	0.06	0.24
Total, mM	109.1 ^{ab}	109.6 ^a	92.3 ^{bcd}	102.3 ^{abc}	92.8 ^{abcd}	82.6 ^d	89.6 ^{cd}	6.74	0.03	0.15	0.05	0.15
Acetate ⁶	57.7	61.7	61.5	56.6	59.7	60.3	60.4	1.8	0.12	0.48	0.08	0.38
Propionate ⁶	23.1 ^{abc}	20.6 ^c	23.8 ^{ab}	24.5 ^a	24.2 ^{ab}	21.0 ^{bc}	24.3 ^a	1.7	0.05	0.03	0.15	0.15
Butyrate ⁶	12.5	11.1	10.7	12.4	10.0	12.5	9.74	1.11	0.15	0.03	0.85	0.44
C2:C3 ⁷	2.61 ^{bc}	3.07 ^a	2.57 ^{bc}	2.40 ^c	2.57 ^{bc}	2.85 ^{ab}	2.63 ^{bc}	0.25	0.06	0.12	0.07	0.06

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

²Highest reported standard error of mean from F-test, model considered all diets.

³Main effect of forage fraction.

⁴Main effect of chemical treatment.

⁵Forage fraction x chemical treatment interaction.

⁶Presented as a molar proportion of total VFA

⁷C2:C3: Acetate to propionate ratio

^{abcd}From the F-test, within a row, values lacking common superscripts, differ ($P < 0.05$).

Running Head: Grain Replacement with distillers and treated stover

CHAPTER IV. Effects of grind size when alkaline treating corn residue and ratio of alkaline treated residue and distillers grains to corn¹

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ABSTRACT

Two studies were conducted to optimize use of alkaline-treated forage and distillers grains as partial corn replacements. In Exp. 1, a finishing experiment utilized 30 pens (12 steers/pen) of calf-fed steers (initial BW = 374 ± 23.9 kg) with a $2 \times 2 + 1$ factorial arrangement of treatments. Factors were grind size, where corn stover was processed through a 2.54 or 7.62 cm screen, and chemical treatment [corn stover either fed in native form (NT; 93.4% DM) or alkaline-treated (AT; 5% CaO hydrated to 50% DM)]. No interactions ($P \geq 0.38$) were noted between grind size and chemical treatment. Feeding AT compared to NT improved ($P \leq 0.02$) final BW, ADG, and G:F. Reducing grind size improved ($P \leq 0.01$) ADG and G:F, and no interaction with chemical treatment was observed. Steers fed AT had similar DMI, ADG, G:F, and carcass characteristics as CON. In Exp. 2, 60 individually fed steers (initial BW = 402 ± 61.4 kg) were assigned randomly to 10 diets. Steers were fed 10, 25, or 40% dry-rolled corn (DRC) which was replaced with varying ratios and proportions of MDGS and calcium oxide treated crop residues. Diets were 2 ratios of MDGS and corn stover (2:1 or 3:1, DM basis), 2 types of treated crop residue (corn stover or wheat straw), and 3 DRC concentrations. The MDGS:treated crop residues consisted of 3:1 ratios of MDGS and treated corn stover or treated wheat straw. As DRC increased G:F ($P = 0.06$) quadratically increased for 3:1 stover diets. Increasing DRC increased ($P = 0.07$) G:F in treated stover diets, regardless of ratio. Increasing DRC increased ($P = 0.10$) ADG for 3:1 ratios. Reducing grind size, feeding a maximum of 20% treated crop residue, and maintaining at least 25% corn in the diet are strategies for optimizing cattle performance when replacing corn with treated crop residues and distillers grains.

Key Words: Alkaline treatment, beef cattle, crop residue, distillers grains, feedlot,

INTRODUCTION

High priced corn has prompted research for the consideration of other ingredients as corn replacements to reduce diet cost. In much of the Corn Belt, supplies of wet or modified distillers grains and crop residues are abundant. These ingredients have been investigated as corn replacements. Shreck et al. (2012) reported similar ADG and G:F when replacing up to 10 percentage units of corn with inclusion (DM basis) of 20% (CaO added at 5%, DM basis) treated corn stover or wheat straw in diets containing 40% wet distillers grains. In that study, corn stover was ground through a 7.62 cm screen prior to treatment. We hypothesized that reducing grind size, prior to treatment with calcium oxide, may provide greater surface area to increase the utility of treatment. This could lead to either improved performance over stover initially processed with larger grind size or may allow for an increased amount of corn that could be replaced (15% vs 10%). A second study was conducted to test maximal corn replacement with distillers grains or treated crop residues. The objectives of these trials were to identify corn replacement strategies with distillers grains and treated crop residues and factors which affect their use.

MATERIALS AND METHODS

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

Exp 1.

Steers used in this experiment were received as calves in October 2010 and initial processing included: modified live virus vaccine for IBR, BVD Types I & II, PI3, and BRSV (Bovi-Shield Gold 5, Pfizer Animal Health, New York, NY), *Histophilus somnus* bacterin (Somubac, Pfizer Animal Health), injectable anthelmintic (Dectomax, Pfizer Animal Health), and metaphylactic antibiotic (Micotil, Elanco Animal Health, Greenfield, IN). Approximately 14 d later, cattle were vaccinated for prevention of pinkeye (Piliguard Pinkeye + 7, Merck Animal Health, Desoto, KS) and given a booster against clostridial infections (Ultrabac-7 Somubac; Pfizer Animal Health). Until trial initiation, steers were limit fed a diet . Steers were limit fed a diet containing 47.5% Sweet Bran (Cargill corn milling, Blair, NE) 47.5% alfalfa hay and 5.0% supplement (DM basis), at 2.0% of BW for 5 d, prior to weighing on d 0 and d 1 for initial BW determination (Stock et al., 1983).

Treatment structure was a $2 \times 2 + 1$ factorial. Factors included initial processing (corn stover was ground through a 2.54 cm or 7.62 cm screen) and chemical treatment [5% calcium oxide + 50% water (**AT**) vs none (**NT**)]. Corn stover replaced two ingredients, one ingredient replaced was a 50:50 blend (DM basis) of high moisture corn (HMC) and dry rolled corn (DRC) and the other ingredient replaced was roughage. Corn stover was fed at 20% of diet DM (Table 1.). The control (CON; plus one) diet contained a greater amount of DRC (51.0 vs. 36.0%; DM basis) and less roughage (5% NT corn stover ground through a 7.62 cm i.d. screen, DM basis) than the other 4 diets. Corn stover was from a single source and brought to the feedlot as round bales. Corn stover was initially processed through a tub grinder (Mighty Giant, Jones Manufacturing, Beemer, NE) equipped with either a 2.54 or a 7.62 cm i.d. screen and stored under roof in

a commodity bay. Chemical treatment consisted of water, CaO (0 to 0.098 cm granular standard quicklime, Mississippi Lime Co., Kansas City, MO), and ground residue weighed and mixed into feed trucks (Roto-Mix, Dodge City, KS). The mixture was calculated to be 50% DM with calcium oxide added at 5.0% of the total DM (treated stover from 2.54 and 7.62 cm grind sizes averaged, 48.1 and 44.8% DM, respectively). Feed trucks dispensed treated residue into a silage bagger (Model 2W08; Kelly-Ryan, Blair, NE) operating at approximately 1379 kPa for anaerobic storage over the duration of the trial. Treatment of corn stover was performed 1 mo prior to trial initiation. Untreated residues were ground as needed and stored under roof in commodity bays throughout the trial. All diets contained 40% (DM basis) modified distillers grains plus solubles (MDGS; 59.3% DM). All finishing diets contained 4.0% dry supplement, which was formulated to provide 33 mg/kg and 90 mg/steer daily monensin and tylosin (Elanco Animal Health, Greenfield, IN), respectively. Feedbunks were assessed at approximately 0630 h and managed so that only traces of feed were left in the bunk each morning at feeding time. Accumulated feed refusals were removed from feed bunks and were dried for 48 h at 60°C in a forced-air oven to determine DM. Orts were assessed weekly and refusals comprised 0.8% of total DM offered. Ingredients were sampled weekly and analyzed for DM content.

Ingredient CP (method 990.06, AOAC 1996) and sulfur were analyzed using a combustion type N and S analyzer (TrueSpec N Determinator and TruSpec Sulfur Add-On Module, Leco Corporation, St. Joseph, MI). Lipid was determined using a biphasic lipid extraction as outlined by Bremer et al. (2010). For MDGS, lipid was first removed and subsequent residue was analyzed for NDF. Monthly composite samples of treated

and untreated crop residues were analyzed for Ca (Servi-Tech Labs, Inc. Hastings, NE), NDF (Van Soest et al., 1991), and pH. For NDF, 0.5 g of sodium sulfite and 0.5 ml of alpha amylase were included during reflux. Briefly, pH was determined by taking 5.0 g (as-is, sample previous dried and ground through 1 mm) of sample and adding 100 ml of distilled water, which was then refrigerated for 12 hr, and pH was measured (Model EN20, Mettler-Toledo, Columbus, OH) after sample was given 20 min to equilibrate to room temperature.

Calcium oxide (formulated to contain 68% Ca based on molecular ratio) replaced limestone in treated diets. Grain adaptation consisted of a series of 4 diets containing 30, 22.5, 15, and 7.5% alfalfa hay (DM basis) which were fed for 6 d per step, with corn replacing alfalfa hay in each diet. Inclusion level of corn stover was the same in the adaptation diets as in the final experimental diets for each treatment. This experiment used 360 calf-fed steers (30 pens, 12 steers/pen) (initial BW: 374 ± 9.9 kg), had three initial weight blocks, five diets with 6 replications per treatment, and was designed as a randomized block design. Steers were assigned randomly within block to pens and pen was assigned randomly to treatment. Steers were fed from January 8th to June 6th, 2011 and fed in soil surfaced pens. On d 28, steers were implanted with Revalor-S (120 trenbolone acetate, 40 mg estradiol; Merck Animal Health) and poured with 15 ml of Saber (1.0% Lambdacyhaltrin, Merck Animal Health). During the course of the study, 4 steers were treated for footrot, 4 steers were treated for pinkeye, one steer was removed for lameness, and two steers died while on study. On d 151, steers were offered 50% of previous day's feed call and were weighed 6 hr post feeding on a pen scale (Norac M2000, Norac Inc. Bloomington, MN) and shipped for slaughter approximately 3 hr

later. Live BW was shrunk 4% to calculate dressing percentage (HCW/shrunk Live BW). On d 151, one pen from the CON treatment had a live BW that was not recorded. Therefore, there were 5 observations for live BW and dressing percent for the CON treatment. Steer ID and HCW were recorded on the day of slaughter (Greater Omaha Packing, Omaha, NE). After a 48 h chill, marbling score, 12th-rib fat thickness, and LM area were recorded from camera measurements. Final BW, ADG, and G:F were calculated based on HCW adjusted to a common dressed yield of 63%. Yield grade was calculated according to Boggs and Merkel (1993) using the carcass measurements (assuming a common 2.5% KPH) and the following formula: $(YG = (2.50 + (0.0017 \times \text{HCW, kg}) + (0.2 \times \text{KPH, \%}) + (6.35 \times 12^{\text{th}} \text{ rib fat, cm}) - (2.06 \times \text{LM area, cm}^2))$.

The energy content of corn stover was estimated using the NRC (1996) model. The NE_g of AT and NT stover was estimated (per pen) relative to CON (treatment average of) by using actual observed DMI and BW inputs as well as manipulating net energy adjusters to match observed ADG for steers consuming CON. Using observed DMI, TDN value of corn stover was increased until the predicted ADG equaled the observed ADG of steers consuming the treated diets. For each pen, actual average BW over the feeding period $[(\text{carcass adjusted final BW} + \text{initial BW})/2]$ and carcass adjusted final BW (for mature size at 27% body fat) were inputted prior to TDN adjustment. Other model inputs included use of implant, ionophore, and assumption of thermoneutral conditions. The NE adjusters required to achieve observed ADG were 0.75 for CON. Block et al. (2006) reported 0.82 NE adjustment for cattle fed under similar conditions. Modified distillers grains plus solubles were assumed to have 2.07 NE_g (112.5 TDN, 125% the value of DRC) based on 40% inclusion level (Klopfenstein et al., 2008;

Nuttelman et al., 2012). Corn stover was assumed to have 0.11 NE_g Mcal/kg (41 TDN; Burken et al., 2013). Briefly, in that study, TDN was determined on corn plants (collected at grain harvest) with grain removed, using in situ NDF disappearance (28 h incubation period) along with total cell soluble concentration and assuming a 12% metabolic fecal loss. The NRC (1996) model equations converted TDN to NE_g. While it was assumed the basal ingredients' energy value (corn and MDGS) were unchanged under this evaluation, we recognize that biologically, stover inclusion could affect utilization of other ingredients. This in turn, however, could provide greater understanding of the mechanism behind observed performance and aid in explaining treatment differences (Vasconcelos and Galyean, 2008).

Data were analyzed using the MIXED procedure of SAS (Version 9.2, SAS Inst. Inc. Cary, NC). The experiment had two weight blocks (3 replications per block), 5 diets (6 replications per treatment) and was designed as a randomized block design. In all analyses, initial BW block was included as a random effect. Two models were constructed to analyze data. To compare AT and NT diets to the control, pair-wise comparisons for treatments were determined by Fisher's LSD method when the F-test statistic was significant at an alpha level of $P = 0.05$. All diets were coded such that the model statement contained the effects of each treatment combination and the control. To evaluate the main effects of grind size and chemical treatment, a second model was constructed. Data were analyzed as a 2 x 2 factorial treatment arrangement. This model contained main effects of chemical treatment (NT vs. AT) and grind size (2.54 or 7.62 cm screen) as well as chemical treatment x grind size interaction. A $P \leq 0.05$ was considered significant and $P \leq 0.10$ were considered statistical trends.

Exp 2.

As replacement of 10 and 15% units of corn with treated stover appeared successful, based on the results of Shreck et al. (2012) and Exp. 1, a subsequent study was conducted to test greater levels of corn replacement by treated crop residues or distillers grains. Sixty yearling steers were individually fed using Calan gates (American Calan, Northwood, NH) for 124 d. Steers were blocked (n = 2) by initial BW and assigned randomly to treatments. Ten dietary treatments (Table 2) were offered. These diets were arranged such that two factorials could be analyzed. In the first factorial, factors were ratio of distillers grain and corn stover (2:1 or 3:1; DG:Stover) with DRC levels (10%, 25%, 40%; DM basis). In the second factorial, factors were 2 types of treated crop residue (corn stover or wheat straw at 3:1 DGCR), with three DRC levels (10%, 25%, 40%; DM basis). Ratios of DGCR replaced DRC and consisted of MDGS and treated corn stover at 3:1 and treated wheat straw at 3:1. A control diet was offered and contained (DM basis) 35% MDGS, 56% DRC, and 5% untreated corn stover. Steers were limit fed (Watson et al., 2012) a diet containing 45.0% Sweet bran (Cargill corn milling), 45.0% alfalfa hay, and 5% supplement (DM basis), at 2% of BW for 5 d, and weighed on three consecutive days for initial BW determination (Stock et al., 1983). Steers were implanted with Revalor-S (120 mg trenbolone acetate, 40 mg estradiol; Merck Animal Health) on d 1. Wheat straw and corn stover were initially ground through a 7.62 cm screen and treated with calcium oxide similar to as described in Exp 1. The mixture was calculated to be 50% DM (treated wheat straw and corn stover used during experiment were: 52.7 and 54.7% DM, respectively) with calcium oxide added at 5% of the forage DM. The pH of treated wheat straw and corn stover averaged 8.16 and 7.29,

respectively, throughout the feeding period. For grain adaptation, steers were offered treatment diets initially at 1.5% of BW and had limited increases in feed offered at 0.23 kg/d (DM basis). No intake restriction for clean bunks was imposed after d 28. Orts were weighed weekly and the amount of DM refused was subtracted from the DM offered to calculate DMI. Steers were weighed individually on d 124 and live BW was shrunk 4% to calculate dressing percent (HCW/shrunk live BW). Feed offered, weighing and shipment time was similar to Exp. 1. Carcass adjusted final BW was calculated from HCW and a 62% dressed yield was assumed. Carcass adjusted final BW was used to calculate ADG and G:F.

Data were analyzed using the MIXED procedure. Initial BW block was considered as a fixed effect. Two models were constructed to analyze data. To compare the 9 diets with varying levels of DRC and proportions of MDGS to the control, pair-wise comparisons for treatments were determined by Fisher's LSD method when the F-test statistic was significant at an alpha level of $P = 0.05$. All diets were coded such that the model statement contained the effects of each treatment combination and the control. To evaluate the main effects of crop residue type and chemical treatment, a separate statistical analysis was completed using the MIXED procedure. For each factorial, main effects and the interaction term were analyzed, An alpha of $P < 0.10$ was considered significant. Initially, no significant interaction terms between MDGS:stover or DGCR were noted ($P > 0.15$). Therefore, data were pooled within factorial and linear and quadratic contrasts were tested across DRC level.

RESULTS

Exp 1.

There were no grind size \times chemical treatment interactions ($P \geq 0.36$) observed (Table 5). Steers fed AT had a 12.5% increase ($P < 0.01$) in ADG compared to NT. Reducing grind size slightly improved ($P = 0.02$) ADG by 3.2%. Expectedly, DMI was lower (10.2 vs. 11.3 kg/d; $P < 0.01$) for AT compared to NT. Intakes were also lower ($P < 0.01$) for AT compared to NT when expressed as a percentage of BW. However, reducing grind size did not affect DMI ($P = 0.87$) or DMI as a % of BW ($P = 0.32$). Gain efficiency was 17.4% greater ($P < 0.01$) for AT compared to NT. Reducing grind size increased G:F ($P < 0.01$) to a smaller degree (3.5% increase for 2.54 cm compared to 7.62 cm grindsize). Greater carcass adjusted final and live BW ($P < 0.01$) was observed for AT compared to NT as well.

Steers fed AT had greater ($P < 0.01$) dressing percent compared to NT. Smaller grind size tended ($P = 0.08$) to increase dressing percent. Steers fed AT had greater ($P < 0.01$) HCW compared to NT; however smaller grind size had no effect ($P = 0.26$). Larger grind size tended to increase marbling score ($P = 0.07$). It is unclear why this occurred. Alkaline treatment tended ($P = 0.07$) to increase 12th rib fat compared to NT. It appears that the decreases in dressing percent by NT and larger grind sizes are mostly attributed to greater ruminal fill but also to decreased 12th rib fat thickness.

Compared to CON, AT was not different ($P \geq 0.05$) for ADG, G:F, adjusted final BW or final BW measured before slaughter, dressed yield, marbling score, 12th rib fat, or calculated YG. Numerically, 2.54 cm AT had greater G:F, ADG, and HCW than CON. Steers fed NT compared to CON had a 13.6% reduction in ADG and 16.9% poorer G:F ($P < 0.05$). Compared to CON, NT had lower final BW, dressing percent, and HCW ($P <$

0.01). However, similar ($P > 0.05$) 12th rib fat, marbling score, and calculated YG were observed between NT and CON.

For calculated NE_g of stover compared to CON, no interaction was observed between grind size and chemical treatment ($P = 0.96$). Smaller grind size increased ($P = 0.02$) NE_g by 29.2%, regardless of whether treated or not. A 3.7 fold increase in NE_g was noted due to chemical treatment ($P < 0.01$). Chemical treatment was effective in solubilizing 30% of the corn stover NDF and also numerically increased pH (Table 1.) For NDF, this is a similar, but slightly larger, increase compared to a previous trial (Shreck et al., 2012). In addition to NDF, feedstuff pH, Ca, and DM could all be used as quality control measures for alkaline treated feedstuffs. No difference in NDF recovered or solubilized by AT was noted between 2.54 and 7.62 ground stover (Table 2). This finding suggests that grinding to a smaller size is additive with chemical treatment. Furthermore, lack of interaction between grind size and chemical treatment on performance suggests that grind size did not enhance chemical treatment success by creating greater surface area for CaO. However, performance was improved for smaller grind size and this could create incentive to grind stover smaller before processing.

Experiment 2- Corn inclusion and ratio of treated residue to distillers grain.

Within each factorial, few significant interactions were observed. Therefore, to increase ability to detect differences due to DRC level, data were pooled across DRC, to test linear and quadratic contrasts of DRC within DG:stover (factorial 1; Table 6.) and DG:CR (factorial 2; Table 7.). For factorial one, significant interactions were noted for 12th rib fat ($P = 0.10$) and LM area ($P = 0.10$). For factorial two, a tendency for a significant interaction was observed for DMI ($P = 0.11$).

For factorial 1, increasing DRC improved ($P = 0.04$) G:F and increased ADG ($P = 0.07$) linearly in treated stover diets (Table 6.). Increasing DRC linearly increased ($P = 0.08$) live BW and tended ($P = 0.12$) to linearly increase carcass adjusted final BW. Increasing DRC quadratically increased ($P = 0.02$) ADG and HCW ($P = 0.05$), but had no effect on G:F ($P \geq 0.15$) with 3:1 ratios. No differences (F-test, $P > 0.23$) for final BW, G:F, ADG, DMI, or HCW were detected compared to the control.

In factorial two, final BW was increased quadratically ($P = 0.05$) by increasing DRC level (Table 7.). A linear ($P = 0.02$) and quadratic ($P = 0.04$) response was observed on ADG as DRC increased. A tendency ($P = 0.15$) for a quadratic response to DRC level was observed for DMI and G:F ($P = 0.13$). Numerically however, as DRC increased, DMI appeared to remain constant in treated stover diets but increase in wheat straw diets. Also, G:F appeared to respond greater to the addition of DRC in stover diets compared to treated wheat straw diets. Although not significant (main effect of crop residue; $P = 0.27$), feeding treated wheat straw increased G:F by 8.7% compared to treated corn stover. Calcium oxide treatment solubilized (relative to untreated) 13.6 and 13.7% of the NDF for treated wheat straw and corn stover, respectively (Table 4). This is slightly lower than what was reported in Exp. 1.

DISCUSSION

The differences in DMI observed in Exp. 1 between AT and NT follow typical relationships of roughage and DMI (Galyean and Defoor, 2003; Arlovich et al., 2008), with NT steers attempting to compensate by having greater DMI as energy density is decreased. It would be expected that DMI of the control would be lower compared to the other diets tested. Owens (2011) evaluated substitution of various roughages for steam

flaked grain and noted that for most roughages, DMI and ADG increased in a curvilinear fashion while expected G:F decreased quadratically. Presumably, energy consumption is limiting intake for control steers (Allen et al., 2009), however it is unknown if gut fill or energy is regulating intake in steers consuming treated and untreated diets. The control in this study supplied 4.1% NDF from roughage which is comparable to what is traditionally fed (Vasconcelos and Galvayan, 2007). Benton et al. (2007) fed 0, low (2.30 to 2.65%), or normal (4.60 to 5.83%) amounts of roughage supplied NDF from various sources (balanced to provide similar amounts of NDF) and found that the addition of roughage increased DMI and ADG but did not depress or improve G:F in diets containing 30% WDGS. They noted increased DMI, ADG, and final BW of steers fed normal amounts of roughage compared to low. The authors concluded addition of roughage in diets containing WDGS appears to have similar effects of roughage addition that are observed in grain based diets.

In the present study with different grind sizes, we estimated the energy value of AT and NT stover relative to the control. This initially required an assumed a NE_g content for the NT stover (5% diet DM) in control diet of 0.11 Mcal/kg (Burken et al., 2013). When compared to 7.62 cm NT stover diet, which had corn stover inclusion at 20% of diet DM, the calculated energy value was slightly higher (0.19 vs. 0.11 NE_g Mcal/kg) than estimated by Burken et al. (2013). It is unlikely that the stover energy content has increased and this increase in energy value could be explained by greater utilization of other ingredients, corn or MDGS. For 2.54 cm NT stover, reducing grind size increased NE_g , presumably due to increased surface area for microbial attachment and increased rate of digestion. In contrast, Shain et al. (1999) noted no difference on

finishing performance between steers fed equal NDF supplied from alfalfa or wheat straw which had been ground from various screen sizes (0.95, 7.6, or 12.7 cm i.d. screens). In that study, however, the diets fed likely posed more risk to sub-acute acidosis, had lower roughage levels, and did not have dietary inclusion of MDGS. Collectively, NDF digestibility may have been much poorer than in the current study, which could have masked differences due to grind size. Calculated NE_g of 2.54 cm AT stover was higher than 7.62 cm ground AT and had comparable energy (1.47 Mcal/kg) to corn grain (1.50 Mcal/kg; NRC, 1996) under this evaluation. This energy value is supported by similar DMI, G:F, and dressing percent, compared to CON. However, *in vitro* data (Shreck et al., 2011) would suggest that effect of chemical treatment alone may increase energy value (using OM disappearance) by 51.4% compared to untreated. Correspondingly, this explains some but not all of the energy value of treated stover.

Mechanisms behind similar performance of treated stovers compared to the CON, as well as the increase in calculated energy content of 7.62 cm NT stover compared to CON, are unclear but may be related to several factors. The inclusion level of corn stover in both AT and NT diets was much higher than commonly used for traditional roughage. Correspondingly, this could create a filter bed effect (Faichney, 1986), leading to greater ruminal retention time of distillers grain or corn (Welch, 1982). In comparison to roughages (Shain et al., 1999) and DRC (Scott et al., 2001), particle size of distillers grains is much smaller than most feedstuffs (Bhatti and Firkins, 1995). Greater stratification of rumen contents, due to inclusion of crop residues, could increase residence time of small particles such as WDGS thereby increasing ruminal digestibility (Welch, 1982). However, given the small difference in NE_g of 7.62 cm NT stover

compared to CON, rumen retention time of other ingredients may not be increased to a great extent.

Some have found decreased ruminal residence time for grain as roughage increased in the diet (Owens and Goetsch, 1986; Moore et al., 1990; Wylie et al., 1990) whereas others have noted no difference (Poore et al., 1990; Shain et al., 1999). Shifting site of digestion for starch toward the small intestine is generally viewed as counterproductive to efficient grain utilization as intestinal starch digestion is limited (Hunington, 1996), despite energy losses associated with fermentation. Owens et al. (1986) hypothesized that shifting site of digestion of starch would result in 42% greater energy capture compared to fermentation. Under the conditions of this study, grain inclusion is much lower for treated stover diets than typically observed for finishing cattle and intestinal starch digestion may not be overwhelmed.

To date, few studies have focused on corn replacement strategies similar to Exp. 2 as historically, corn was inexpensive and most economical source of energy (Corah, 2008). Still today, corn is the primary grain used in finishing diets (Vasconcelos and Galyean, 2007) typically comprising at least 50% of the diet (DM basis). Sewell et al. (2008) fed Holstein steers ($n = 32$) a diet which replaced all of the DRC with pellets that contained 25% (DM basis) DDGS and calcium oxide treated (5% DM basis) wheat straw or corn bran (in varying proportions) that comprised the majority of the pellet composition. In that study, no difference in ADG was observed but replacing all of DRC increased DMI, which lead to 11.9% (corn fiber: wheat chaff blend) and 25.8% (wheat straw) reductions in G:F compared to a control diet that contained 50% DRC, 25% DDGS, and 15% corn silage (DM basis). That study suggested that calcium oxide treated

crop residues fed in conjunction with a distillers grain-based diet may be a feeding strategy to reduce diet costs while maintaining acceptable performance. Rich et al. (2011) fed levels of WDGS in excess of 70% with and without DRC and varying roughage levels. From that study, it appeared that even small inclusions of DRC (17% and 9%, DM basis) improved ADG, G:F and reduced DOF dramatically.

Using distillers grains to replace corn can be an option. Optimal inclusion of wet or modified distillers grains is 30 to 40% of diet DM (Klopfenstein et al., 2008) but exceeding this level can reduce performance. Rich et al. (2011) noted large depressions in DMI, ADG, and HCW for steers fed (DM basis) 70% WDGS, 16.8% DRC and 8% wheat straw compared to steers consuming 40% WDGS, 50% DRC, and 5% corn stover. In that study, high dietary sulfur content (0.63% for 70% WDGS diet compared to 0.41% for 40% WDGS diet) likely contributed to the poorer performance of steers consuming high levels of WDGS. Excess sulfur (> 0.46% diet DM, Nichols et al., 2011) has been characterized as detrimental to both animal health (Gould, 1998) and performance (Sarturi et al., 2013). Dietary sulfur exceeded recommended levels (Vanness et al., 2009) for many of the treatments in Exp. 2 however; no steers had symptoms associated with polioencephalomalacia (PEM). The high fiber diets fed in Exp. 2 likely suppressed PEM from occurring (Vanness et al., 2009; Morine et al., 2012).

The results of these studies suggest that when feeding a diet consisting of 40% MDGS, up to 15% units of the dry rolled corn in the diet can be replaced by calcium oxide treated corn stover. Grinding corn stover smaller prior to treatment resulted in greater performance, but this effect was additive with chemical treatment by calcium oxide. To displace more than 15% units of corn from a finishing diet, using a higher

proportion (3:1 vs 2:1) of modified distillers grains relative treated stover or straw is possible. We conclude that a maximum of 20% treated residue (DM basis), and at least 25% DRC are needed to support feed efficiency similar to that of a 56% DRC, 5% roughage diet. Collectively, studies demonstrate corn replacement options which should reduce diet costs, maintain performance and ultimately increase profitability.

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Table 1. Composition of diets (% of diet DM) fed to finishing steers (Exp. 1).

Item	Screen size, cm				
	Control	2.54		7.62	
		AT ¹	NT ¹	AT ¹	NT ¹
MDGS ²	40.0	40.0	40.0	40.0	40.0
Dry-rolled corn	25.5	18.0	18.0	18.0	18.0
High-moisture corn	25.5	18.0	18.0	18.0	18.0
Stover-treated ³	–	20.0		20.0	20.0
Stover-not treated ⁴	5.00	–	20.0	–	20.0
Dry Supplement ⁵					
Fine ground corn	1.622	3.491	1.622	3.491	1.622
Limestone	1.868	–	1.868	–	1.868
Salt	0.300	0.300	0.300	0.300	0.300
Tallow	0.100	0.100	0.100	0.100	0.100
Trace mineral ⁶	0.050	0.050	0.050	0.050	0.050
Thiamine ⁷	0.017	0.017	0.017	0.017	0.017
Vitamin A-D-E premix ⁸	0.015	0.015	0.015	0.015	0.015
Rumensin-90 ⁹	0.017	0.017	0.017	0.017	0.017
Tylan-40 ¹⁰	0.011	0.011	0.011	0.011	0.011

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form.

²MDGS: Modified distillers grains plus solubles.

³Formulated to contain 3.15% Ca and supply 0.63% dietary Ca at 20% inclusion

⁴Control treatment contained untreated corn stover ground through a 7.62 cm screen

⁵Supplement formulated to be fed at 4% of diet DM.

⁶Premix contained 6% Zn, 5% Fe, 4% Mn, 2% Cu, 0.28% Mg, 0.2% I, and 0.05% Co.

⁷Premix contained 88 g of thiamine·kg⁻¹.

⁸Premix contained 30,000 IU of vitamin A, 6,000 IU of vitamin D, 7.5 IU of vitamin E/g.

⁹Premix contained 198 g/kg of monensin (Elanco Animal Health, Greenfield, IN).

¹⁰Premix contained 88 g/kg of tylosin (Elanco Animal Health).

Table 2. Nutrient composition of diets (% of DM) fed to finishing steers (Exp. 1).

Item	Screen size, cm				
	Control	2.54		7.62	
		AT ¹	NT ¹	AT ¹	NT ¹
Crop Residue					
NDF	81.1	65.5	77.9	66.1	81.1
Roughage supplied					
NDF	4.1	13.1	15.6	13.2	16.2
Dietary					
CP	15.8	15.3	15.0	15.2	15.0
NDF	20.3	31.8	34.1	31.9	34.7
Ether Extract	6.3	5.9	5.9	5.9	5.9
Ca	0.72	0.63	0.73	0.64	0.73
S	0.40	0.39	0.39	0.39	0.39

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

² Calculated as crop residue NDF * dietary DM inclusion.

Table 3. Composition of diets (% of diet DM) fed to finishing steers in Exp. 2.

Item	Control	2:1 Corn Stover ¹			3:1 Corn Stover ¹²			3:1 Wheat Straw ²		
		DRC level, %								
		10	25	40	10	25	40	10	25	40
MDGS ³	35.00	57.33	47.33	37.33	64.50	53.25	42.00	64.50	53.25	42.00
Dry-rolled corn	56.00	10.00	25.00	40.00	10.00	25.00	40.00	10.00	25.00	40.00
Stover-treated ⁴	–	28.66	23.66	18.66	21.50	17.75	14.00	–	–	–
Straw-treated ⁴	–	–	–	–	–	–	–	21.50	17.75	14.00
Stover-not treated	5.00									
Dry Supplement ⁵										
Fine ground corn	2.021	3.316	3.316	3.316	3.316	3.316	3.316	3.316	3.316	3.316
Limestone	1.446	0.201	0.201	0.201	0.201	0.201	0.201	0.300	0.300	0.300
Salt	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.201	0.201	0.201
Tallow	0.125	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
Trace mineral ⁶	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Thiamine ⁷	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Vitamin A-D-E ⁸	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-90 ⁹	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
Tylan-40 ¹⁰	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010

¹Set of diets included in factorial of ratio of MDGS and treated stover × DRC

²Set of diets included in factorial of crop residue × DRC

³Modified distillers grains plus solubles

⁴Treated with 5% (DM basis) calcium oxide at 50% DM

⁵Supplement formulated to be fed at 4% of diet DM.

⁶Premix contained 6% Zn, 5% Fe, 4% Mn, 2% Cu, 0.28% Mg, 0.2% I, and 0.05% Co.

⁷Premix contained 88 g of thiamine·kg⁻¹.

⁸Premix contained 30,00 IU of vitamin A, 6,000 IU of vitamin D, 7.5 IU of vitamin E/g.

⁹Premix contained 198 g/kg (Elanco Animal Health, Greenfield, IN).

¹⁰Premix contained 88 g/kg (Elanco Animal Health).

Table 4. Nutrient composition of diets (% of DM) fed to finishing steers in Exp. 2.

Item	Control	2:1 Corn Stover ¹			3:1 Corn Stover ¹²			3:1 Wheat Straw ²		
		DRC level, %								
		10	25	40	10	25	40	10	25	40
Dietary										
CP	15.0	18.6	16.8	15.0	20.4	18.3	16.2	20.6	18.5	16.3
NDF	18.5	38.4	33.6	30.4	37.2	32.9	28.6	37.4	33.1	28.7
Ether Extract	6.0	8.0	7.2	6.0	8.3	7.4	6.5	8.3	7.4	6.5
Ca	0.56	0.74	0.60	0.60	0.60	0.57	0.47	0.67	0.57	0.47
S	0.37	0.52	0.46	0.38	0.55	0.48	0.41	0.55	0.48	0.41

¹Set of diets included in factorial of ratio of MDGS and treated stover × DRC

²Set of diets included in factorial of crop residue × DRC

Table 5. Performance and carcass characteristics of steers fed treated or untreated crop residues ground through two screen sizes (Exp. 1).

Item	Screen size, cm					SEM ²	F-test	G ³	T ⁴	GxT ⁵
	Control	2.54		7.62						
		AT ¹	NT ¹	AT ¹	NT ¹					
Performance										
Initial BW, kg	374	374	374	373	375	4.5	0.99	0.94	0.80	0.88
Final BW, kg ⁶	626 ^a	630 ^a	600 ^{bc}	619 ^{ab}	595 ^c	6.7	0.05	0.52	0.03	0.83
Live BW, kg ⁷	629	624	609	618	606	6.9	0.09	0.24	<0.01	0.60
ADG, kg	1.67 ^a	1.70 ^a	1.49 ^b	1.63 ^a	1.46 ^b	0.022	<0.01	0.02	<0.01	0.40
DMI, kg/d	10.9 ^{abc}	10.7 ^{bc}	11.1 ^{ab}	10.7 ^c	11.3 ^a	0.15	0.04	0.87	<0.01	0.53
DMI, % BW	2.18 ^a	2.14 ^a	2.29 ^b	2.15 ^a	2.32 ^b	0.021	<0.01	0.32	<0.01	0.58
G:F	0.153 ^a	0.158 ^a	0.134 ^c	0.152 ^b	0.130 ^c	0.002	<0.01	<0.01	<0.01	0.78
Stover NE _g , Mcal/ kg	-	1.47	0.40	1.26	0.19	-	-	0.02	<0.01	0.96
Dressing, % ⁸	62.7 ^a	63.6 ^a	62.1 ^b	63.1 ^a	61.9 ^b	0.002	<0.01	0.08	<0.01	0.37
Carcass characteristics										
HCW, kg	395 ^a	397 ^a	378 ^b	390 ^a	375 ^b	4.3	<0.01	0.26	<0.01	0.63
12 th -rib fat, cm	1.45	1.40	1.30	1.42	1.32	0.06	0.24	0.51	0.07	0.96
LM area, cm ²	85.5	85.6	84.8	85.5	82.6	1.13	0.32	0.30	0.13	0.36
Marbling ⁹	595	568	546	590	579	13.4	0.11	0.07	0.27	0.69
Calc. YG ¹⁰	3.48	3.43	3.21	3.41	3.32	0.1	0.38	0.63	0.13	0.50

¹AT: alkaline treated crop residue with 5% CaO and water added to 50% DM, NT: not treated, fed in native form

²Highest reported standard error of mean from F-test, model considered all diets.

³Main effect of grind size.

⁴Main effect of chemical treatment.

⁵Grind size × chemical treatment interaction.

⁶Calculated as HCW/common dress (63%).

⁷Pen weight before slaughter, pencil shrunk 4%.

⁸Calculated as: HCW/ (Live BW*0.96).

⁹500 = Small⁰⁰, 600 = Modest⁰⁰.

¹⁰YG = [2.5 + (6.35*fat thickness, cm) + (0.2*2.5% KPH) + (0.0017*HCW, kg) – (2.06*LM area, cm²)]; (Boggs and Merkel, 1993).

^{abcd}From the F-test, within a row, values lacking common superscripts, differ ($P < 0.05$).

Table 6. Performance and carcass characteristics of steers fed varying ratios of MDGS and treated stover replaced by varying proportions of dry rolled corn (Exp. 2).

Item	Control	MDGS:Stover ¹						SEM ²	F-test	Lin ³	Quad ⁴
		2:1			3:1						
		10	25	40	10	25	40				
Performance											
Initial BW, kg	401	400	404	402	405	404	400	6	0.99	0.85	0.41
Final BW, kg ⁵	614	585	598	607	583	609	601	13	0.57	0.12	0.38
Live BW, kg ⁶	622	611	622	635	609	618	620	11	0.54	0.08	0.84
ADG, kg	1.71	1.50	1.56	1.65	1.44	1.66	1.62	0.10	0.45	0.07	0.46
DMI, kg/d	11.3	11.5	11.5	11.4	11.2	11.0	11.0	0.3	0.81	0.52	0.99
G:F	0.152	0.130	0.136	0.145	0.129	0.150	0.148	0.008	0.27	0.04	0.46
Dressed yield, % ⁷	61.9	59.6	59.6	59.3	59.5	61.3	60.2	0.01	0.36	0.77	0.20
Carcass characteristics											
HCW, kg	380	363	370	376	361	378	372	8	0.57	0.12	0.38
12 th -rib fat, cm	1.14	0.91	1.02	0.76	1.07	1.07	1.19	0.16	0.05	0.86	0.59
LM area, cm ²	85.5	90.1	95.8	95.2	99.2	92.0	87.0	4.4	0.22	0.34	0.73
Marbling score ⁸	500	468	452	452	487	503	472	30	0.63	0.56	0.73
Calculated YG ⁹	3.20	2.52	2.40	2.23	2.22	2.72	2.97	0.30	0.05	0.36	0.74

¹MDGS:Stover: 2:1 or 3:1 (DM basis) ratio of modified distillers grains plus solubles to treated corn stover replaced by 10, 25, or 40% DRC. Corn stover treated with 5% CaO and water added to 50% DM.

²Highest reported standard error of mean from F-test, model considered all diets listed.

³Linear contrast of pooled data across DRC inclusion level, interaction between MDGS:Stover was not significant ($P \geq 0.15$)

⁴Quadratic contrast of pooled data across DRC inclusion level, interaction between MDGS:Stover was not significant ($P \geq 0.15$)

⁵Calculated as HCW/common dress (63%).

⁶Pen weight before slaughter, pencil shrunk 4%.

⁷Calculated as: HCW/ (Live BW*0.96).

⁸500 = Small⁰⁰, 600 = Modest⁰⁰.

⁹YG = [2.5 + (6.35*fat thickness, cm) + (0.2*2.5% KPH) + (0.0017*HCW, kg) - (2.06*LM area, cm²)]; (Boggs and Merkel, 1993).

Table 7. Performance and carcass characteristics of steers fed a 3:1 ratio of MDGS and treated stover or wheat straw replaced by varying proportions of dry rolled corn (Exp. 2).

Item	MDGS:Crop Residue ¹							SEM ²	F-test	Lin ³	Quad ⁴
	Corn Stover			Wheat Straw							
	Control	DRC level, %			DRC level, %						
	10	25	40	10	25	40					
Performance											
Initial BW, kg	401	400	404	402	405	403	406	6	0.98	0.75	0.68
Final BW, kg ⁵	614	585	598	607	593	606	619	13	0.46	0.08	0.05
Live BW, kg ⁶	622	611	622	635	616	618	625	11	0.82	0.24	0.13
ADG, kg	1.71	1.50	1.56	1.65	1.52	1.64	1.72	0.10	0.41	0.04	0.02
DMI, kg/d	11.3	11.5	11.5	11.4	10.4	11.0	11.3	0.3	0.29	0.28	0.15
G:F	0.152	0.130	0.136	0.145	0.147	0.151	0.152	0.008	0.55	0.16	0.13
Dressed yield, % ⁷	61.9	59.6	59.6	59.3	59.8	60.8	61.1	0.01	0.57	0.15	0.18
Carcass characteristics											
HCW, kg	380	363	370	376	367	376	384	8	0.46	0.08	0.05
12 th -rib fat, cm	1.14	0.91	1.02	0.76	1.14	1.19	1.12	0.16	0.99	0.73	0.49
LM area, cm ²	85.5	90.1	95.8	95.2	86.9	89.8	89.8	4.4	0.29	0.21	0.51
Marbling score ⁸	500	468	452	452	518	482	470	30	0.91	0.25	0.23
Calculated YG ⁹	3.20	2.52	2.40	2.23	2.96	2.91	2.92	0.30	0.31	0.15	0.56

¹MDGS:Crop residue: 3:1 ratio (DM basis) of modified distillers grains plus solubles treated corn stover or wheat straw replaced by 10, 25, or 40% DRC. Crop residues treated with 5% CaO and water added to 50% DM.

²Highest reported standard error of mean from F-test, model considered all diets listed.

³Linear contrast of pooled data across DRC inclusion level, interaction between MDGS:Stover was not significant ($P \geq 0.15$)

⁴Quadratic contrast of pooled data across DRC inclusion level, interaction between MDGS:Stover was not significant ($P \geq 0.15$)

⁵Calculated as HCW/common dress (63%).

⁶Pen weight before slaughter, pencil shrunk 4%.

⁷Calculated as: HCW/ (Live BW*0.96).

⁸500 = Small⁰⁰, 600 = Modest⁰⁰.

⁹YG = [2.5 + (6.35*fat thickness, cm) + (0.2*2.5% KPH) + (0.0017*HCW, kg) – (2.06*LM area, cm²)]; (Boggs and Merkel, 1993).