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Evaluation of Corn Condensed Distillers Solubles in Beef Cattle Diets and Grazing Double-Cropped Forages Following Corn Harvest

by

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Corn condensed distillers solubles (CDS) is a protein and energy dense by-product from dry-milled production of ethanol. Recent oil extraction has posed modifications to the nutrient profile of CDS, suggesting that de-oiled CDS needs to be re-evaluated in beef cattle diets. Three experiments were conducted to evaluate the effects of CDS in high-concentrate diets, forage-based diets, as well as evaluate the effects of CDS on diet digestibility and rumen fermentation parameters in forage-based diets. Feeding CDS in high-concentrate diets up to 20% of the diet DM or in combination with wet distillers grains plus solubles (WDGS) improved performance and resulted in greater energy value compared to corn. Feeding values of 20% CDS or the combination of 16% CDS and 20% WDGS were 147 and 129% compared to corn, respectively. Feeding CDS in forage-based diets up to 40% of the diet DM diminished performance and resulted in a lesser energy value compared to corn. Linear decreases were observed in total tract digestibility of NDF and the acetate to propionate ratio in rumen fluid.

Double-cropped forages following corn harvest offer livestock producers an opportunity to extend their grazing season on high quality forage in the fall. Additionally, crop producers may benefit from the implementation of grazing animals due to added soil nutrients and removal of residue. Therefore, an experiment was conducted to evaluate the effects of double-cropped oats following corn silage (CS) or high-moisture corn (HMC) on calf gains, forage production, and subsequent cash crop yields. Oats seeded after CS produced more forage biomass than oats seeded after HMC. Both treatments produced high quality oats (22% CP, 39% NDF, and 24% ADF averaged across treatments). Calf gains were greater grazing oats following CS compared to HMC at 1.10 and 0.84 kg / d, respectively. Across 1-yr of data, subsequent cash crop yields were not different for HMC and soybeans with increased CS yields in both covered/grazed and non-covered/non-grazed treatments compared to the covered/non-grazed treatment.

Key words: beef cattle diets, corn condensed distillers solubles, double-cropped forages, energy value

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Dedication

"Commit your work to the Lord, and your plans will be established"

-Proverbs 16:3

"When you have eaten and are satisfied, praise the Lord your God for the good land he has given you."

-Deuteronomy 8:10

Table of Contents

CHAPTER I. Review of Literature

Ethanol Process

Condensed Distillers Solubles Production

Fuel ethanol production is comprised of both dry and wet milling of grains. The wet milling process is much more complex, due to kernel separation, than dry milling and produces a number of products. The primary goal of each is starch separation, although it is done very differently. The wet milling process separates the starch from the kernel, whereas dry milling production starts with grinding the grain to ferment the starch into alcohol. Stock et al. (2000) describes these processes in detail. Dry milling, which accounts for 90% of the ethanol production in the US (Liska et al. 2009), produces by-products that have been widely accepted as feedstuffs in feedlot diets. These feedstuffs are derived from the whole stillage and are separated into wet grains and thin stillage. Wet grains (30% DM) can be dried down to produce modified distillers grains (50% DM) or dried distillers grains (90% DM). Thin stillage goes through an evaporator to produce corn condensed distillers solubles (30% DM; CDS). The CDS are often then put back onto the grains to produce wet (WDGS), modified (MDGS), or dried distillers grains plus solubles (DDGS). Alternatively, CDS can be marketed separate from the grains and is often priced economically for feedlots. Management, storage, and availability of the feedstuff reduce the number of producers able to take advantage of its price.

Regional Interest

Nebraska produces 1.7 billion bushels of corn and 2.2 billion gallons of ethanol each year with 2.5 million head of cattle on feed continuously (USDA, 2016). These are all ranked in the top 3 states of the US, illustrating Nebraska’s opportunity to utilize by-products from the ethanol industry. According to a survey of 49 consulting feedlot nutritionists, representing 14,000,000 cattle annually, 97.1% indicated that grain by-products were a prevalent feed utilized in finishing diets (Samuelson et al., 2016). Nebraska's proximity to ethanol production and the vast use of by-products in finishing diets gives the Nebraska feedlot industry an economical advantage over states without these resources.

Oil Removal

Historically, the fat content of distillers grains plus solubles (DGS) was 10-13% (Buckner et al., 2011). In 2014, approximately 85% of ethanol plants had the capability to extract oil (RFA, 2015). Due to the value of corn oil for the biodiesel industry or feed market, many plants are removing oil via centrifugation of the thin stillage portion. Fat content of DGS now varies between 4-13% (Nelson, 2016). The fat content of CDS, which is made from thin stillage, has a much more dramatic decline. Previously CDS had 20% fat, whereas current CDS can be as low as 6% fat. Concurrently ethanol production has more than doubled in the last decade going from 5 billion gallons of ethanol produced in 2006 to 15 billion gallons produced in 2016 (EIA, 2017). This increase in ethanol production and therefore increase in supply of DGS has led to increased inclusions in feedlot diets. Many feedlots are now including DGS above 25% and utilizing the feedstuff as an energy source, instead of historic inclusions of 15% as a protein source. Klopfenstein et al. (2008) attribute the fat in DGS as part of the greater feeding value compared to corn. This logically led to the concern that if ethanol plants removed fat from DGS, the feeding value would decline.

Recent research on forage-based diets conducted by Jolly et al. (2013a) evaluated the effects of CDS with or without oil extraction. Both de-oiled (6.3% fat) and normal (20.1% fat) CDS were fed at either 20 or 40% inclusions. Calves had greater ending BW and ADG as CDS inclusions increased. Fat content of CDS only affected the 20% inclusion where calves fed normal CDS were 13.4% more efficient. When calves were fed 40% CDS there were no differences between the normal or de-oiled CDS. Likewise, Bremer et al. (2014) fed MDGS in a forage-based diet at 20 or 40% inclusion in both the de-oiled (7.2% fat) and normal (12.0% fat) form. Fat content did not affect ending BW or ADG with steers fed de-oiled MDGS having greater DMI. Preliminary data would conclude that oil removal from CDS only impacts G:F at lower inclusions, whereas oil removal from MDGS does not negatively impact performance in forage-based diets. This is likely due to a larger reduction in the fat content of CDS compared to MDGS.

Jolly et al. (2013b) conducted a study to evaluate the effects of oil removal from both MDGS and CDS in high concentrate diets. Diets displaced a dry rolled (DRC) and high-moisture corn (HMC) blend with either 40% MDGS, de-oiled (9.2% fat) and normal (11.8% fat), or 27% CDS, de-oiled (6.0% fat) and normal (21.1% fat). Final BW, ADG, HCW, and G:F were greater for cattle fed MDGS or CDS compared to the corn control. Fat content of MDGS and CDS did not affect performance or carcass characteristics. Jolly et al. (2014) also evaluated the effects of oil removal from WDGS in high concentrate diets. Diets displaced a corn blend with both de-oiled (7.9% fat) and normal (12.4% fat) WDGS at 35, 50, or 65% inclusions. Similarly to MDGS and CDS, fat content of WDGS did not affect performance or carcass characteristics. These data suggest that oil removal from distillers by-products does not affect their feeding value in high concentrate finishing diets.

Corn Condensed Distillers Solubles in Beef Cattle Diets

Finishing Diets

Feeding CDS in high concentrate diets has shown variable results. Sharp and Birkelo (1996) fed CDS up to 20% of the diet replacing a blend of DRC and HMC and reported an increase in ADG with 10 and 20% CDS inclusions having the highest gains. Due to numerical increases in DMI, G:F was not different among treatments. Dressing percent and HCW also increased with increasing inclusions of CDS. Trenkle (2002) fed CDS up to 8% of the diet DM replacing cracked corn and reported a decrease in DMI with increasing CDS, while ADG was maximized at 4% inclusion. Furthermore, Trenkle and Pingel (2004) fed CDS up to 12% of the diet DM replacing dry-rolled corn, in an attempt to narrow in on the optimal inclusion of CDS in finishing diets. No differences in DMI, ADG, or G:F were reported. However, cost of gains were found to be much more favorable for the steers fed 12% CDS with the concurrent feed prices. More recently, Pesta et al. (2015) replaced a DRC:HMC blend with CDS at 0, 9, 18, 27, and 36% of the diet and reported a quadratic increase for both ADG and G:F. Similar to previous research a linear decrease in DMI was reported as CDS inclusion increased. Using the first derivative of the quadratic response, maximum ADG was calculated when CDS were fed at 20.8% of the diet, while G:F was maximized when CDS were fed at 32.5% of the diet. Relative feeding values compared to corn were also calculated using the percentage change in G:F divided by the percentage change in CDS inclusion. Feeding values were 210, 166, 142, and 139% for the 9, 18, 27, and 36% inclusions, respectively.

Furthermore, Titlow et al. (2013) fed CDS at either 0, 15, or 30% inclusions with either steam-flaked corn (SFC) or DRC. When CDS were fed with DRC a quadratic decline was reported for DMI, while ADG, G:F, and HCW quadratically increased. Maximum performance was reported when CDS was fed at 30% of the diet DM although the percentage improvement was much greater going from 0 to 15% CDS inclusion than it was from 15 to 30% inclusion. Dissimilarly, when CDS were fed with SFC, ADG and HCW linearly increased as G:F increased quadratically with increasing inclusions of CDS. Authors concluded that the optimal inclusion of CDS was different depending on the type of corn processing and that optimal inclusions of CDS with DRC were between 15 and 30%, while inclusions of CDS with SFC may be greater than 30% of the diet. Therefore, Harris et al. (2014) fed CDS at 0, 9, 18, 27, and 36% of diet replacing SFC. As CDS increased, DMI quadratically decreased whereas both ADG and G:F quadratically increased. Both ADG and G:F were maximized when CDS was fed at 27% of the diet.

Previous research has also evaluated the effects of CDS fed in combination with other by-products in finishing diets. Bremer et al. (2009) looked at differing inclusions of CDS (0, 6.7, 13.3, and 20%) fed in combination with 35% wet corn gluten feed (WCGF). No differences were reported for DMI, ADG, or G:F with similar performance to diets including combinations of WDGS and WCGF at similar inclusions. Pesta et al. (2015) fed 0, 7, 14, or 21% CDS in combination with either MDGS or Synergy (an ADM product consisting of a blend of MDGS and WCGF) and reported that ADG was greatest at the 14% CDS inclusion when fed with MDGS and at the 21% inclusion when fed with Synergy. Dissimilarly, G:F was improved regardless of what CDS was fed in combination with up to the 21% CDS inclusion.

Forage-based Diets

As previously described, Jolly et al. (2013a) fed CDS at either 20 or 40% of the diet replacing two different forage sources and reported a linear increase in ending BW, DMI, and ADG with increasing inclusions of CDS. Other research evaluating CDS specifically in forage-based diets is limited. Corrigan et al. (2009a) evaluated the effects of level of CDS (0, 5.4, 14.5, 19.1, or 22.1% CDS in DDG) in DDGS being supplemented to growing steers. Authors reported linear improvements in ADG at the three lowest levels of CDS, whereas a quadratic response was observed for ADG at the 19.1 and 22.1% CDS treatments. As the proportion of CDS increased in DDGS, optimal supplementation, with regard to ADG, decreased. Authors attributed this interaction to the increase in fat content of DDGS, as the proportion of CDS increased, possibly compromising NDF digestibility. Wilken et al. (2009) ensiled CDS or WDGS with corn stalks in a 50:50 blend, fed at 15, 20, 25, or 30% of the diet with the remainder of the diet being grass hay, and reported that WDGS had greater ADG and G:F than CDS. Conroy et al. (2016) fed CDS at 15% of the diet replacing DRC in a forage-based diet and reported no difference in ending BW, DMI, or ADG. Authors calculated feeding values and estimated that CDS had a feeding value that was 93% of DRC in forage-based diets. Ulmer et al. (2016) fed differing combinations of CDS (18.75, 25, and 30% of the diet), corn stover, and high-protein DDG and compared them back to MDGS fed at 50% of the diet in forage-based diets and reported a decrease in ending BW and ADG for diet combinations including CDS. In summary, data regarding the effects of CDS in forage-based diets is not clear, but the fat content of the de-oiled CDS does not seem to influence performance.

Distillers Grains in Beef Cattle Diets

Finishing Diets

There has been an abundance of research focused on the interaction of DGS inclusion and type (WDGS, MDGS, or DDGS), corn processing (SFC, HMC, or DRC), diet type (forage or concentrate), and cattle type (yearling or calf-fed). Bremer et al. (2011) evaluated the effects of drying DGS fed at 0, 10, 20, 30, or 40% of the diet in finishing diets. Across all DGS types (WDGS, MDGS, and DDGS), DMI declined quadratically. Quadratic increases were reported for both ADG and G:F when either WDGS or MDGS were fed with the greatest gains being achieved at 30% inclusion, while G:F was greatest for 40% inclusion. Linear improvements were reported for ADG and G:F when DDGS were fed. Feeding values were calculated and averaged 140, 122, and 112% compared to corn for the WDGS, MDGS, and DDGS, respectively. Similarly, Vander Pol et al. (2006a) evaluated the effects of WDGS inclusion (0, 10, 20, 30, 40, 50% of the diet) on finishing steer performance. Quadratic responses were reported for ADG and G:F with feeding values averaging 144% the value of corn. Additionally, Larson et al. (1993) reported a feeding value of 135% the value of corn for WDGS fed at 40% of the diet.

In the interest of evaluating the effects of corn processing in diets containing WDGS, Vander Pol et al. (2006b) fed 30% WDGS across six different methods of corn processing. Processing methods included fine ground corn, SFC, HMC, DRC:HMC (50:50), DRC, and whole corn. Intakes were greatest for cattle fed whole corn or DRC, while gains were greatest for cattle fed DRC, HMC, or DRC:HMC. Cattle converted the best when fed HMC or DRC, although numerically HMC was slightly better than the

DRC due to lower intakes. Authors concluded that WDGS performs the best when corn is processed as either HMC or DRC and does not perform as well with SFC or fine ground corn. Corrigan et al. (2009b) found similar results with cattle fed WDGS in combination with either HMC or DRC performing better than cattle fed WDGS in combination with SFC. Authors reported that there was no difference in G:F for cattle fed WDGS up to 40% of the diet DM in combination with SFC, whereas linear increases were observed for G:F with cattle fed WDGS up to 40% in combination with both DRC and HMC.

Benton et al. (2015) evaluated the response of roughage level and source in finishing diets containing 30% WDGS. Although the data illustrated that WDGS did not control acidosis through its contribution to dietary NDF, WDGS did improve performance of the low quality roughage (cornstalks). This study concluded that cornstalks performed as well as alfalfa or corn silage as a roughage source when WDGS was included in the finishing diet. Therefore, distillers grains may be just as beneficial in forage-based diets utilizing lower quality sources of forage as in finishing diets. Distillers grains, as shown above, displaces corn, contributes more energy than corn, and offers the opportunity to utilize lower quality roughages in finishing diets.

Forage-based Diets

This leads to the question of DGS contribution in forage-based diets. A meta-analysis conducted by Griffin et al. (2012) utilizing 20 growing studies (13 pasture based studies and 7 confinement fed studies) evaluated DDGS supplementation on cattle performance. In a pasture setting, final BW and ADG increased linearly with increasing DDGS supplementation. When cattle were fed DDGS in confinement, final BW and ADG increased quadratically with increasing DDGS supplementation. Cattle also increased total intake with a quadratic effect near 2.0 kg / hd per day of supplemental DGS, while forage intake quadratically decreased. These data suggest that for every kilogram increase in DGS supplementation above 2.0 kg / hd there was a larger decrease in forage intake. Similarly, Bremer et al. (2014) observed an increase in final BW, ADG, and DMI when cattle were fed normal or de-oiled MDGS at either 20 or 40% of the diet, with performance not differing between normal or de-oiled MDGS. Additionally, Corrigan et al. (2007) supplemented steers DDGS at 0, 0.25, 0.5, 0.75, or 1.0% of BW and observed increased final BW and ADG, while DMI decreased with increasing DDGS supplementation. Furthermore, Ahern et al. (2016) evaluated the feeding value of distillers grains compared to corn in forage-based diets. Ahern et al. (2016) observed a 137 and 136% feeding value compared to corn for WDGS fed at 15 or 30% inclusions.

In the interest of evaluating DGS effects on fiber digestion, Loy et al. (2007) supplemented cannulated heifers either DRC or DDGS with ad-libitum grass hay (8.2% CP). Treatments included DRC or DDGS supplemented daily at 0.4% of BW or on alternate days at 0.8% of BW with an additional no supplement control. Heifers not supplemented had greater hay intake with lower total intakes. For heifers supplemented DRC or DDGS on alternate days, hay intake was lower on days supplement was fed. Additionally, heifers had a greater rate and extent of in-situ NDF disappearance on the control treatment compared to the supplement treatments. Rate of in-situ NDF disappearance was lower for heifers supplemented DRC compared to DDGS. Lastly, frequency of supplementation had no effect on rate or extent of in-situ NDF disappearance. Authors concluded that supplementation of DRC or DDGS displaced hay in forage-based diets with reductions in rate and extent of NDF disappearance.

Additionally, DDGS supplementation did not affect rate of NDF disappearance to the degree DRC supplementation did with supplementation of either DRC or DDGS on alternate days having no effect on NDF disappearance. Furthermore, Leupp et al. (2009) supplemented cannulated steers increasing levels of DDGS (0, 0.3, 0.6, 0.9, or 1.2% of BW) with ad-libitum bromegrass hay (10.6% CP) to determine the optimum level of DDGS supplementation. Hay OM intake linearly decreased, while total OM intake linearly increased with increased supplementation of DDGS. Additionally, duodenal flow of OM and CP, as well as total tract digestibility of OM and NDF linearly increased with increased supplementation of DDGS. In-situ rate of DM disappearance responded cubically for both hay and DDGS as supplementation increased with supplementation at 0.9% of BW having the greatest rate of disappearance. Authors concluded that supplementing DDGS up to 1.2% of BW increased nutrient supply with no adverse effects on forage digestion when fed with moderate-quality bromegrass hay.

Loy et al. (2008) supplemented heifers DRC, DDGS, or DRC plus corn gluten meal (DRC + CGM) with ad-libitum grass hay (8.7% CP) to determine the energy value of DDGS in forage-based diets. Additionally, supplements were fed daily or alternately (3 times per week) at 0.21% of BW (low) or 0.81% of BW (high). At low levels of supplementation, steers had greater ADG and G:F with DDGS compared to DRC or DRC + CGM. At high levels of supplementation, ADG and G:F were not different between DDGS and DRC + CGM supplementation, although both treatments were greater than steers supplemented DRC. Average daily gain and G:F were greater for the high compared to the low levels of supplementation with greater hay intake for steers on low levels of supplementation. Furthermore, daily supplementation resulted in greater ADG, hay intake, and total intake compared to alternate supplementation with no difference in G:F. Lastly, calculated TDN was greater for DDGS compared to DRC concluding that DDGS has a greater energy value than corn in forage-based diets. Similar to previously reported data (Loy et al. 2007), steers supplemented DRC likely had greater negative effects on fiber digestion compared to steers supplemented DDGS and CGM. At higher inclusions of DDGS and CGM, potentially enough starch was being displaced, from the DRC, to negate the associative effects of starch on fiber digestion.

Energy Calculation in Forage-Based Diets

Total digestible nutrient (TDN) values are commonly reported as a proxy for the energy value of a feed. As described by Peterson (2014), in order to determine the TDN value of a feed, performance measurements from a common diet containing feeds with known TDN values must be attained. Then, by displacing a component of the common diet with the feedstuff of interest and comparing subsequent performance measurements back to that of the common diet, a TDN value can be estimated utilizing the equations from the NRC (1996). The NRC (1996) equations are utilized to establish the common diets net energy (NE) for maintenance and gain. This is done by entering all feedstuffs known nutrient values and inclusions in the diet. Then NE adjusters are manipulated until the performance variables from the NRC match those observed from the common diet. Once performance variables match, the feedstuff of interest is entered in place of the feedstuff displaced in the common diet and the TDN value is manipulated until the performance variables from the NRC match those observed from the experimental diet. This is then the TDN value for the feedstuff of interest based off the NE equations from the model.

Metabolism of Condensed Distillers Solubles Nutrients

Research regarding the effects of CDS on metabolism of nutrients are relatively consistent. Ham et al. (1994) utilized cannulated steers to infuse 15% CDS into the rumen and observed a decrease in ruminal pH and acetate:propionate ratio, while total tract digestibility of OM increased compared to four other by-product and basal corn finishing diets. Gilbery et al. (2006) fed CDS in a forage-based diet at 0, 5, 10, or 15% as either a total mixed ration (TMR) or separate from the rest of the ration. When fed separately, there were no differences in ruminal, postruminal, or total tract digestibility as CDS level increased. When fed as a TMR, increasing inclusions of CDS linearly increased ruminal OM, NDF, and ADF digestibility. No differences were observed for postruminal or total tract digestibility of any nutrients. In another three-part study, Corrigan et al. (2009a) fed differing levels of CDS within DGS in forage-based diets. The first metabolism experiment fed either 0 or 22.1% CDS in DGS and found no differences in digestibility of any nutrients except ether extract, which increased with the DGS containing 22.1% CDS. The second experiment fed increasing levels of CDS (0, 5.4, 14.5, 19.1, and 22.1%) within DGS and observed a linear increase in ruminal DM digestibility. However, postruminal and total tract DM digestibility responded quadratically with the 14.5 and 19.1% levels having the greatest postruminal and 19.1 and 22.1% levels having the greatest total tract digestibility. These digestibilities matched well with the concurrent performance experiment, reported previously (Corrigan et al 2009a), which resulted in a quadratic response to ADG as the CDS level within DGS increased with optimal levels at 15%. The author attributed these responses to the increase in ether extract digestibility. These data would conclude that CDS fed in forage-based diets, as a TMR, increase propionate production and, although variable, increase ruminal nutrient digestibility with inclusions up to 15% of the diet. In finishing diets, Pesta et al. (2012) fed either CDS or WDGS solely or in combination and found no differences in nutrient digestibility, although steers fed CDS had lower average ruminal pH and acetate production compared to WDGS. Bremer et al. (2010) fed four separate fat sources (corn oil, tallow, CDS, and WDGS) formulated to provide 8.5% dietary fat. Steers fed CDS had the lowest average pH with increased DM digestibility. The steers fed CDS also increased fat and fatty acid digestibility compared to steers fed corn or corn oil; and increased NDF digestibility compared to steers fed corn oil or tallow. Authors noted that although CDS and corn oil contain similar fat, digestion of the fat is different. These data illustrating increased nutrient digestibility, fat utilization, and propionate production may explain the increased performance reported previously when cattle are fed CDS in finishing diets.

Effects of Fat on metabolism

In general, fat and its effects on metabolism in beef cattle have been well researched and documented. Early research conducted by Zinn (1989a) supplemented cattle either yellow grease or blended animal-vegetable fat (BVF) in a finishing diet at 4 or 8% with an additional 6% BVF treatment. Increased fat supplementation linearly decreased ruminal and total tract digestibility of OM and ADF, intestinal digestion of fat, and acetate production, with an increase in diet digestible energy and metabolizable energy. Plascencia et al. (2003) reported similar results with increasing yellow grease supplementation decreasing ruminal and total tract digestion of OM and NDF. When comparing fat source, cattle supplemented yellow grease had greater ruminal fiber digestion and propionate production compared to the BVF supplemented cattle. These same dietary treatments were then replicated in a performance trial (Zinn, 1989b) where increased fat supplementation linearly increased ADG, G:F, and net energy (NE) value of the diet. Researchers concluded that the improvement in performance was due to the increased energy metabolized by the animal from the fat, but the decreased fiber digestion caused by the fat proposed the hypothesis that fat supplemented at greater concentrations may negatively affect performance regardless of the increased energy intake. Therefore, Zinn et al. (1994) supplemented tallow at 0, 4, 8, and 12% of the diet to try and establish a fat threshold in finishing diets. Similarly, increased fat supplementation linearly decreased ruminal digestion of OM and ADF, total tract digestion of OM, and postruminal digestion of fat. Dissimilarly, performance did not follow suit and increased fat supplementation decreased ADG, G:F, and NE value of the diet, with a quadratic decrease in DMI at the 8 and 12% fat levels. Researchers concluded that for optimal performance fat supplementation in finishing diets should not exceed 1.6 g / kg BW. This calculates to be roughly 8% of the diet. Additionally, Hatch et al. (1972) found that fat supplementation above 6% in the diet had a large impact on DMI and ADG during the first 21 d of the feeding period. Depressed DMI was characterized as the most consistent effect of increased fat supplementation. Similar to Zinn et al. (1994), authors concluded that performance was hindered when fat supplementation exceeded 6% of diet and that any level of fat supplementation should be gradually added throughout the adaptation period to minimize the negative effects of fat supplementation on gain and intake.

The amount of energy metabolized, and therefore utilized from fat by ruminants is largely dependent on the intestinal digestion of the fat source. Amount of fat digested in the intestine is then dependent on the degree of ruminal biohydrogenation (Zinn et al. 2000). Zinn et al. (2000) determined this by supplementing cattle 2% yellow grease, 2% yellow grease and 4% Rumentek (low biohydrogenation), 4% yellow grease and 2% Rumentek (medium biohydrogenation), or 6% yellow grease (high biohydrogenation). Rumentek is a formaldehyde-protected fat that inhibits rumen biohydrogenation. Supplementation of fat at greater amounts decreased intestinal digestibility of 18:0, while increasing digestibility of 18:1, 18:2, and 18:3. Digestibility of each fatty acid profile, as well as total fatty acids were inversely related to biohydrogenation. Researchers calculated that every percent increase in the amount of 18:1 fat entering the small intestine led to a percent increase in 18:0 digestibility. Furthermore, as level of biohydrogenation increased, ruminal digestion of NDF quadratically decreased with the greatest ruminal NDF digestion observed in the low biohydrogenation treatment. They concluded that decreasing ruminal biohydrogenation increases postruminal digestion of fat and depresses the negative effects of supplemental fat on fiber digestion. More recently, Vander Pol et al. (2007) fed cattle WDGS, a composite of corn bran with corn gluten meal (COMP), COMP plus corn oil, and then the basal corn diet plus corn oil in an attempt to delineate if there is a difference in biohydrogenation of fat from WDGS compared to corn oil. Steers fed WDGS had increased propionate production, greater total tract digestion of fat, and a greater amount of unsaturated fatty acids in the duodenum. Researchers concluded that fat from WDGS does not go through the extent of biohydrogenation as fat from corn oil does and that the unsaturated fatty acids have a greater intestinal digestibility compared to saturated fatty acids.

Sulfur-Induced Polioencephalomalacia

Overview of S-PEM

Polioencephalomalacia (PEM) is a neurological disease in ruminants that causes cerebral necrosis of the brain (Gould, 1998). This necrosis refers to softening of the grey matter (Gould, 1998). The disease can be associated with a number of causes including thiamine deficiency, acute lead poisoning, sodium ion toxicity due to water deprivation, and excessive dietary sulfur from feed or water (Gould, 1998). Sulfur-induced polioencephalomalacia (S-PEM) caused by excessive dietary sulfur has been heavily researched, as of late, due to the increasing use of ethanol by-products, which alternatively increases the concentration of dietary sulfur in diets (Drewnoski et al., 2014). By-products in both the wet and dry milling industry are associated with higher sulfur concentration. The wet milling process utilizes sulfuric dioxide in the steeping process of wet corn gluten feed and wet corn gluten meal, whereas the dry milling process use sulfuric acid to control fermentation conditions for DGS (Kerr et al. 2008). Sulfur-induced polioencephalomalacia is not limited in association to ethanol by-products; it encompasses any feed that increases the concentration of dietary sulfur in the diet, as well as the consumption of high sulfate water. Consumption of excess dietary sulfur produces H_2S in the rumen and is the primary cause associated with the negative effects of high sulfur diets on cattle performance and health (Gould, 1998). The negative effects also have greater impacts on cattle consuming a high-concentrate diet, which tend to be less tolerable compared to cattle on forage-based diets (Drewnoski et al., 2014). A strong negative correlation between ruminal pH and H_2S production illustrates why detrimental effects are seen on high-concentrate diets (Morine et. al. 2014).

Mechanisms of Sulfur-Induced Polioencephalomalacia

The mechanisms of S-PEM seem to be largely associated with the reduction of ruminal sulfate by bacteria. Bacterial reduction of sulfate is classified as dissimilatory or assimilatory (Drewnoski et al., 2014). Bradley et al. (2011) further explains that dissimilatory reduction of sulfate utilizes sulfate-reducing bacteria (SRB) to produce H_2S as an end product of their metabolism, whereas assimilatory reduction of sulfate utilizes bacteria to produce H_2S as an intermediate for production of sulfur containing amino acids, biotin, or pantothenic acid making dissimilatory reduction the most logical pathway.

Gould (1998) suggested that the production of H_2S in the rumen, eructation, and then subsequent inhalation of this toxic gas is largely associated with S-PEM and the necrosis of the cerebral cortex. Therefore, decreases in ruminal pH, such as at times of feeding, will result in a greater production of H_2S with 70-80% of eructated gas being inhaled (Dougherty and Cook 1962). This illustrates that the association between H_2S production and ruminal pH is a major factor, in terms of how prolific gas production becomes and that inhalation of H_2S gas is likely the foremost route.

Sarturi et al. (2013) more recently proposed a concept known as ruminally available sulfur (RAS; Figure 1.1), which has given more explanation to the mechanism of H_2S production and more specifically the differentiation of DGS from other sources of dietary sulfur. Sarturi et al. (2013) simply made inference to the differences in rumen availability when comparing inorganic sources (ammonium sulfate) of sulfur to organic sources (corn gluten meal) or a combination of organic and inorganic sources (DGS). It has already been identified that H_2S production is a much better predictor of S-PEM, as well as the more general sub-acute sulfur toxicity effects than total dietary sulfur intake is (Loneragan et al. 2005). Sarturi et al. (2013) further illustrated this using the RAS concept; the challenge being that total dietary sulfur intake was easy to account for, where as an indicator for H_2S production had not yet been determined. In an attempt to find a better indicator, Sarturi et al. (2013) calculated adjusted ruminal protein sulfur (ARPS) intake by accounting for sulfur containing protein and then measured RAS and total dietary sulfur intake. Hydrogen sulfide production was then regressed upon these variables. Regression models found that total dietary sulfur intake explained 29% of the variation (Figure 1.2), ARPS intake explained 58% of the variation (Figure 1.3), and lastly RAS explained 65% of the variation (Figure 1.4). This concept of RAS has given a much better indicator for H_2S production, allowing for differentiation between sulfur sources to be better estimated. Calculations to determine ARPS can then be used as an estimator of RAS. This is done by calculating the proportion of ruminally undegradable protein-containing sulfur-attached amino acids and subtracting that portion from total dietary sulfur to calculate RAS.

Effects on Beef Cattle Performance

The effects of increased dietary sulfur, as previously referred to, is largely associated with ruminal pH (Morine et al. 2014). Spears et al. (2011) exhibited this association as it relates to performance of growing and finishing steers. Steers on this study consuming high-roughage diets, in the form of corn silage, showed no depression in DMI when dietary sulfur was increased from 0.12-0.46%. Conversely, steers on a high-concentrate diet linearly decreased DMI when dietary sulfur was increased from 0.12-0.46%. A number of other studies have agreed with these findings that increases in dietary sulfur negatively affect finishing performance (Loneragan et al., 2001; Zinn et al., 1997; and Drewnoski and Hansen, 2013). These data would suggest that cattle on high-concentrate diets are more susceptible to increases in dietary sulfur, as well as S-PEM risk, most likely due to a decrease in ruminal pH. Interestingly, the vast research done on finishing performance with increased inclusions of DGS, which increases dietary sulfur, does not support this idea (Klopfenstein et al., 2008; Galyean et al., 2012, and Erickson et al., 2012). Drewnoski et al. (2014) associates this discrepancy of DGS with the increased nutrient profile, type (dry, wet, or modified), and interactions between other components in the diet potentially concealing the negative effects of increased dietary sulfur on finishing performance. To prove this, Drewnoski et al. (2014) conducted a meta-analysis comparing the effect of increases in strictly inorganic sulfur sources compared to increases in sulfur content via DGS. They found that increasing dietary sulfur greater than 0.2% of the diet from strictly inorganic sources negatively affected DMI, ADG, and HCW, while increases in dietary sulfur from DGS only negatively affected DMI and ADG and at a much smaller degree than that of the strictly inorganic sources. Altogether these data would suggest that increasing dietary sulfur does negatively affect finishing performance and can lead to an increased risk of S-PEM. Conversely, increasing dietary sulfur through DGS seems to have a less significant impact on performance due to its interactions with other components in the diet and possibly in correlation to Sarturi et al. (2013) RAS concept. These data would suggest that DGS could be fed at higher concentrations compared to other inorganic sources of sulfur.

Management Strategies

Utilizing the RAS model, Nichols et al. (2012) concluded that increasing dietary NDF decreased the risk of S-PEM. They attributed this to the increase in ruminal pH, therefore decreasing H_2S production when dietary NDF was increased. Assuming dietary sulfur is sourced from DGS and normal forage NDF is present, Nichols et al. (2012) recommend not exceeding 0.46% S in the diet; correlating to a RAS value around 0.30% S. Drewnoski et al. (2014) also recommended a minimum of 7-8% NDF in diets containing 0.40% S or higher.

Multiple studies across a number of sulfur sources have concluded that S-PEM is not due to a thiamine deficiency and blood thiamine concentrations were within normal ranges during incidences of S-PEM (Sager et al., 1990; Gould et al., 1991; Mella et al., 1976; McAllister et al., 1997; and Loneragan et al., 2005). Similarly, no research to date has concluded that thiamine improves finishing performance for cattle on high sulfur diets. Gould (1998) attributes the use of thiamine as a management tool for S-PEM to its non-specific therapeutic benefits on cerebral diseases. Ensley (2011) reported that injections of thiamine, regardless of PEM cause, is the primary mode of treatment. Drewnoski et al. (2014) attributes thiamine supplementation use as a "safeguard" against clinical signs of S-PEM.

Lastly H_2S production has been shown to peak between 14 and 60 d on finishing diets, with increased dietary sulfur (Drewnoski et al. 2014). This directly correlates to the adaptation period of cattle onto concentrate diets. Similarly, Loneragan et al. (2005) reported peak H_2S production on d 31 of a study observing increased concentrations of sulfate in water. Drewnoski et al. (2014) suggests that SRB, which are lactate utilizers, may not have to compete for the abundance of lactate being produced during the adaptation period and that competition later in the feeding phase with bacteria such as Megasphera elsdenii may hinder SRB's ability to produce H_2S. Altogether these data suggest that managing dietary sulfur in finishing diets, especially during the adaptation period is critical to lower potential risk of S-PEM.

The lack of etiological understanding of S-PEM leads to minimal supportive management strategies. Strategies previously reported that have been found beneficial include increasing dietary NDF content (Nichols et al., 2012), additives such as thiamine (Gould, 1998) and antioxidants (Pogge and Hansen, 2013), and lastly sound management especially during adaptation periods onto finishing diets. Additionally, the Sarturi et al. (2013) method of calculating ARPS and utilizing RAS as a predictor of H_2S production should be considered to aid in diet evaluation regarding excess sulfur.

Double-Cropped Annual Forages for Fall Grazing

The advent of cover crops and their adoption into agronomic practices has prompted research in this area. Research has mostly been centered around the benefits of cover crops following a cash crop without harvesting the cover crop via machine or animal. Benefits reported include weed suppression (Brandsaeter and Netland, 1999), wind and water erosion control, as well as soil nitrogen fixation from utilization of legume species (Mitchell and Teel, 1977), soil organic nitrogen management (Ranells and Wagger, 1997), and an increase in soil OM due to increased root growth (Fae, 2009). Again, most of these benefits were observed in studies that utilized cover crops for their sole purpose, cover. However, interests have arisen around the idea of grazing the secondary crop as an additional economic benefit, if animals are able to achieve profitable gains off of the forage. The published literature that has focused on grazing these double-cropped annual forages after a cash crop have focused on factors related to forage type, planting date, animal performance, and subsequent cash crop yield.

Brassicas have been a forage type with a substantial amount of interest for fall grazing due to their nutritional quality and ability to over-winter. Wiedenhoeft and Barton (1994) described brassicas nutritional value as more similar to concentrates than traditional forages due to their relatively low fiber content (avg. ADF = 24% and NDF = 28%) and high protein value (avg. CP = 19.8%). Similarly, Lambert et al. (1987) reported an associative effect with rape and orchardgrass hay similar to the classical associative effect between forage and concentrates, and concluded that some amount (~18% DM) of supplemental hay is necessary to increase digestible DMI. In a study to determine the influence of planting and harvest date on the nutritive quality of brassicas, Wiedenhoeft and Barton (1994) planted three brassicas (rape, turnip, and a turnip hybrid) on three separate planting dates (late-May to early-June, late-June to early-July, and late-July to early-August). Nutritive values were lowest in July and August when temperatures were warmer and moisture levels in the soil lower. May planted brassicas, regardless of species, were greater in NDF and ADF values with lower CP levels compared to the August planting date. Magnesium levels were comparable to traditional forages, while Ca and P levels were greater. Researchers concluded that brassicas, regardless of species, offer a high quality forage option in the fall, with retained nutrients into the winter. Additionally, their low fiber content, high CP value, and Ca:P ratio need to be accounted for.

Koch et al. (2002), in a 10-yr study conducted near Powell, WY, evaluated four types of brassicas (turnips, tyfon, rape, and radishes) to determine effects of planting date (July 17 to August 12), tillage practice (no-till vs. tilled), and animal performance. Biomass production was not different between species, although researchers noted that in late-fall almost half of the turnip production was from its tuberous root. Brassicas planted in no-till resulted in a 20% reduction in biomass production. However, researchers went on to explain that the 20% reduction was less than the average loss in biomass production from delaying planting (average of one week) to prepare the seedbed when utilizing tillage. In addition, no-till practices are less expensive per hectare and provide the benefits of supplemental roughage and re-growth from the previous crop (Koch et al., 2002). Similar gains were reported for each species with lamb gains averaging 0.18 kg / d. Lambs grazing July-planted brassicas gained 41% more than the lambs grazing the August-planted brassicas due to the increased amount of forage production in the July-planted species. Researchers concluded planting date was the biggest factor in affecting brassica productivity. Regardless of species or tillage practice, after July 20th forage production declines by 770 kg / ha per week. Turnips planted in July produced 3900 kg DM / ha on average, while August planted turnips produced 2500 kg DM / ha on average.

Fae et al. (2009) conducted a 2-yr study near Columbus, OH to determine the potential of cover crop forages for production after corn silage and their effect on subsequent corn silage yield, and soil characteristics. Three treatments (annual ryegrass, winter rye-oat mix, and no cover) were seeded into a no-till seedbed following corn silage harvest in early-September. Dairy heifers were stocked at 1,152 kg live BW / ha. Winter rye-oat mix resulted in a 38-73% greater yield over the two years compared to annual ryegrass, largely due to the increased forage DM accumulation in the spring from the winter rye. Winter rye-oat mix produced 4,763 kg / ha of dry forage over the 2006-2007 gazing season, while annual ryegrass produced 3,449 kg / ha. Subsequently, in the 2007-2008 grazing season, winter rye-oats produced 8,339 kg / ha and annual ryegrass produced 4,821 kg / ha. No differences were found for subsequent corn silage yield either year, although soil penetration resistance was 7-15% greater in the grazed treatments compared to the no cover treatment in May 2007. Cover treatments had three to five-fold greater root growth, a three-fold increase in soil microbial biomass in the spring of 2008, and 23% greater soil particulate organic carbon in the first 15-cm compared to the no cover treatment. Forage provided an average of 105 animal unit grazing days per hectare across both treatments. Heifers gained an average of 0.81 kg / d and ate an average of 2.9% of live BW across both treatments.

In the interest of considering different backgrounding strategies in the fall, a study was conducted to evaluate the effects of backgrounding calves utilizing corn residue or fall double-cropped forages near Clay Center, NE (Cox et al., 2016). Backgrounding treatments included grazing corn residue with DGS supplementation (0.86% of BW / d), grazing an oat-brassica forage, or feeding a corn silage based grower ration in the dry-lot. The oat-brassica forage was utilized as a double-crop after corn silage harvest, seeded in early-September. Calves in the grazing treatments, grazed for 64 d and were then fed the corn silage based grower ration for 21 d to meet the predetermined end target weight of 363 kg live BW. During the grazing period, calves on the oat-brassica forage had the greatest gains at 1.02 kg / d, whereas the calves supplemented DGS on cornstalks gained 0.80 kg / d. When looking at the entire growing period, calves in the dry-lot gained the most at 1.62 kg / d, followed by calves grazing oat-brassica at 1.20 kg / d, and lastly the calves supplemented DGS on cornstalks at 1.01 kg / d. Authors went on to perform an economic analysis on the different backgrounding systems. Calves supplemented DGS on cornstalks had the lowest cost of gain ($ 0.76 / kg gain), followed by the dry-lot calves ($ 0.88 / kg gain), and lastly the calves grazing the oat-brassica forage had the highest cost of gain ($ 1.06 / kg gain). Authors attributed almost 40% of the oat-brassica cost to inorganic nitrogen applied during seeding, and they noted application through a cheaper source, such as manure, would be more economical.

Lastly, two separate 2-yr experiments were conducted to determine the potential for a brassica-based mixture to be grazed following wheat harvest or for oats and an oat-turnip mixture to be grazed following either corn silage or HMC harvest near Mead, NE (Ulmer, 2016). In experiment 1, the brassica-based mixture following wheat was drilled for two consecutive years in mid-August and produced an average of 3,124 kg DM / ha by late-October. Steers grazed for an average of 50 d starting in mid-November, with an average gain for the two years of 0.85 kg / hd. In experiment 2, the oat-turnip mixture in year 1 was drilled in early-September following corn silage or mid-September following HMC harvest. The oat-turnip mixture following corn silage produced 1,047 kg DM / ha by late-October, while only 487 kg DM / ha were produced following HMC harvest. In year 2, oats following corn silage were drilled in early-September and produced 3,200 kg DM / ha by late-October, while oats drilled after HMC harvest in mid-September only produced 586 kg DM / ha. Steers only grazed in year 2 due to a herbicide restriction in year 1. Grazing began in mid-November and lasted 62 d with gains averaging 0.59 kg / hd on the oats following corn silage and 0.33 kg / hd on the oats following HMC harvest.

Conclusions

In summary, Nebraska has a regional advantage for DGS production and utilization of DGS is widely accepted in both concentrate and forage-based diets for cattle. Distillers have been documented to have a higher energy value than corn in beef cattle diets and the recent removal of oil has had minimal impact on energy value. Additionally, when economical, CDS have been shown to be an acceptable feedstuff in high-concentrate diets. Combinations of CDS with other by-products have also been shown to improve performance in high-concentrate diets. Utilization of CDS within forage-based diets has shown variable performance outcomes and its current value in the diet is unclear. However, the literature seems to agree that CDS will increase nutrient digestibility, fat digestion, and propionate production with a reduction in ruminal pH. Sulfur concentration needs to be considered when feeding by-products, especially CDS. Strategies for managing sulfur in by-products include increasing dietary NDF, supplementation of thiamine and antioxidants, sound management during the adaptation period, and the use of the RAS model to more accurately account for deleterious sulfur concentrations.

Separately, there are opportunities both economically and agronomically to planting annual forages in the fall as a double-crop. Producers in the cow-calf, stocker, or feedlot sector may benefit from utilization of crop ground to achieve favorable animal gains at an equitable cost. Likewise, crop producers may benefit by spreading out their cost of production, removing unwanted residue, and realizing better soil characteristics. In order to do so, type of forage and time of planting must be managed. Brassicas along with winter annuals have been shown to produce forage of adequate quantity and nutritive value to achieve desirable animal performance, while also enhancing the soil characteristics and nutrient profile within a cropping system. Planting of annual forages should likely be done in early-September and species should be selected dependent on mode of desiccation before preparation for the following crop season. With the previous literature reviewed, the objectives for the resulting research are: 1) to determine the effects of increasing CDS inclusions in finishing diets; 2) to determine the effects of increasing CDS inclusions in growing diets; 3) to determine the effects of CDS on ruminal and total tract metabolism in forage-based diets; 4) to determine the effects of grazing double-cropped annual forages following corn production.

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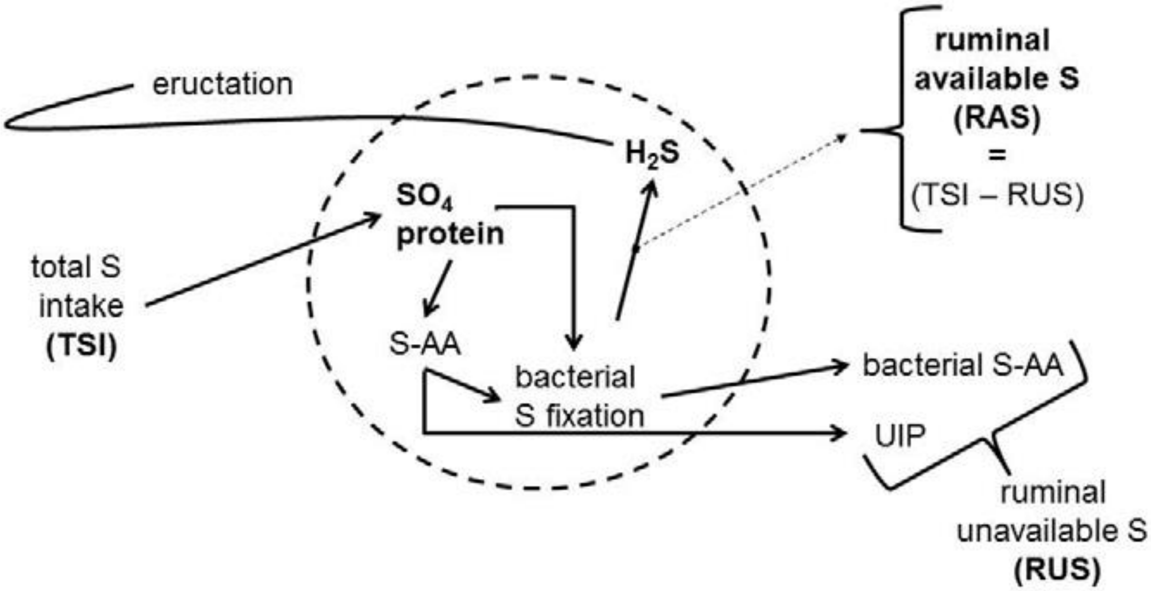
Figure 1.1.



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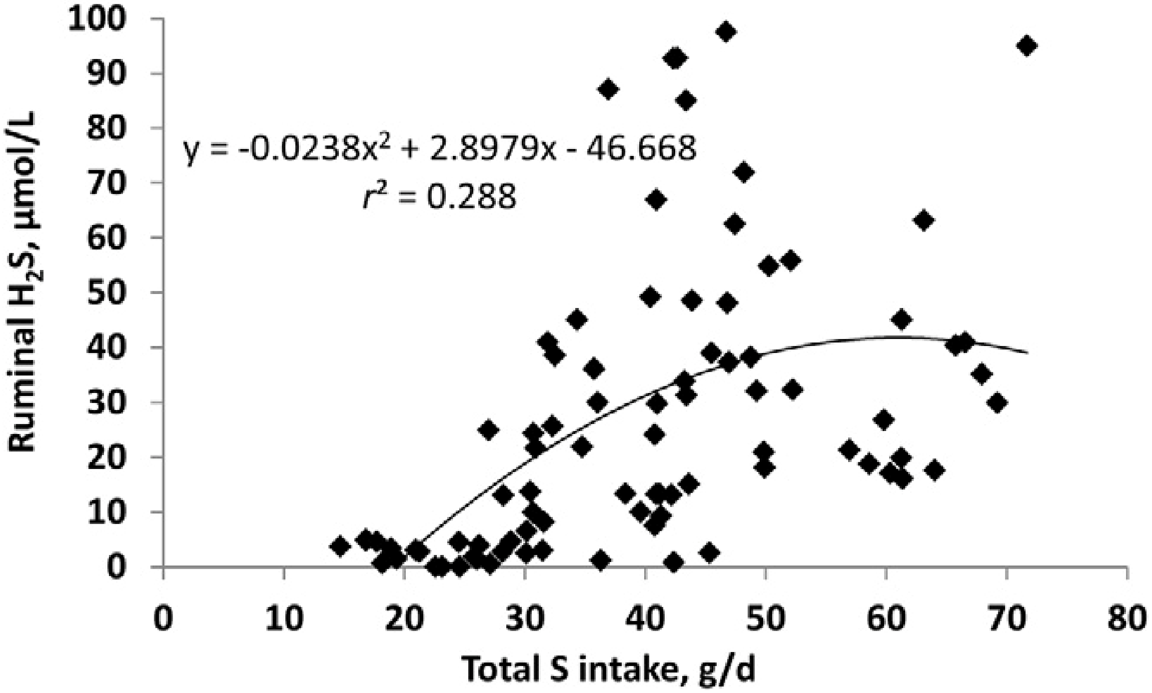

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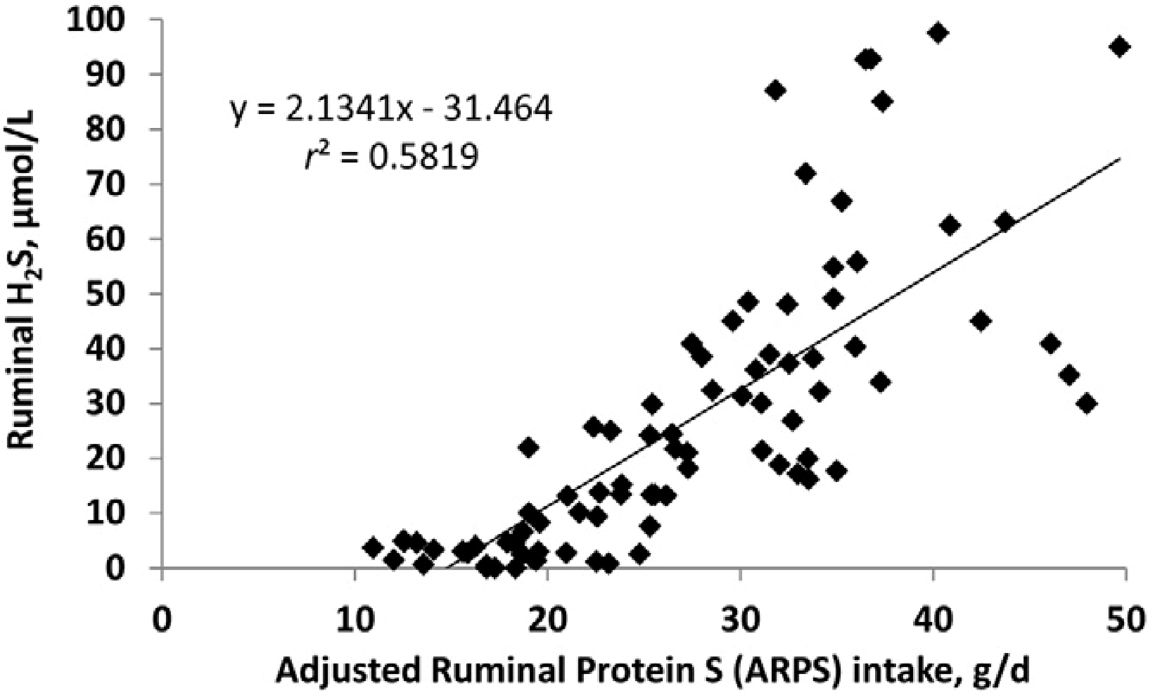

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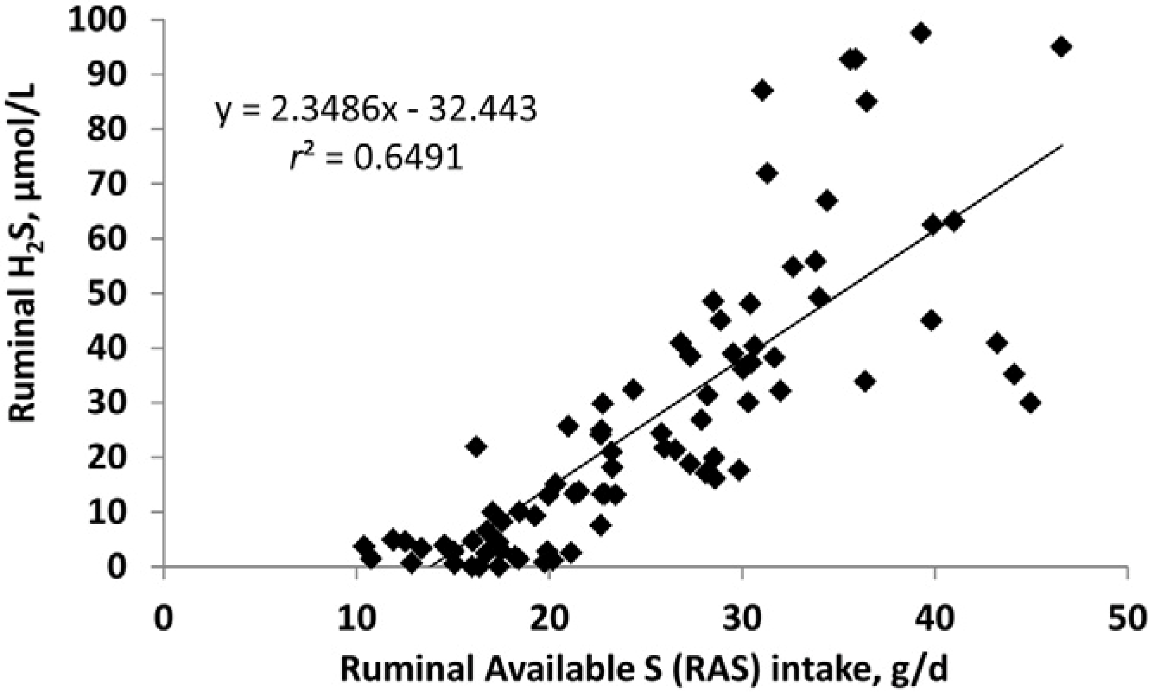

CHAPTER II. Finishing Performance of Steers Fed Increasing Inclusions of Corn Condensed Distillers Solubles

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Abstract

Six hundred crossbred steers (initial BW = 435 kg; SD = 41 kg) were used to evaluate the effects of de-oiled corn condensed distillers solubles (CDS) on performance and carcass characteristics of finishing steers. Five treatments with 6 pens per treatment (20 steers / pen, n = 6) were used in a generalized randomized block designed experiment with 3 BW blocks. Treatments consisted of a control diet containing 68% dry-rolled corn, 17% high moisture corn, 10% alfalfa, and 5% supplement. Condensed distillers solubles (5.3% fat) were included at 8, 16, or 20% of diet DM and replaced the corn blend. A fifth treatment included 16% CDS with 20% WDGS to compare common industry inclusions of WDGS with additional CDS to the performance of the 16% CDS inclusion alone. Steers were limit fed for 5 d at the beginning of the trial and weighed on d 0 and 1 to account for gut fill. Steers were harvested at 110 d (heaviest 2 blocks) or 117 d (lightest block) and carcass data were collected. Linear and quadratic effects of increasing inclusions of CDS were evaluated using orthogonal contrasts and a pairwise comparison was used to compare the 16% CDS with 20% WDGS diet to the 16% CDS diet. Final BW, ADG, G:F, fat thickness, and HCW linearly increased ($P \leq 0.05$) with increasing inclusions of CDS, while DMI tended to increase quadratically ($P = 0.06$) with increasing CDS inclusion. When comparing the 16% CDS with 20% WDGS diet to the 16% CDS diet, DMI decreased ($P = 0.04$) with a tendency for improved G:F ($P = 0.08$). No differences for carcass characteristics were observed ($P \geq 0.13$) when comparing the 16% CDS with 20% WDGS diet to the 16% CDS diet. The feeding value of CDS when compared to the corn blend was calculated at 139, 146, and 147% for the 8, 16, and 20% inclusions of CDS. When 16% CDS was compared to 16% CDS in combination with

20% WDGS, a feeding value of 115% was calculated for the WDGS relative to corn. With recent changes in oil removal from CDS, the feeding value appears consistent with previous work and suggests CDS has more energy than corn for finishing cattle.

Key words: condensed distillers solubles, feeding value, finishing cattle, wet distillers grains plus solubles

Introduction

Dry-mill ethanol plants produce by-products, such as distillers grains plus solubles (DGS) and condensed distillers solubles (CDS). In 2014, 85% of ethanol plants had the capability to extract oil (RFA, 2015). Current fat content of DGS varies between 4-13% (Nelson, 2016) whereas Buckner et al. (2011) reported a fat content of 10-13% for traditional DGS prior to oil removal. Because the fat is centrifuged from the thin stillage, the fat content of CDS is affected more so than the distillers grains. Previously, CDS contained 20% fat whereas current CDS has a fat content near 6% (Jolly et al. 2013).

Pesta et al. (2015) displaced up to 36% of diet DM (dry-rolled corn (DRC) and high-moisture corn (HMC)) with CDS (18.6% fat) and reported a quadratic increase for both ADG and G:F. Feeding values were calculated at 210, 166, 142, and 139% the value of corn for inclusions of CDS at 9, 18, 27, and 36%, respectively. Furthermore, Jolly et al. (2013) evaluated the effects of oil removal on feeding value of both CDS and modified distillers grains plus solubles (MDGS) in finishing diets. Steers were fed either 27% CDS containing normal fat (21.1% fat) or reduced fat (6.0% fat), or 40% MDGS containing normal fat (11.8% fat) or reduced fat (9.2% fat). Performance outcomes were consistent with previous observations where by-products resulted in greater final BW, ADG, G:F, and HCW compared to the corn control diet with no by-products. Additionally, fat content of the by-products had no effect on performance or carcass characteristics.

Similar data are needed for de-oiled CDS. Thus, the objective of this trial was to evaluate performance and carcass characteristics of steers fed de-oiled CDS in finishing diets.

Materials and Methods

The University of Nebraska-Lincoln Institutional Animal Care and Use Committee approved all animal care and management procedures.

A 114-d finishing study was conducted at the Eastern Nebraska Research and Extension Center feedlot near Mead, NE. Six hundred crossbred yearling steers (initial BW = 435 kg; SD = 41 kg) were utilized. Prior to trial initiation, steers were processed with Titanium 5 + PH-M (Elanco Animal Health, Greenfield, IN) for protection against BVD Type I & II, IBR, PI_3, BRSV, *Mannheimia haemolytica*, and *Pasteurella multocida*; Somnu Shield (Elanco Animal Health) for protection against *Haemophilus somnus*; and Dectomax (Zoetis Animal Health, Parsippany, NJ) for parasite control. Approximately three weeks later, steers were re-vaccinated with Titanium 5 (Elanco Animal Health) and Ultrabac-7 (Zoetis Animal Health). Steers over-wintered on cornstalks (approximately 110 d) and were supplemented with 2.3 kg / d WDGS and then grazed bromegrass pastures (approximately 60 d) until trial initiation. Five d prior to the trial, steers were limit fed a common diet of 50% Sweet Bran (Cargill Corn Milling, Blair, NE) and 50% alfalfa hay at 2.0% of BW and weighed for 2 consecutive d (d 0 and 1) to limit differences in BW due to gut fill and establish initial BW (Watson et al., 2013). Steers were blocked by BW (n = 3), stratified within block, and assigned randomly to pen. Pens were assigned randomly to one of the five treatments with 20 steers / pen and 6 pens / treatment.

Treatments consisted of increasing inclusions of CDS at 0, 8, 16, and 20% of the diet DM displacing an 80% DRC: 20% HMC blend (Table 2.1). A fifth treatment included 16% CDS with 20% WDGS to compare common industry inclusions of WDGS with additional CDS, to the performance of the 16% CDS inclusion alone. Steers were adapted to diets over a 21-d step-up period where by-product inclusions were held constant while the corn blend replaced alfalfa hay, which started at 45% of diet DM in the first adaptation diet. The average nutrient profile of the CDS (Aurora Pacific Ethanol, Aurora, NE and Green Plains Ethanol, Wood River, NE) utilized in this study contained 29.7% DM, 30.2% CP, 5.3% fat, and 1.4% S. The average nutrient profile of WDGS (Abengoa Ethanol, York, NE) was 30.6% DM, 37.9% CP, 14.4% fat, and 0.8% S. Incidences of sulfur-induced polioencephalomalacia (n = 4; Gould, 1998 and Drewnoski et al., 2014)) were observed during the first 60 d of the trial due to dietary sulfur concentrations of 0.50% or greater for the 24% CDS diet and the 16% CDS with 20% WDGS combination diet. Steers diagnosed were removed from the trial. Alfalfa hay inclusion was increased from 7.5% to 10% (Nichols et al., 2012), the original 24% CDS diet was reduced to 20% CDS, thiamine was added to all diets containing CDS (Gould, 1998 and Ensley, 2011), and CDS were re-sourced. The original source of CDS averaged 1.6% S and the second source of CDS averaged 1.1% S. All diets included alfalfa hay at 10% and dry supplement at 5%. Supplements were formulated to provide 33 mg / kg of Rumensin (Elanco Animal Health) and 9.7 mg / kg of Tylan (Elanco Animal Health). Thiamine was provided at 150 mg / steer in diets containing by-products. Urea was added at 1.40% in the corn control diet, 1.04% in the 8% CDS diet, 0.69% in the 16% CDS diet, and 0.35% in the 20% CDS diet to ensure rumen degradable protein requirement was met. In order to provide incremental amounts of urea, supplements were formulated for the control with 1.04% urea, the 8% CDS diet with 1.04% urea, and the combination diet (16% CDS + 20% WDGS) with no urea. Supplements formulated for the 8% CDS diet and the combination diet were then blended two-third to one-third for the 16% CDS diet and on-third to two-third for the 20% CDS diet, respectively.

On d 1, steers were implanted with 200 mg trenbolone acetate, 20 mg estradiol, and 29 mg tylosin (Component TE-200, Elanco Animal Health). Steers were harvested on d 110 (heaviest 2 blocks) and d 117 (lightest block) at Greater Omaha (Omaha, NE). During harvest, HCW and liver abscesses were recorded and a common (63%) dressing percentage was assumed to calculate final BW. Following a 48-hr chill, fat thickness, LM area, and USDA marbling scores were recorded.

Feed ingredients were sampled weekly and composited by month. Condensed distillers solubles were analyzed for sulfur using a TrueSpec micro analyzer (LECO Corp., Saint Joseph, MI) upon arrival of each load. Monthly composites of feed ingredients were dried at 100^{o}C for 24 h to determine DM. Crude protein and sulfur were analyzed using a TrueSpec micro analyzer (LECO Corp.) and fat was analyzed using Buckner et al. (2008) procedure. Additionally, ruminal available sulfur (RAS) was calculated for each diet as described by Sarturi et al. (2013). This is calculated by subtracting total dietary sulfur intake by rumen undegradable sulfur. Rumen undegradable sulfur is calculated by taking the relative percent of sulfur containing amino acids in each feed ingredient and multiplying it by their respective percent RUP. This calculation assumes that all other inorganic sulfur is 100% available for ruminal reduction by sulfide and does not account for the sulfur incorporated in the microbial biomass.

Data were analyzed using the MIXED procedure of SAS as a generalized randomized block design with 3 blocks and 2 reps / block. Pen was the experimental unit and BW block was analyzed as a fixed effect. Orthogonal contrasts were used to analyze linear and quadratic effects of CDS displacing corn. Due to unequal spacing between treatments, coefficients were determined using the IML function of SAS. A pairwise comparison was used to compare effects of the 16% CDS with 20% WDGS diet to the 16% CDS diet.

Similar to previous research (Peterson et al., 2014) NE equations from the NRC (1996) were used to predict energy values, based on animal performance, for each CDS diet compared to the corn blend. In order to do so, actual intake, average BW, and TDN values were applied for the 0% by-product diet (DRC = 88% TDN, HMC = 93% TDN, and alfalfa hay = 58% TDN) and then NE adjusters were used to match observed animal performance. Diet NE adjusters were set at 87.0% for both NE_m and NE_g. The corn blend was replaced with CDS at each respective inclusion and TDN values of the CDS were adjusted until each diet met the observed ADG outcomes, respectively. In the combination diet (16% CDS + 20% WDGS), the TDN value predicted for CDS in the 16% CDS diet (110.2%) was applied and TDN values for WDGS were adjusted until the diet met the observed ADG outcome. Therefore, energy values were predicted for CDS and WDGS (% TDN), as well as for each diet (NE_m and NE_g). Feeding values for each by-product treatment were calculated by dividing percentage change in G:F for treatment averages compared to the control by percentage inclusion of by-product in each respective treatment, multiplying by 100, and adding 100 (Klopfenstein et al., 2008). This resulted in the feeding value of each inclusion of by-product compared to the corn blend.

Results and Discussion

Condensed Distillers Solubles Effect

Dry matter intake tended to decrease in a quadratic manner (*P* = 0.06) as CDS inclusion increased with the cattle fed 20% CDS having the least DMI (Table 2.2). Previous work has shown decreased DMI with CDS fed at both lesser (Trenkle et al. 2002) and greater inclusions (Pesta et al. 2015, Titlow et al. 2013, and Harris et al. 2014) in finishing diets. Biologically this could be explained by increased dietary sulfur, fat, or energy intake. Furthermore, if energy intake were the driver it could be hypothesized that DMI should be further depressed when CDS is fed with SFC rather than DRC due to the increased energy offered from SFC. Titlow et al. (2013) reported a quadratic depression in DMI when CDS was fed with either SFC or DRC at 12.0, 11.7, and 10.6 kg /d for 0, 15, and 30% inclusions of CDS, respectively. Similarly, Harris et al. (2014) reported a quadratic depression in DMI when CDS was fed with SFC at 11.8, 11.8, 11.5, 11.4, and 10.8 kg /d for 0, 9, 18, 27, and 36% inclusions of CDS, respectively. These observations suggest energy intake is one of several factors influencing the impacts of CDS on DMI. Dietary sulfur and fat intake may play a larger role in intake regulation for CDS. In the current study, dietary sulfur exceeded 0.50% in the 20% CDS and 16% CDS with 20% WDGS diets. Excessive dietary sulfur (0.46% or greater) has been shown to decrease intake especially when fed in high-concentrate diets (Spears et al. 2011, Loneragan et al. 2001, Zinn et al. 1997, Sarturi et al. 2013, and Drewnoski and Hansen, 2013). Sarturi et al. (2013) fed low S (0.82%) and high S (1.16%) DGS at 20, 30, and 40% inclusions and reported a 6 and 17% reduction in DMI for high S DGS diets fed at 30 and 40% inclusions, respectively. Interestingly, dietary rumen available sulfur (RAS) was calculated at 0.25 and 0.38% for low and high S DGS diets, respectively. Similar to dietary RAS calculated during the current study at 0.07, 0.17, 0.28, and 0.33% for the 0, 8, 16, and 20% CDS inclusions, respectively. Additionally, Hatch et al. (1972) concluded that suppressed DMI was the most consistent effect of fat supplementation. With a lower fat content in CDS (5.3%) than previously observed, dietary fat likely had little impact on intake. Dietary sulfur is a more logical explanation for the quadratic response in DMI during this trial.

Average daily gain and G:F linearly increased ($P < 0.01$) as the inclusion of CDS increased. Previous data have shown increased ADG coupled with lower DMI, leading to improved G:F when CDS is fed in finishing diets (Titlow et al. 2013, Harris et al. 2014, and Pesta et al. 2015). Titlow et al. (2013) fed CDS at 0, 15, and 30% of diet DM displacing DRC or SFC. When displacing DRC, ADG and G:F increased quadratically with the greatest ADG at 15% CDS and the greatest G:F at 30% CDS inclusions. The relative percent improvement in G:F from 15 to 30% CDS was calculated at 4.3%.When displacing SFC, ADG increased linearly and G:F increased quadratically with the greatest G:F still at the 30% CDS inclusion. Dissimilarly to CDS fed in DRC diets, increasing inclusions of CDS from 15 to 30% in SFC diets improved G:F by 12%. Harris et al. (2014) fed CDS at 0, 9, 18, 27, and 36% of diet DM displacing SFC. Both ADG and G:F responded quadratically with the greatest performance for each at the 27% CDS inclusion. Averaged across the studies cited above, ADG was greatest at 15% CDS inclusion with G:F optimized at 30% CDS inclusion displacing corn. Most recently, Pesta et al. (2015) used the first derivative of the quadratic response to calculate maximum ADG at 20.8% CDS inclusion and maximum G:F at 32.5% CDS inclusion. All of these previous studies used CDS with approximately 20% fat. Fat content of the CDS utilized during the current study was 5.3%. Linear increases in ADG and G:F with CDS fed up to 20% of the diet infer that the recent reduction in fat content may allow CDS to be fed at higher inclusions than it previously has been; however, previous inclusions were not exceeded. Level of ruminally available sulfur (Sarturi et al. 2013) in the diet may be the only limit to the amount of CDS that can be fed in a finishing diet.

Final BW and HCW increased linearly ($P < 0.01$) with increasing inclusions of CDS. Steers fed 20% CDS finished 12 kg heavier with 7 kg more HCW than steers feed corn only. Fat thickness increased linearly ($P = 0.05$) with increasing inclusions of CDS, although numerically steers fed 20% CDS had only 0.06 cm more back fat than steers fed corn only. Marbling score, calculated YG, and LM area were not impacted by increasing inclusions of CDS ($P \geq 0.11$).

Energy values for CDS compared to the corn blend (DRC = 88% TDN and HMC = 93% TDN) were predicted at 108.1, 110.2, and 111.8% TDN for the 8, 16, and 20% inclusions, respectively (Table 2.2). Using these TDN values for CDS, dietary energy values were predicted for NE_m and NE_g. Dietary energy values for NE_m were predicted at 1.95, 1.99, 2.04, and 2.08 Mcal / kg for the 0, 8, 16, and 20% CDS diets, respectively. Dietary energy values for NE_g were predicted at 1.19, 1.22, 1.25, and 1.28 Mcal / kg for the 0, 8, 16, and 20% CDS diets, respectively. These energy values suggest that CDS has more energy than a HMC:DRC blend and that dietary energy increases as CDS inclusions increase in a finishing diet. Feeding values for CDS compared to the corn control were calculated at 139, 146, and 147% for the 8, 16, and 20% inclusions, respectively. Previous feeding values for CDS averaged across two studies were 197, 159, 145, and 132% for 9, 18, 27, and 36% inclusions of CDS, respectively (Pesta et al. 2015 and

Harris et al. 2014). These values are useful for pricing feedstuffs based off performance outcomes compared to corn and suggest that de-oiled CDS is worth approximately 147% the price of corn when included in a finishing diet at 20% in place of corn.

Wet Distillers Grains plus Solubles Effect

When comparing the combination diet (16% CDS + 20% WDGS) to that of the 16% CDS diet, DMI decreased (*P* = 0.04) with a tendency for improved G:F (*P* = 0.08). Klopfenstein et al. (2008) illustrated the classic response when WDGS is fed in finishing diets with decreased DMI and improved G:F in a review of distillers by-products. Interestingly, it seems that much of the gain response is due to the CDS, since the addition of 20% WDGS did not affect ADG. Also and more importantly, the data illustrate that an additional 16% CDS can be fed with WDGS to further displace corn from the diet and improve efficiencies by another 3%. Previously, Bremer et al. (2009) fed CDS at 0, 6.7, 13.3, or 20% of the diet in combination with 35% wet corn gluten feed (WCGF) and reported similar DMI, ADG, and G:F with increasing inclusions of CDS compared to the corn control. Similarly, Pesta et al. (2015) fed CDS at 0, 7, 14, and 21% of the diet in combination with 20% MDGS or Synergy (blend of MDGS and WCGF; Archer Daniels Midland, Columbus, NE). Similar to Bremer et al. (2009) data, the combination of CDS and Synergy resulted in no ADG response, while the combination of CDS and MDGS resulted in a quadratic response with the greatest ADG at the 14% inclusion of CDS. Pesta et al. (2015) reported a linear increase in G:F regardless of whether CDS was added to MDGS or Synergy at 20% of diet DM. These data would agree that feeding by-product combinations with CDS, other than WCGF, improve ADG and G:F and further displace corn.

An energy value was predicted for WDGS in the 16% CDS with 20% WDGS combination diet at 96% TDN (data not shown). Since the TDN value of CDS predicted in the 16% CDS diet (110.2%) was applied, the TDN value of WDGS is likely underestimated (Bremer et al., 2011). Nevertheless, the combination of CDS and WDGS resulted in dietary energy values for NE_m of 2.08 Mcal / kg and for NE_g of 1.28 Mcal / kg. Feeding values were calculated for the 16% CDS with 20% WDGS combination diet compared to the 16% CDS diet, as well as the control diet. A feeding value for WDGS of 115% was calculated for the combination diet compared to the 16% CDS diet, representing the feeding value of the WDGS compared to corn. A feeding value of 129% was calculated for the combination diet compared back to the control, representing the feeding value of the by-product combination compared to corn. These values suggest that, in the combination diet, CDS accounted for 14% of the feeding value, whereas WDGS accounted for 15% of the feeding value compared to the corn blend. Additionally, energy values for the combination diet were greater in both NE_m and NE_g ($P < 0.01$) than that of the 16% CDS diet.

Feeding CDS at inclusions up to 20% of diet DM increased ADG and G:F, with feeding values up to 147% compared to corn. Feeding a combination of CDS and WDGS maximized ADG while decreasing DMI, resulting in the greatest G:F, with a feeding value of 129% compared to corn. Energy values increased linearly with increasing CDS inclusions and were maximized in the combination diet. With the recent reduction in the fat content of CDS, the data imply that CDS can be fed at greater inclusions than 20% and can certainly be fed in combination with WDGS. The limiting factor to the level of CDS inclusion in finishing diets is likely S content.

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Table 2.1. Composition of diets (DM-basis) containing condensed distillers solubles and distillers grains

	CDS[1], % Inclusion				
Ingredient	0	8	16	20	16 + 20[2]
Dry-rolled corn	68.0	61.6	55.2	52.0	39.2
High-moisture corn	17.0	15.4	13.8	13.0	9.8
Condensed distillers solubles	-	8.0	16.0	20.0	16.0
Wet distillers grains plus solubles	-	-	-	-	20.0
Alfalfa hay	10.0	10.0	10.0	10.0	10.0
Supplement[3]					
Fine Ground Corn	1.169	1.908	2.256	2.603	2.950
Limestone	1.528	1.519	1.518	1.518	1.517
Tallow	0.125	0.125	0.125	0.125	0.125
Urea	1.403	1.040	0.693	0.347	-
Potassium Chloride	0.385	-	-	-	-
Thiamine	-	0.016	0.016	0.016	0.016
Salt	0.300	0.300	0.300	0.300	0.300
Beef Trace Mineral[4]	0.050	0.050	0.050	0.050	0.050
Vitamin A-D-E[5]	0.015	0.015	0.015	0.015	0.015
Rumensin-90[6]	0.017	0.017	0.017	0.017	0.017
Tylan-40[7]	0.009	0.010	0.010	0.010	0.010
Nutrient Composition, % of DM					
DM	86.7	82.3	77.8	75.6	66.7
CP	13.0	13.7	14.4	14.4	18.4
Fat	4.03	4.07	4.15	4.19	6.15
Sulfur	0.13	0.23	0.34	0.39	0.48
RAS[8]	0.07	0.17	0.28	0.33	0.38

[1] CDS = Condensed distillers solubles (de-oiled)

[2] 16 + 20 = 16% condensed distillers solubles + 20% wet distillers grains plus solubles

[3] Supplement fed at 5% diet DM

[4] Premix contained 10% Mg, 6% Zn, 4.5% Mn, 0.5% Cu, 0.3% I, and 0.05% Co

[5] Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per g

[6] Formulated to supply Rumensin-90 (Elanco Animal Health) at 33 mg / kg

[7] Formulated to supply Tylan-40 (Elanco Animal Health) at 9.7 mg / kg

[8] Ruminal available sulfur (RAS) = total dietary S intake – ruminal undegradable S. Ruminal undegradable S is calculated by multiplying percent S containing amino acids by percent RUP. This calculation does not account for ruminal S incorporated in the microbial biomass and assumes all other inorganic S is 100% available for ruminal reduction

Table 2.2. Effects of condensed distillers solubles (CDS) inclusion and CDS in combination with wet distillers grains plus solubles (WDGS) on performance and carcass characteristics[1]

	CDS, % Inclusion						*CDS Effect*		*WDGS*
	0	8	16	20	16 +20[2]	SEM	Lin[3]	Quad[4]	*P*-value[5]
Performance									
Initial BW, kg	435	435	435	435	435	0	0.24	0.49	0.76
Final BW, kg	606^{c}	612^{bc}	620^{a}	618^{ab}	621^{a}	2	<0.01	0.40	0.78
DMI, kg / d	11.4	11.4	11.5	11.2	11.3	0.1	0.28	0.06	0.04
ADG, kg	1.55^{b}	1.60^{b}	1.68^{a}	1.66^{a}	1.69^{a}	0.02	<0.01	0.47	0.73
G:F	0.136^{b}	0.140^{b}	0.146^{a}	0.149^{a}	0.150^{a}	0.002	<0.01	0.65	0.08
Energy Values									
NE$_{m}$[6], Mcal / kg	1.95	1.99	2.04	2.08	2.08	-	-	-	-
NE$_{g}$[7], Mcal / kg	1.19	1.22	1.25	1.28	1.28	-	-	-	-
CDS TDN[8], %		108.1	110.2	111.8	110.2				
Feeding Values[9]	-	139	146	147	129[10]	-	-	-	-
	-	-	-	-	115[11]	-	-	-	-
Carcass Characteristics									
HCW, kg	382^{c}	385^{bc}	390^{a}	389^{ab}	391^{a}	1	<0.01	0.40	0.78
LM area, cm^{2}	84.2	84.4	85.3	85.2	84.1	0.05	0.11	0.90	0.13
Fat thickness, cm	1.24	1.28	1.32	1.30	1.33	0.02	0.05	0.43	0.64
Marbling score[12]	454	460	474	469	461	9	0.15	0.79	0.34
Calculated YG[13]	3.25	3.32	3.35	3.33	3.43	0.04	0.20	0.45	0.18

[1] Superscripts represent the overall F-test

[2] 16+20 = 16% CDS + 20% WDGS

[3] Lin = Linear response to CDS inclusion

[4] Quad = Quadratic response to CDS inclusion

[5] *P*-value = comparison of 16% CDS to 16% CDS + 20% WDGS

[6] Predicted NE$_{m}$ values for the diets calculated using NRC (1996) equations, assumed TDN value of corn (88%), and predicted TDN value of CDS

[7] Predicted NE$_{g}$ values for the diets calculated using NRC (1996) equations, assumed TDN value of corn (88%), and predicted TDN value of CDS

[8] Predicted TDN values for CDS compared to assumed TDN value of corn (88%)

[9] Feeding value = % change in feed efficiency / % inclusion by-product

[10] Feeding value of 16+20 compared to 0, representing the feeding value of the by-product combination

[11] Feeding value of 16+20 compared to 16, representing the feeding value of the WDGS

[12] Marbling score: 400 = Slight^{00}, 450 = Slight^{50}, 500 = Small^{00}, etc

[13] YG = 2.50 + (0.9843 * rib fat thickness, cm) + (0.2 * 2.5% KPH) + (0.0084 * HCW, kg) – (0.0496 * LM area, cm^{2})

CHAPTER III. Growing Performance and Metabolism of Steers Fed Increasing Inclusions of Corn Condensed Distillers Solubles in Forage-Based Diets

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Abstract

Two experiments were conducted to: 1) determine the energy value of corn condensed distillers solubles (CDS) and wet distillers grains plus solubles (WDGS) in beef cattle growing diets; and 2) determine the effect of CDS on diet digestibility and rumen fermentation parameters in forage-based diets. In Exp. 1, 120 crossbred steers (initial BW = 366 kg; SD = 30 kg) were utilized in a generalized randomized complete block designed study. Steers were individually fed increasing inclusions of CDS or WDGS at 0, 10, 20, 30, or 40% of the diet displacing corn for 96 d. The basal diet (0% CDS or WDGS) contained 50% grass hay, 40% dry-rolled corn, 5% supplement, 3% treated soybean meal, and 2% corn gluten meal. A quadratic response was observed for DMI ($P = 0.02$) as it increased and was greatest at 20% CDS diet and G:F ($P = 0.02$) as it decreased and was least for the 20% CDS diet. Steers fed CDS quadratically declined in G:F with an 11, 16, 13, and 11% decline compared to corn for the 10, 20, 30, and 40% inclusions of CDS, respectively. A TDN value of 73.7% was calculated for CDS fed at 40% of the diet compared to corn at 83% TDN. Dry-matter intake ($P < 0.01$) and ADG ($P = 0.05$) linearly increased with no change in G:F ($P \geq 0.68$) as WDGS inclusion increased. A TDN value of 77.8% was calculated for WDGS fed at 40% of the diet compared to corn. In Exp. 2, 6 ruminally cannulated steers (BW = 404 kg; SD = 34 kg) were utilized in a 6 x 6 Latin square design to determine the effects of CDS in a forage-based diet on diet digestibility and rumen fermentation parameters. Steers were fed increasing inclusions of CDS at 0, 10, 20, 30, or 40% of the diet displacing corn, and an all grass hay control. Intakes linearly decreased ($P = 0.01$) for DM, OM, and NDF with increasing inclusions of CDS. Total tract digestibility of DM and OM were not different with a linear decline in NDF digestibility ($P < 0.01$) as CDS inclusion increased. Dietary DE (Mcal / kg) linearly increased ($P < 0.01$) with inclusions of CDS. Molar concentration of acetate linearly decreased ($P < 0.01$) while propionate ($P = 0.01$) and butyrate ($P < 0.01$) linearly increased concentration as CDS inclusion increased. Diets containing de-oiled CDS appear to have lower total tract NDF digestibility and less energy, resulting in poorer efficiency, compared to corn in forage-based diets. A 73.7% TDN value was estimated for CDS fed at 40% of the diet compared to corn.

Key words: corn condensed distillers solubles, energy value, forage-based diet, metabolism, wet distillers grains plus solubles

Introduction

Forage-based diets containing corn condensed distillers solubles (CDS) have been reported to result in similar DMI and ADG with 93% the feeding value compared to corn (Conroy et al., 2016); however, when fed in high concentrate diets, CDS improved G:F with 139% the feeding value compared to corn (Pesta et al., 2015). Additionally, Jolly et al. (2013) evaluated the effects of oil removal from CDS (normal 20.1% fat, de-oiled 6.1% fat) at two inclusions (20 and 40%) in forage-based diets and found no effect on performance due to oil removal. Cattle fed normal fat CDS at the 20% inclusion were 13.4% more efficient than the cattle fed the de-oiled CDS, but cattle fed de-oiled CDS still out performed the control cattle at the 20% inclusion with no differences in efficiency due to oil removal at the 40% inclusion. These data would suggest that the fat content of CDS only affects performance of cattle fed CDS at lower inclusions (20%) in forage-based diets (Jolly et al., 2013).

Research available on the digestion of nutrients in CDS fed in forage-based diets are relatively consistent. Gilbery et al. (2006) fed CDS up to 15% of the diet as either a total mixed ration (TMR), or separate from the ration replacing switchgrass hay. When CDS were fed as a TMR, linear increases in ruminal OM, NDF, and ADF digestibility were observed as inclusions increased with no digestibility differences observed when CDS were fed separately. Similarly, Corrigan et al. (2009) fed increasing levels of CDS (0, 5.4, 14.5, 19.1, 22.1%) within dried distillers grains (DDG) and reported linear increases in ruminal DM digestibility, with a quadratic effect for postruminal and total tract DM digestibility at the 14.5 to 19.1% inclusions. These findings supported the concurrent performance study (Corrigan et al., 2009) that resulted in a quadratic improvement in ADG, with maximum ADG at the 15% inclusion.

Previous research on forage-based diets containing wet distillers grains plus solubles (WDGS) has suggested a TDN value for WDGS of 113%. Using this TDN value, a feeding value was then calculated at 137% the value of corn for WDGS in forage-based diets (Ahern et al., 2016). Similar values are needed for CDS. Furthermore, discrepancies between the digestion of nutrients in CDS and performance of cattle fed de-oiled CDS in forage-based diets needs to be evaluated. Thus, the objective of these trials was to evaluate CDS and WDGS in forage-based diets and effects on growing steer performance, as well as, evaluate the effects of CDS in forage-based diets on digestion.

Materials and Methods

The University of Nebraska-Lincoln Institutional Animal Care and Use Committee approved all animal care and management procedures.

Exp. 1

A 96-d growing study utilizing 120 crossbred steers (initial BW = 366 kg; SD = 30 kg) was conducted at the Eastern Nebraska Research and Extension Center feedlot near Mead, NE. Prior to trial initiation, steers were processed with Titanium 5 + PH-M (Elanco Animal Health, Greenfield, IN) for protection against BVD Type I & II, IBR, PI_3, BRSV, *Mannheimia haemolytica*, and *Pasteurella multocida*; Somnu Shield (Elanco Animal Health) for protection against *Haemophilus somnus*; and Dectomax (Zoetis Animal Health, Parsippany, NJ) for parasite control. Steers over-wintered on cornstalks (approximately 110 d) and were supplemented 2.3 kg / d WDGS and then grazed bromegrass pastures (approximately 60 d) until trial initiation. Approximately three weeks prior to trial initiation, steers were trained to individual Calan gates. Forty extra steers, totaling 160 steers, were initially trained and all steers were offered access to individual bunks and feed for two weeks. Steers that did not enter the individual bunks were removed. After two weeks, Calan gate collars were assigned to steers. One hundred and twenty steers were then selected from the pool. Steers were limit fed a common diet of 50% Sweet Bran (Cargill Corn Milling, Blair, NE) and 50% alfalfa hay at 2.0% of BW for 5 d and weighed for 3 consecutive d to limit differences in BW due to gut fill at the beginning and end of the trial (Watson et al., 2013). Steers were stratified by BW and assigned randomly to treatment. Nine treatments were utilized with 13 steers / treatment, except for the 0% by-product diet, which included 16 steers. Steers were implanted with 36 mg zeranol (Ralgro, Merck Animal Health, Madison, NJ) on d 1.

Treatments consisted of increasing inclusions of CDS (0, 10, 20, 30, and 40%) or WDGS (0, 10, 20, 30, and 40%) with the 0% by-product treatments being the same (Table 3.1). By-products (WDGS or CDS) replaced corn in the diets. The nutrient profile of CDS utilized in the study (Aurora Pacific Ethanol, Aurora, NE and Green Plains Ethanol, Wood River, NE) contained 29.7% DM, 30.2% CP, 5.3% fat, and 1.4% S. The nutrient profile of WDGS utilized in the study (Abengoa Ethanol, York, NE) contained 30.6% DM, 37.9% CP, 14.4% fat, and 0.8% S. All diets included 50% grass hay, 3% treated soybean meal (SoyPass; LignoTech USA, Rothschild, WI), 2% corn gluten meal (CGM), and 5% dry supplement. SoyPass and CGM were blended due to their complementarity in AA profiles to ensure RUP exceeded the MP requirements. Supplements were formulated to provide 27.6 mg / kg monensin (Rumensin; Elanco

Animal Health). Urea was added at 0.65% of the diet DM for the 0% by-product diets and 0.33% of the diet for 10% inclusions of CDS or WDGS in order to meet the RDP requirement. Water was added to diets containing 0 or 10% CDS and WDGS for equalization of dietary DM between diets to ensure dry diets held together and sorting was minimized in the diets.

Individual steer feed refusals were sampled weekly and dried at 100^{o}C for 24 h to correct DMI. Feed ingredients were sampled weekly and composited by month. Monthly composites of feed ingredients were dried at 100^{o}C for 24 h to determine DM. Crude protein was analyzed using a TrueSpec micro analyzer (LECO Corp., Saint Joseph, MI) and fat was analyzed using Buckner et al. (2008) procedure.

Data were analyzed using the MIXED procedure of SAS as a randomized block design. The model included treatment as a fixed effect. Steer was the experimental unit. Orthogonal contrasts were used to analyze linear and quadratic effects of CDS or WDGS displacing corn. Similar to previous research (Peterson et al., 2014) NE equations from the NRC (1996) were used to predict energy values, based on animal performance, for each CDS and WDGS diet compared to corn. In order to do so, actual intake, average BW, and TDN values were applied for the 0% by-product diet (DRC = 83% TDN and grass hay = 55% TDN) and then NE adjusters were used to match observed animal performance. Diet NE adjusters were set at 105.7% for both NE_m and NE_g. Corn was replaced with CDS or WDGS at each respective inclusion and TDN values of CDS or WDGS were adjusted until each diet met the observed ADG outcomes, respectively.

Exp. 2

Six ruminally cannulated steers (BW = 404 kg; SD = 34 kg) were utilized in a 6 x 6 Latin square designed digestion trial to determine the effects of CDS inclusion on digestion and rumen fermentation parameters in forage-based diets. Steers were housed individually in 2.4 x 1.5 m^2 concrete slatted-floor pens with ad-libitum access to water. Housing rooms were temperature controlled at 25°C. Treatments (n = 6) consisted of increasing inclusions of CDS at 0, 10, 20, 30, or 40% of the diet displacing corn (Table 3.2). A grass hay control diet without corn or CDS was also included. Grass hay was included at 55% of diet DM in all CDS diets. The control was included to determine possible associative effects between grass hay and corn or CDS. All supplements included 27.6 mg / kg monensin (Rumensin; Elanco Animal Health). Urea and soybean meal were included in supplements at 1.0 and 2.0%, respectively for the control, 0, and 10% CDS diets and included at 0.5 and 1.0%, respectively for the 20 and 30% CDS diets to ensure RDP requirements were met or exceeded.

Steers were fed once daily at 0700 h, feed refusals were collected daily prior to feeding. Refusals were dried for 48 h in a 60°C forced air oven to determine DM and to correct DMI. Diet ingredient samples were collected on d 10 and 12, subsampled, composited by period and frozen at -20°C. A second subsample was dried for 48 h in a forced air oven at 60°C to correct ingredient DM. After trial completion, ingredient samples were freeze dried and ground through a 1-mm screen in a Wiley Mill (Thomas Scientific, Swedesboro, NJ).

Periods consisted of 14 d with 9 d of adaptation and 5 d of collection. Steers were continuously ruminally dosed with 5 g of TiO_2, as an indigestible marker, twice daily at 0800 and 1600 h for a total of 10 g / d of TiO_2. Collections occurred from d 10 to d 14.

During collection on d 10 through 13, fecal samples and rumen fluid samples were collected at 4 times at 0700, 1100, 1500, and 1900 h. Samples were immediately frozen at -20^{o}C. After period completion, fecal samples were composited by day for each steer, freeze dried, and ground through a 1-mm screen using a Wiley Mill (Thomas Scientific). Freeze dried and ground fecal samples were then composited by period for each steer. After trial completion, rumen fluid samples for each steer within each time point were composited by period and immediately analyzed for VFA concentration to prevent further fermentation. Dacron in-situ bags (5 x 10 cm; Ankom Technology, Macedon, NY) containing 0.5 g of grass hay or corn bran, ground to 2-mm, were inserted at 96, 48, 24, 16, 8, and 4 h incubation time points with 2 bags / steer for each feed type and time point starting on d 11 and continuing until d 14. Bags were placed into a mesh bag and inserted into the ventral sac of the rumen. Feed was ground to 2-mm to match masticate grind size. On d 14, at 1500 h, in-situ bags were removed. In-situ bags were machine rinsed 5 times with 3 min per rinse (1 min agitation and 2 min spin) as described by Whittet et al. (2003) and frozen at -20^{o}C. Whole rumen samples were taken and half were dried at 100^{o}C for 24 h to determine DM, the other half were weighed (approximately 300 g) into two 1,000 mL gas bottles fit with Ankom (Ankom Technology) gas production modules and immediately incubated at 39^{o}C for 24 h to determine gas production and gas rate.

Feed and fecal samples, composited by period, were dried at 100^{o}C for 24 h to determine DM and burned in a cool muffle furnace at 600^{o}C for 6 h to determine OM. Additionally, feed and fecal samples were analyzed for NDF as described by Van Soest et al. (1991). Alpha-amylase was added in 0.5 mL increments at the beginning and 30 min into reflux for all fecal, dry-rolled corn, and supplement composites. Sodium sulfite was added to all samples at 0.5 g. Titanium dioxide concentration was determined for fecal samples using a procedure described by Myers et al. (2004), and the concentration of TiO_2 was used to calculate fecal output. Gross heat was determined for feed and fecal samples using a Parr 6400 oxygen bomb calorimeter (Parr Instrument Company, Moline, IL). In-situ bags were analyzed for NDF in an Ankom Fiber Analyzer (Ankom Technology), dried at 100^{o}C for 12 h, and weighed back to determine NDF disappearance. Hourly period composites of rumen fluid samples were prepared as described by Erwin et al. (1961) in triplicates, and analyzed for VFA concentration using a Trace 1300 gas chromatograph (Thermo Fischer Scientific, Inc., Omaha, NE) fitted with a Zebron capillary column (Phenomenex, Torance, CA). The capillary column was 30 m long and 0.32 mm in diameter with a film thickness of 1 µm. All samples included crotonic acid (Sigma Aldrich, St. Louis, MO) as an internal marker. The gas chromatograph ran for a total of 9.75 minutes, inlet and flame ionization detector temperatures were held at 280^{o}C, and oven temperatures increased 8^{o}C per minute starting at 160^{o}C and reaching 200^{o}C. Column carrier flow of Helium (Matheson Tri-Gas, Lincoln, NE) was set to 2.4 mL / min with flow rates of compressed air and hydrogen (Matheson Tri-Gas) set at 350 and 30 mL / min, respectively.

Intakes, fecal output, and digestibility data were analyzed using the GLIMMIX procedure of SAS. The model included period and treatment as independent fixed effects. Steer within period was the experimental unit and steer was considered a random effect. The nonlinear function of SAS was used to calculate in-situ NDF digestibility and rate of digestion using a modified Gompertz model (Milgen and Baumont, 1995). Similarly, the nonlinear function of SAS was used to calculate gas production and rate using a modified Gompertz model (Schofield et al., 1994 and Huhtanen et al., 2008). Nonlinear estimates were then analyzed using GLIMMIX procedure of SAS with the same model as intake, fecal output, and digestibility data. Data for VFA concentration were analyzed as a repeated measure by hour using the GLIMMIX procedure of SAS. Steer and steer within period were the covariance parameters and compound symmetry was used as the covariance structure. The model included time, treatment, and time by treatment interactions, in addition to period as an independent fixed effect. Steer was considered a random effect. Orthogonal contrasts were used to analyze the effect of CDS inclusion, as well as a pairwise comparison between the control and 0% CDS diets on all data. Probabilities were considered significant at $P < 0.10$.

Condensed distillers solubles TDN values were calculated for each diet from DE (Mcal / kg). In order to do so, dietary TDN values were calculated assuming 1 kg TDN equals 4.409 Mcal of DE (NASEM, 2016). Grass hay TDN value was then calculated from the control diet, containing 95% grass hay, assuming it contributed all dietary TDN. The calculated TDN value of grass hay from the control diet (39.01% TDN) was then held constant in all other diets. Dry-rolled corn TDN value was calculated from the 0% CDS diet (64.24% TDN) and similarly held constant in all other diets. Condensed distillers solubles TDN value was then calculated assuming the remainder of the dietary TDN contribution, after grass hay and DRC were subtracted in each diet, was due to CDS respective inclusion in each diet.

Results and Discussion

Exp. 1

Condensed Distillers Solubles Effect

A quadratic increase was observed for DMI (*P* = 0.02) as CDS inclusion increased (Table 3.3). Intakes were greatest for cattle fed CDS at 20% of the diet. Increases in DMI for cattle fed increasing inclusions of CDS, displacing forage, have been previously reported (Jolly et al., 2013). In previous trials with forage-based diets, DMI increased due to less gut fill and an increased energy content of the diet; however, in this trial corn was displaced. Therefore, forage inclusion was not different between diets, inferring that differences in energy content or passage rate between CDS and corn were likely factors in intake regulation. Furthermore, data from Conroy et al. (2016) suggests CDS has an equal energy value to corn in forage-based diets.

Average daily gain and ending BW were not different for increasing inclusions of CDS ($P \geq 0.42$). The lack of response in ADG resulted in a quadratic decrease for G:F (*P* = 0.02) with lower efficiencies for all CDS inclusions compared to the 0% CDS diet. Compared to a 40% inclusion of corn, steers were 11, 16, 13, and 11% less efficient when fed 10, 20, 30, or 40% inclusions of CDS, respectively. These data suggest CDS has less energy than corn, in addition to an apparent negative associative effect between corn and CDS in forage-based diets. Research regarding CDS in forage-based diets has not yet directly compared CDS to corn. Conroy et al. (2016) reported no difference in ADG or G:F comparing CDS to DRC, but CDS was fed at 15% in combination with 25% DRC. Wilken et al. (2009) and Ulmer et al. (2016) both reported decreased ADG and G:F when CDS was fed in combination with cornstalks or a blend of cornstalks and high-protein

DDG compared to WDGS with cornstalks or MDGS alone. Jolly et al. (2013) reported the only data with increasing ADG and G:F for CDS in forage-based diets. Interestingly, CDS displaced brome hay and sorghum silage, which increased the energy content of the diet as CDS inclusion increased.

Similar to Peterson et al. (2014), TDN values were estimated using NRC (1996) equations based off observed performance from steers fed increasing inclusions of CDS. Total digestible nutrient values were estimated at 51.7, 55.2, 68.9, and 73.7% for the 10, 20, 30, and 40% CDS inclusions, respectively. Based on performance of the steers fed CDS, estimates suggest that the energy value of CDS is much less than corn in forage-based diets.

WDGS Effect

Dry matter intake increased linearly ($P < 0.01$) for cattle fed WDGS with a tendency for a quadratic response ($P = 0.07$) at the 30% inclusion (Table 3.4). Similarly, ADG linearly increased ($P = 0.05$) with increasing inclusions of WDGS, although there were no differences in ending BW. Therefore, cattle fed increasing inclusions of WDGS resulted in no difference for G:F, because both DMI and ADG linearly increased. Dissimilarly, previous research has reported no difference in DMI for cattle fed WDGS, displacing corn, in forage-based diets (Bremer et al., 2014). Additionally, research has reported increases in ADG and G:F when comparing WDGS or MDGS to corn in forage-based diets (Ahern et al., 2016 and Bremer et al., 2014). Ahern et al. (2016) reported increases in ADG and G:F in one of three total experiments comparing WDGS to corn with an estimated TDN value of 113.5% for WDGS fed at 15% of the diet. These data suggest that WDGS has a greater energy value than corn in forage-based diets.

Alternatively, TDN values for WDGS in the current study were estimated at 62.5, 73.1, 73.6, and 77.8% for the 10, 20, 30, and 40% inclusions, respectively.

Typical performance of steers fed WDGS in forage-based diets was not observed during the current study. The linear increase in DMI may suggest increased palatability, due to physical characteristics (Klopfenstein et al., 2008), or passage rate of the WDGS diets. Additionally, dietary fat of the 40% WDGS diet was near 5% of the diet at 7.23%, 5% has been suggested to be optimum for maintaining DMI and limiting reduction of NDF digestion (Pantoja et al., 1994). Fat content is a possible explanation for the tendency of a quadratic response in DMI with a numerical decrease in DMI at the 40% WDGS inclusion. Alternatively, the additional intake did not convert to additional gain with only a 6% improvement in ADG for the 40% WDGS diet compared to the 0% WDGS diet. Bremer et al. (2014) observed a 30 and 21% improvement in ADG comparing 40% de-oiled and normal MDGS, respectively to 40% DRC. All diets in the current study contained supplemental RUP (SoyPass and corn gluten meal) to ensure MP requirements were met, and to avoid a performance response due to protein deficiency, thereby ensuring any response was due to energy differences between by-products and DRC. Alternatively, diets in the previous study (Bremer et al., 2014) contained no supplemental RUP, inferring a possible protein response. Interestingly, an average improvement in ADG of 7% was observed comparing WDGS to DRC with supplemental RUP (Ahern et al., 2016). Additionally, Ahern et al. (2016) formulated the DRC and WDGS diets to be isocaloric, assuming WDGS had 130% the energy value of corn. In a meta-analysis of 20 feedlot trials replacing corn with WDGS (Bremer et al., 2011) only two trials resulted in similar performance between WDGS and corn diets (Godsey et al., 2009 and Meyer et al., 2009). This suggests WDGS have a higher energy value than corn in beef cattle diets and performance responses observed during the current study are uncommon.

Exp. 2

Intakes linearly decreased ($P = 0.01$) across all nutrients as CDS inclusion increased, and were greater ($P < 0.01$) in the 0% CDS diet than the grass hay control diet for both DM and OM (Table 3.5). Fecal output linearly decreased for OM ($P < 0.01$) with increasing inclusions of CDS, and was greater ($P \leq 0.03$) in the 0% CDS diet than the grass hay control for both DM and OM. Total tract digestibility of DM and OM was similar across CDS inclusion ($P \geq 0.24$), whereas NDF digestibility linearly decreased ($P < 0.01$) with increasing inclusion of CDS. Additionally, DM and OM digestibility were greater ($P < 0.01$) in the 0% CDS diet than the grass hay control. The control diet consisted of grass hay and supplemental urea with no corn or CDS. Therefore, dissimilarities in intake and digestibility between the control and 0% CDS diet are logical. Although previous research has been variable, in general most of the data suggest an increase in digestibility when CDS displaced corn in finishing diets (Ham et al., 1994) or was supplemented in forage-based diets with no concentrate (Gilbery et al., 2006 and Corrigan et al., 2009). Furthermore, performance data also suggests increased digestibility of CDS nutrients because cattle fed CDS in place of forage (Jolly et al., 2013) or DGS (Corrigan et al., 2009) also had increased gains. Alternatively, the current experiment illustrates that de-oiled CDS fed in forage-based diets, displacing DRC, does not improve nutrient digestibility and may actually hinder NDF digestibility at inclusions greater than 20% of the diet.

Energy intake was not different with increasing inclusions of CDS ($P \geq 0.12$) with the 20% inclusion having the numerically greatest energy intake. As expected, energy intake of the grass hay control was less ($P < 0.01$) than the 0% CDS diet. Similarly, DE intake (Mcal / d) was not different with increasing inclusions of CDS ($P \geq 0.23$) with the 0% CDS diet having greater ($P < 0.01$) DE intake than the grass hay control. Dietary DE (Mcal / kg) linearly increased ($P < 0.01$) as CDS inclusion increased with the grass hay control being less ($P < 0.01$) than the 0% CDS diet. This linear response to dietary DE is due to the linear decline in intake as CDS inclusion increased. Additionally, TDN values calculated from DE (Mcal / kg) for CDS were 118.3, 96.8, 85.7, and 91.3% for inclusions of CDS at 10, 20, 30, and 40% of diet DM, respectively. These TDN values largely differ from the predicted TDN values from Exp.1, which were 51.7, 55.2, 68.9, and 73.7% for inclusions of CDS at 10, 20, 30, and 40% of diet DM, respectively. Differences in intakes between Exp. 1 and Exp. 2 make interpretation of the data challenging. During Exp. 1, steers had a quadratic increase in DMI with the greatest intakes achieved at the 20% CDS diet, whereas intakes during Exp. 2 linearly declined with increasing inclusions of CDS. Nevertheless, these data suggest that CDS has a greater energy value than DRC in forage-based diets. These data are in contrast to Exp. 1, in which steers performed worse as CDS inclusions increased with a quadratic reduction in G:F.

Extent (96 h incubation) and rate of in-situ NDF digestibility were not different ($P \geq 0.21$) with increasing inclusions of CDS when grass hay was used as a substrate (Table 3.6). Rate of in-situ digestibility was greater ($P = 0.04$) in the grass hay control compared to 0% CDS diet when grass hay was used as a substrate. Extent and rate of in-situ NDF digestibility linearly increased ($P \leq 0.05$) with increasing inclusions of CDS and were greater ($P \leq 0.01$) in the grass hay control compared to the 0% CDS diet when corn bran was the substrate. These data suggest ruminal NDF digestion is not negatively affected by increasing inclusions of CDS and more digestible feedstuffs, such as corn bran, have improved digestibility with CDS. Biologically, it is unlikely that the linear decline in total tract NDF digestibility is due to postruminal digestion. This suggests that other factors, such as increased ruminal passage rate or differing effects on cellulose and hemicellulose when fed increasing inclusions of CDS, may better explain the discrepancies during this experiment between total tract and in-situ NDF digestibility.

Molar concentration of acetate linearly decreased ($P < 0.01$) while propionate and butyrate linearly increased ($P \leq 0.01$) with increasing inclusions of CDS (Table 3.7). This logically led to a linear decrease ($P < 0.01$) in the acetate to propionate ratio (A:P). Acetate, propionate, and butyrate were greater ($P \leq 0.03$) in the 0% CDS diet compared to the grass hay control along with a lower A:P ($P < 0.01$). Increases in propionate concentration and reductions in A:P are consistent with previous work (Ham et al., 1994). However, these increases in propionate concentration did not translate to improved performance during Exp. 1, potentially due to increases in concentration of butyrate or differences in total VFA production compared to previous CDS research. Total gas production was greater ($P = 0.03$) for the grass hay control compared to the 0% CDS diet with no linear or quadratic relationships ($P \geq 0.18$) as CDS inclusion increased. Gas rate, expressed as percentage per hour, linearly increased ($P = 0.07$) with CDS inclusion.

In summary, results from Exp. 1 conclude that CDS has less energy than corn in forage-based diets. Additionally, steers fed WDGS did not perform as expected with diminished feed efficiencies compared to the corn control. Results from Exp. 2

determined that increasing inclusions of CDS linearly decreased total tract NDF digestibility with no effect on in-situ NDF digestibility of grass hay. Furthermore, increasing inclusions of CDS resulted in greater digestible energy of the diet compared to DRC with linear decreases in A:P. Overall, data from the two experiments make it difficult to propose a reason for the negative effects of CDS in forage-based diets. Nonetheless, CDS has less energy than corn in forage-based diets and may negatively impact fiber digestion.

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Table 3.1. Dietary composition (DM basis) of treatments fed to yearling steers (Exp. 1)

		CDS, % Inclusion				WDGS, % Inclusion			
Ingredient[1]	0	10	20	30	40	10	20	30	40
DRC	40	30	20	10	-	30	20	10	-
CDS[2]	-	10	20	30	40	-	-	-	-
WDGS[3]	-	-	-	-	-	10	20	30	40
Grass Hay	50	50	50	50	50	50	50	50	50
SoyPass[4]	3	3	3	3	3	3	3	3	3
CGM	2	2	2	2	2	2	2	2	2
Supplement[5]	-	-	-	-	-	-	-	-	-
Fine Ground Corn	2.446	3.096	3.096	3.096	3.096	3.096	3.096	3.096	3.096
Limestone	1.400	1.400	1.400	1.400	1.400	1.400	1.400	1.400	1.400
Tallow	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Urea	0.650	-	-	-	-	-	-	-	-
Salt	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Beef Trace Mineral[6]	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Vitamin A-D-E[7]	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-90[8]	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Nutrient Composition, %									
DM[9]	66.1	66.1	66.1	58.3	52.2	66.1	64.2	56.2	50.0
CP	13.3	13.8	16.0	18.1	20.3	14.6	17.5	20.4	23.4
Fat	3.16	3.31	3.41	3.51	3.61	4.21	5.22	6.22	7.23
Sulfur	0.20	0.35	0.50	0.65	0.80	0.27	0.33	0.40	0.47

[1] DRC = dry-rolled corn, CDS = condensed distillers solubles (de-oiled), WDGS = wet distillers grains plus solubles, CGM = corn gluten meal

[2] CP = 30.2%, Fat = 5.3%, S = 1.4%

[3] CP = 37.9%, Fat = 14.4%, S = 0.8%

[4] SoyPass (Lignotech USA, Rothschild, WI) treated soybean meal that is a highly digestible RUP supplement

[5] Supplement fed at 5% diet DM

[6] Premix contained 10% Mg, 6% Zn, 4.5% Mn, 0.5% Cu, 0.3% I, and 0.05% Co

[7] Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per g

[8] Formulated to supply monensin (Rumensin; Elanco Animal Health) at 27.6 mg / kg

[9] Water was added to 0% by-product, 10% CDS, and 10% WDGS diets for equalization of dietary DM

Table 3.2. Dietary composition (DM basis) of treatments fed to cannulated steers (Exp. 2)

		CDS, % Inclusion				
Ingredient[1]	Control	0	10	20	30	40
DRC	-	40	30	20	10	-
CDS	-	0	10	20	30	40
Grass Hay	95	55	55	55	55	55
Supplement[2]	-	-	-	-	-	-
Fine Ground Corn	0.116	0.116	0.116	1.471	1.471	2.826
Limestone	1.380	1.380	1.380	1.525	1.525	1.670
Tallow	0.125	0.125	0.125	0.125	0.125	0.125
Urea	1.000	1.000	1.000	0.500	0.500	-
Soybean Meal	2.000	2.000	2.000	1.000	1.000	-
Salt	0.300	0.300	0.300	0.300	0.300	0.300
Beef Trace Mineral[3]	0.050	0.050	0.050	0.050	0.050	0.050
Vitamin A-D-E[4]	0.015	0.015	0.015	0.015	0.015	0.015
Rumensin-90[5]	0.014	0.014	0.014	0.014	0.014	0.014
Nutrient Composition, %						
DM[6]	70.0	70.0	70.0	66.1	58.4	52.2
OM	88.6	92.0	90.8	89.6	88.5	87.3
NDF	67.8	45.8	45.0	44.3	43.5	42.7
CP	13.6	12.9	15.7	16.6	19.3	20.3

[1] DRC = dry-rolled corn, CDS = condensed distillers solubles (de-oiled)

[2] Supplement fed at 5% diet DM

[3] Premix contained 10% Mg, 6% Zn, 4.5% Mn, 0.5% Cu, 0.3% I, and 0.05% Co

[4] Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per g

[5] Formulated to supply monensin (Rumensin; Elanco Animal Health) at 27.6 mg / kg

[6] Water was added to control, 0, and 10% CDS diets for equalization of dietary DM

Table 3.3. Effect of condensed distillers solubles (CDS) inclusion on performance of growing steers (Exp. 1)

	CDS, % Inclusion						*CDS Effect*	
Performance	0	10	20	30	40	SEM	Lin[1]	Quad[2]
Initial BW, kg	366	365	366	367	366	9	0.95	0.96
Final BW, kg	473	464	469	468	480	9	0.92	0.68
DMI, kg / d	9.3	9.7	10.7	10.2	10.1	0.3	0.04	0.02
ADG, kg	1.11	1.03	1.07	1.06	1.07	0.04	0.72	0.42
G:F	0.119	0.106	0.100	0.104	0.106	0.005	0.07	0.02
CDS TDN[3], %	-	51.7	55.2	68.9	73.7	-	-	-

[1] Linear effect of CDS

[2] Quadratic effect of CDS

[3] Predicted TDN values for CDS compared to assumed corn TDN (83%)

Table 3.4. Effect of wet distillers grains plus solubles (WDGS) inclusion on performance of growing steers (Exp. 1)

	WDGS, % Inclusion						*WDGS Effect*	
Performance	0	10	20	30	40	SEM	Lin[1]	Quad[2]
Initial BW, kg	366	367	365	365	366	9	0.96	0.92
Final BW, kg	473	475	479	484	480	9	0.39	0.76
DMI, kg / d	9.3	10.0	10.3	10.8	10.3	0.3	<0.01	0.07
ADG, kg	1.11	1.12	1.18	1.23	1.18	0.04	0.05	0.37
G:F	0.119	0.113	0.115	0.114	0.115	0.005	0.71	0.68
WDGS TDN[3], %	-	62.5	73.1	73.6	77.8	-	-	-

[1] Linear effect of WDGS

[2] Quadratic effect of WDGS

[3] Predicted TDN values for WDGS compared to assumed corn TDN (83%)

Table 3.5. Effect of condensed distillers solubles (CDS) inclusion on intake and total tract digestibility (Exp. 2)

		CDS, % Inclusion						*CDS Effect*		*Control vs. 0*
	Control	0	10	20	30	40	SEM	Lin[1]	Quad[2]	*P*-value[3]
DM										
Intake, kg	6.8	9.5	9.4	9.7	8.6	8.2	0.5	0.01	0.16	<0.01
Fecal output, kg	3.8	4.4	4.1	4.4	4.3	3.9	0.2	0.12	0.20	0.03
Digestibility, %	43.7	52.8	55.8	53.8	50.1	52.3	2.1	0.24	0.61	<0.01
OM										
Intake, kg	6.1	8.7	8.5	8.7	7.6	7.2	0.5	<0.01	0.18	<0.01
Fecal output, kg	3.2	3.8	3.6	3.7	3.6	3.2	0.2	<0.01	0.21	<0.01
Digestibility, %	46.9	55.4	58.2	56.5	53.4	55.5	2.0	0.37	0.65	<0.01
NDF										
Intake, kg	4.6	4.3	4.2	4.3	3.7	3.5	0.3	<0.01	0.18	0.24
Fecal output, kg	2.4	2.2	2.2	2.4	2.4	2.2	0.1	0.96	0.24	0.37
Digestibility, %	48.2	47.5	48.7	43.3	37.2	37.5	2.7	<0.01	0.78	0.84
Energy										
Intake, Mcal	27.5	39.5	40.3	42.6	38.5	37.8	2.3	0.31	0.12	<0.01
DE, Mcal / d	11.9	21.0	22.7	24.2	20.9	21.9	1.8	0.98	0.23	<0.01
DE, Mcal / kg	1.72	2.17	2.40	2.45	2.45	2.64	0.09	<0.01	0.59	<0.01
CDS TDN[4], %	-	-	118.3	96.8	85.7	91.3	-	-	-	-

[1] Linear effect of CDS without control on response variables

[2] Quadratic effect of CDS without control on response variables

[3] Pairwise comparison of control and 0% CDS diets

[4] Calculated TDN values for CDS from measured dietary DE values assuming calculated TDN value of DRC and grass hay stay constant

Table 3.6. Effect of condensed distillers solubles (CDS) inclusion on the extent and rate of in-situ NDF digestion of grass hay and corn bran (Exp. 2)

		CDS, % Inclusion						*CDS Effect*		*Control vs. 0*
	Control	0	10	20	30	40	SEM	Lin[1]	Quad[2]	*P*-value[3]
Grass Hay										
96 h NDFD[4], %	61.7	62.3	62.0	60.9	62.7	62.1	0.6	0.81	0.23	0.39
Rate, % / h	3.22	2.47	2.82	2.52	2.98	2.87	0.24	0.21	0.86	0.04
Corn Bran										
96 h NDFD[5], %	91.6	89.5	90.2	92.0	92.3	92.6	0.5	<0.01	0.16	<0.01
Rate, % / h	3.82	3.13	3.61	3.45	3.83	3.60	0.22	0.05	0.21	0.01

[1] Linear effect of CDS without control on response variables

[2] Quadratic effect of CDS without control on response variables

[3] Pairwise comparison of control and 0% CDS diets

[4] NDFD = extent of in-situ neutral detergent fiber digestibility of grass hay

[5] NDFD = extent of in-situ neutral detergent fiber digestibility of corn bran

Table 3.7. Main effects of condensed distillers solubles (CDS) inclusion on ruminal VFA molar concentration, amount, and rate of ruminal gas production (Exp. 2)

		CDS, % Inclusion							*CDS Effect*		*Control vs. 0*
	Control	0	10	20	30	40	SEM	Hour*Trt	Lin[1]	Quad[2]	*P*-value[3]
Ruminal VFA[4], mmol / 100 mol											
Acetate	54.3	61.2	58.2	52.4	48.4	47.0	2.7	0.06	<0.01	0.55	0.03
Propionate	13.6	18.6	19.2	20.1	20.1	22.7	1.4	0.03	0.01	0.45	<0.01
Butyrate	5.0	9.5	11.7	12.9	11.8	13.0	0.9	0.08	<0.01	0.08	<0.01
A:P[5]	4.02	3.42	3.03	2.64	2.47	2.14	0.10	<0.01	<0.01	0.34	<0.01
Gas Production[6]											
Total, mL	18.9	15.5	15.5	16.5	14.7	13.5	1.4	-	0.18	0.21	0.03
Rate, % / h	18.7	18.1	19.6	18.3	19.0	21.9	1.2	-	0.07	0.28	0.72

[1] Linear effect of CDS without control on response variables

[2] Quadratic effect of CDS without control on response variables

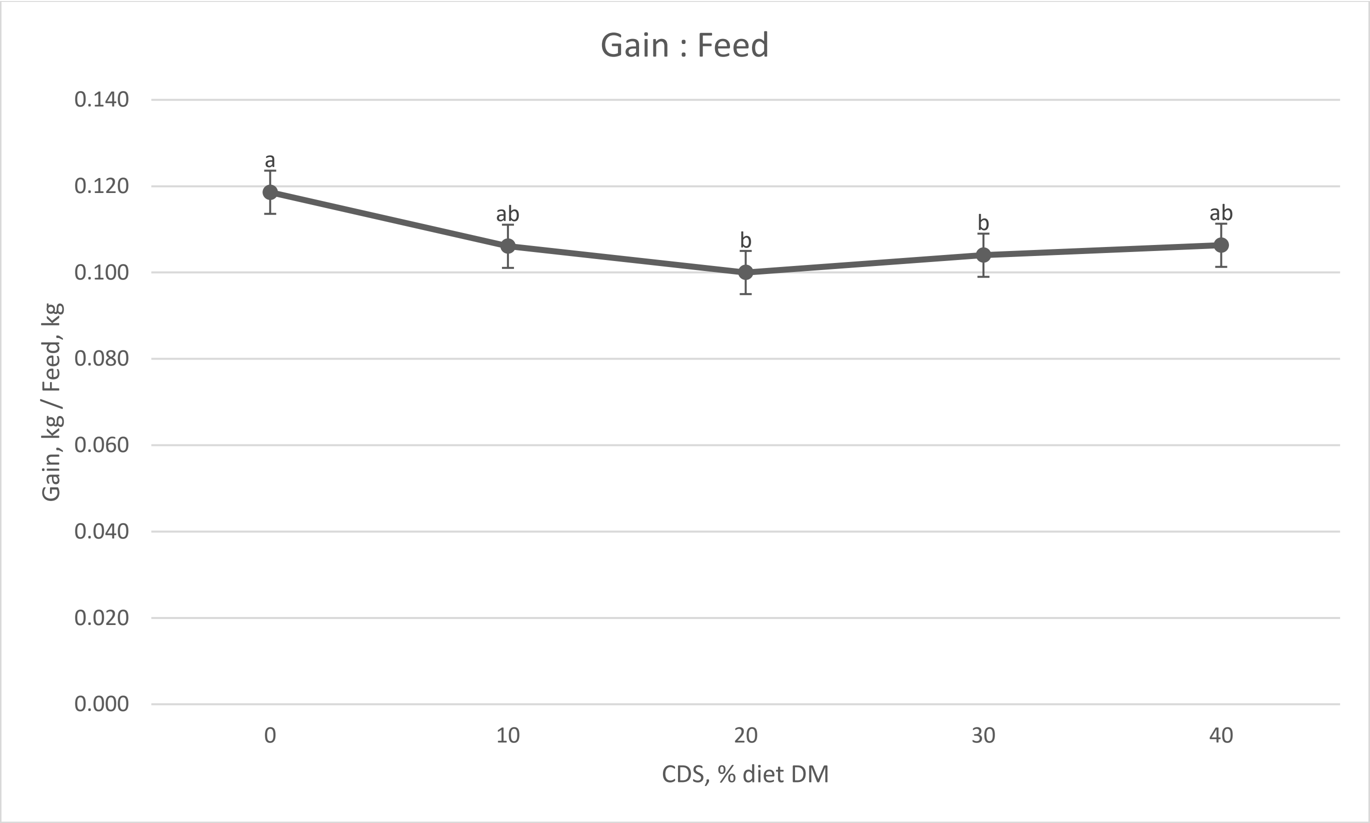
[3] Pairwise comparison of control and 0% CDS diets

[4] VFA concentration sampled at 0700, 1100, 1500, and 1800 h

[5] A:P = acetate to propionate ratio

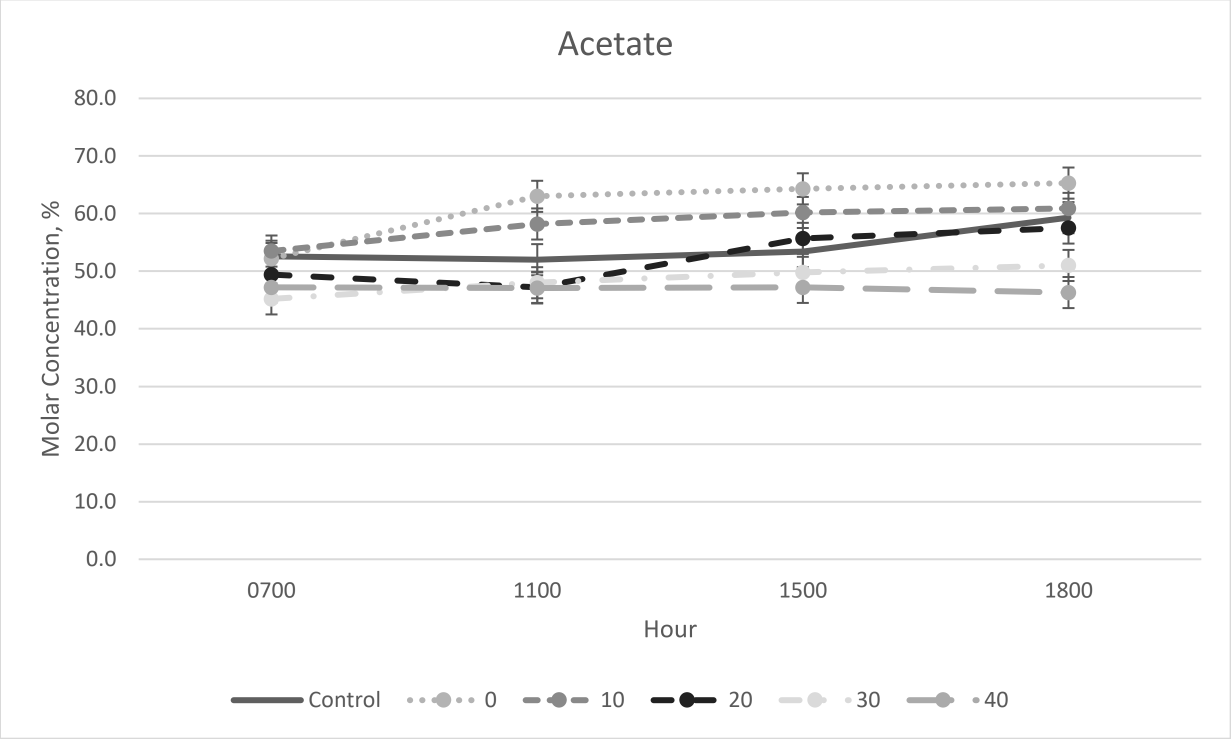
[6] Whole rumen contents sampled on d 14 at 1500 h, incubated in gas bottles with Ankom (Ankom Technology, Macedon, NY) gas production modules for 24 h, calculated mL gas / g whole rumen content (DM) from cumulative pressure using the Ideal gas law and Avogadro's law, then analyzed mL / g DM using Gompertz model to estimate total and rate of gas production

Figure 3.1. Effect of condensed distillers solubles (CDS) inclusion on Gain:Feed of growing steers (Exp. 1)



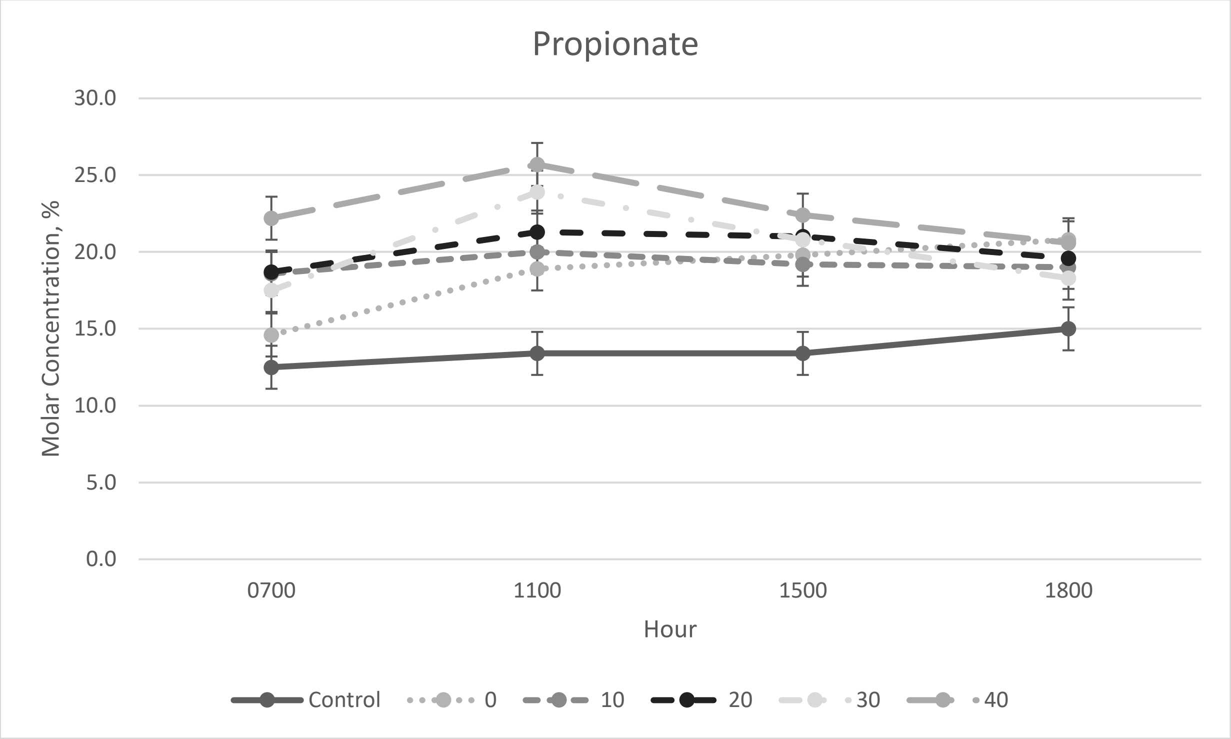
Description: Superscripts represent the overall F-test. Significance was set at $P \leq 0.05$. Treatments included 0, 10, 20, 30, or 40% inclusion of CDS displacing DRC with all diets containing 50% grass hay.

Figure 3.2. Simple effect of condensed distillers solubles (CDS) inclusion on Acetate molar concentration at 0700, 1100, 1500, and 1800 h (Exp. 2)



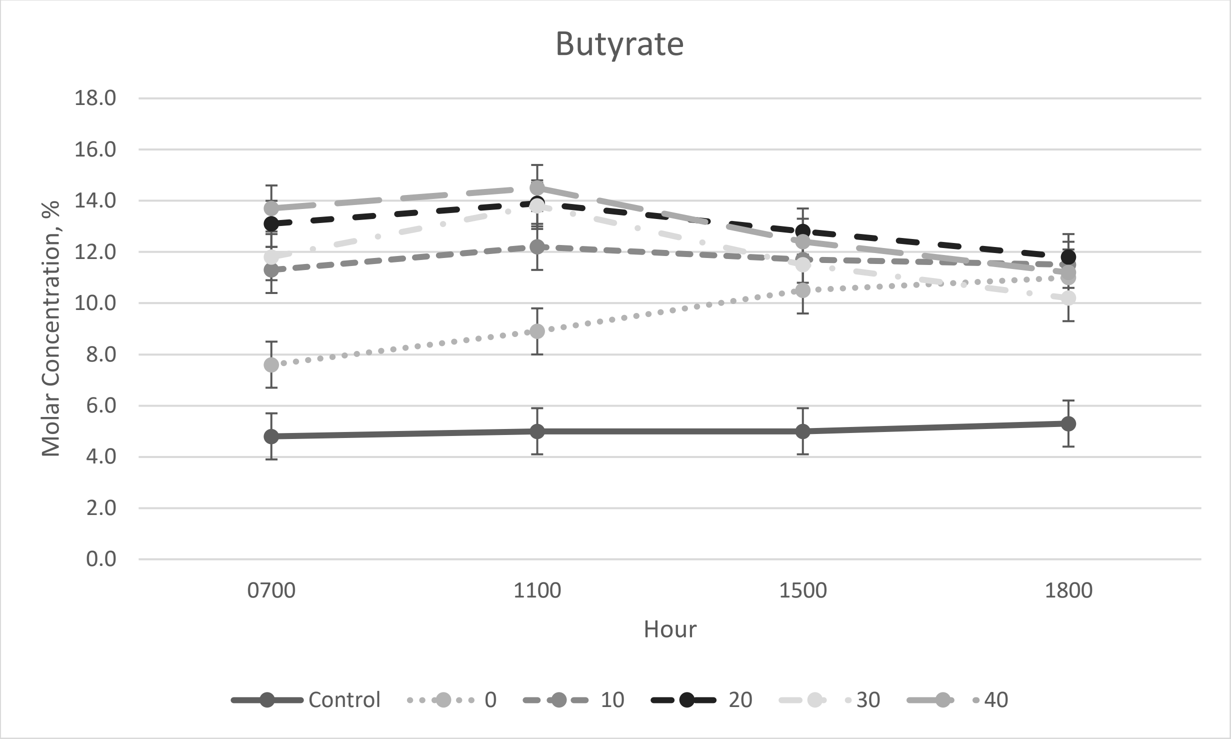
Description: Treatments included 0, 10, 20, 30, and 40% inclusions of CDS displacing DRC with all diets containing 55% grass hay. The control diet was 95% grass hay. There was an hour x treatment interaction ($P = 0.06$) for molar concentration of acetate. Treatment differences within time points were significant at ($P \leq 0.05$). At 0700 h, molar concentration of acetate were greatest for the control, 0, 10, 20, and 40% CDS diets and least for the 30% CDS diet. At 1100 h, molar concentration of acetate were greatest for the 0 and 10% CDS diets and least for the 20, 30, and 40% CDS diets. The control diet was intermediate, although not different from the 10, 20, 30, and 40% CDS diets. At 1500 h, molar concentration of acetate were greatest for the 0 and 10% CDS diets and least for the 40% CDS diet. The control, 10, 20, and 30% diets were intermediate with the control and 30% CDS diet not different from the 40% CDS diet. At 1800 h, molar concentration of acetate were greatest for the control, 0, 10, and 20% CDS diets and least for the 40% CDS diet. The 30% CDS diet was intermediate but not different from the 20 and 40% CDS diets.

Figure 3.3. Simple effect of condensed distillers solubles (CDS) inclusion on Propionate molar concentration at 0700, 1100, 1500, and 1800 h (Exp. 2)



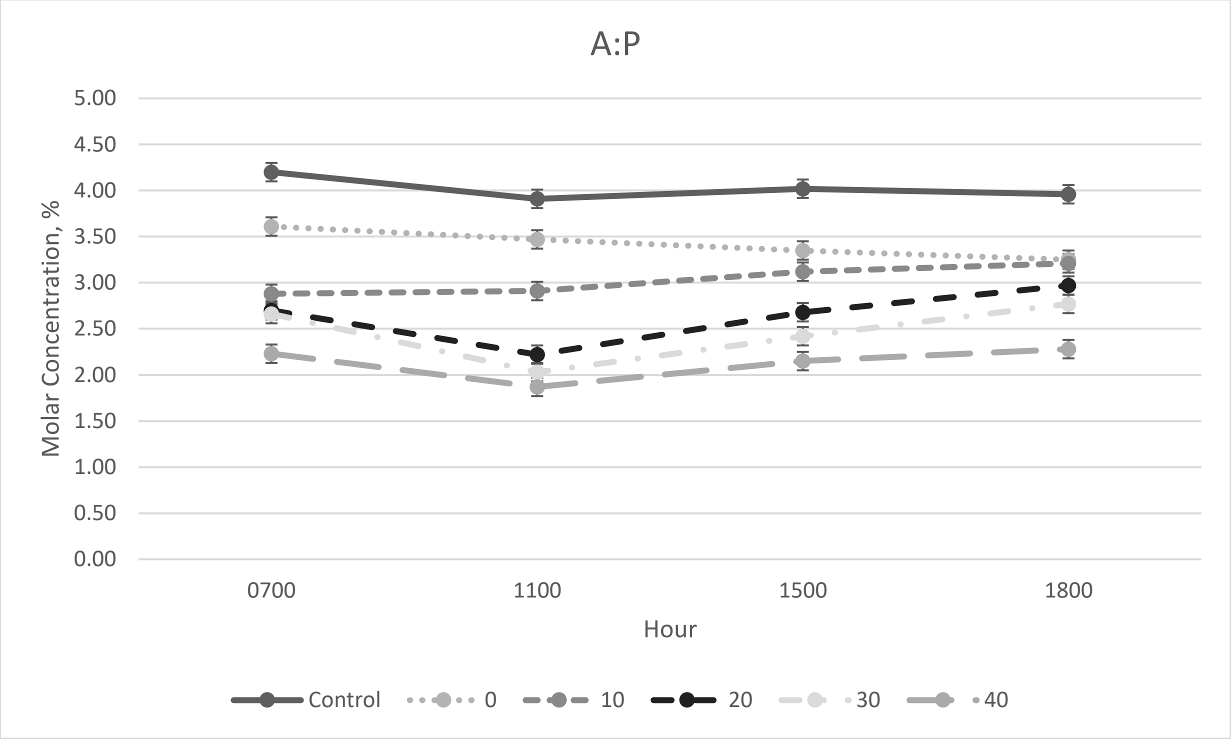
Description: Treatments included 0, 10, 20, 30, and 40% inclusions of CDS displacing DRC with all diets containing 55% grass hay. The control diet was all grass hay. There was an hour x treatment interaction ($P = 0.03$) for molar concentration of propionate. Treatment differences within time points were significant at ($P \leq 0.05$). At 0700 h, molar concentration of propionate were greatest for the 10, 20, and 40% CDS diets and least for the control and 0% CDS diets. The 30% CDS diets was intermediate, although no different from the 10 and 20% CDS diets. At 1100 h, molar concentration of propionate were greatest for the 30 and 40% CDS diets and least for the control diet. The 0, 10, and 20% CDS diets were intermediate. At 1500 h, molar concentration of propionate were greatest for the 0, 10, 20, 30, and 40% CDS diets and least for the control diet. At 1800 h, molar concentration of propionate were greatest for the 0, 20, and 40% CDS diets and least for the control. The 10 and 30% CDS diets were intermediate but not different from the 0, 20, and 40% CDS diets or the control.

Figure 3.4. Simple effect of condensed distillers solubles (CDS) inclusion on Butyrate molar concentration at 0700, 1100, 1500, and 1800 h (Exp. 2)



Description: Treatments included 0, 10, 20, 30, and 40% inclusions of CDS displacing DRC with all diets containing 55% grass hay. The control diet was all grass hay. There was an hour x treatment interaction (*P* = 0.08) for molar concentration of butyrate. Treatment differences within time points were significant at ($P \leq 0.05$). At 0700 h, molar concentration of butyrate were greatest for the 10, 20, 30, and 40% CDS diets and least for the control diet. The 0% CDS diet was intermediate. At 1100 h, molar concentration of butyrate were greatest for the 10, 20, 30, and 40% CDS diets and least for the control diet. The 0% CDS diet was intermediate. At 1500 h, molar concentration of butyrate were greatest for the 0, 10, 20, 30, and 40% CDS diets and least for the control diet. At 1800 h, molar concentration of butyrate were greatest for the 0, 10, 20, 30, and 40% CDS diets and least for the control.

Figure 3.5. Simple effect of condensed distillers solubles (CDS) inclusion on Acetate:Propionate molar concentration at 0700, 1100, 1500, and 1800 h (Exp. 2)



Description: Treatments included 0, 10, 20, 30, and 40% inclusions of CDS displacing DRC with all diets containing 55% grass hay. The control diet was all grass hay. There was an hour x treatment interaction (*P* < 0.01) for A:P. Treatment differences within time points were significant at (*P* ≤ 0.05). At 0700 h, A:P was greatest for the control diet followed by the 0% CDS diet and least for the 40% CDS diet. The 10, 20, and 30% CDS diets were intermediate. At 1100 h, A:P was greatest for the control diet, followed by the 0% CDS diet, then the 10% CDS diet and least for the 20, 30, and 40% CDS diets. At 1500 h, A:P was greatest for the control diet and least for the 30 and 40% CDS diets. The 0, 10, and 20% CDS diets were intermediate with the 0 and 10% CDS diets being greater than the 20% CDS diet and the 20% CDS diet no different from the 30% CDS diet. At 1800 h, A:P was greatest for the control and least for the 40% CDS diet. The 0, 10, 20, and 30% CDS diets were intermediate with the 0 and 10% CDS diets being greater than the 20 and 30% CDS diet.

CHAPTER IV. Forage Production and Calf Gains Grazing Oats Following Corn Harvest

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Abstract

A study was conducted to evaluate forage production and calf gains on a double-cropped annual forage following corn silage (CS) or high-moisture corn (HMC) production. An irrigated corn field was split in half and harvested as either CS or HMC. Cash crops were sampled to determine the effects of cover or grazing on subsequent yields. Following harvest of CS (September 6) and HMC (September 20) oats were drilled. Three treatments were applied: cover / grazed (Cov-G), cover / no graze (Cov-NG), or no cover / no graze (NC-NG). Subsequent soybean yields were not different among treatments ($P \geq 0.11$) with an average grain yield of 4,566 kg DM / ha and an average stover yield of 3,270 kg DM / ha. Due to previous grazing restrictions, subsequent corn yields for CS and HMC were a comparison between previous cover or no cover without the addition of grazing and were not different ($P \geq 0.35$). Averaged across treatments of either cover or no cover, CS yielded 18, 375 kg DM / ha, HMC grain yielded 14,663 kg DM / ha, and HMC stover yielded 8,655 kg DM / ha. Forage production was greater ($P < 0.01$) for oats seeded after CS at 2,547 kg DM / ha compared to HMC at 597 kg DM / ha. On November 2, fifty-five crossbred steers (initial BW = 228 kg; SD = 13 kg) were turned out and grazed for 42 d. Steers were allocated 819 kg DM / animal of oats on the CS side and 187 kg DM / animal of oats with 617 kg DM / animal of corn residue on the HMC side. Steers had greater ADG ($P = 0.05$) grazing oats following CS compared to HMC at 1.10 and 0.84 kg / d, respectively. Additionally, ending BW was greater ($P = 0.04$) for steers grazing oats following CS compared to HMC at 274 and 263 kg, respectively. Gain per hectare was not different between treatments ($P = 0.14$) with gains of 144 and 113 kg / ha after CS and HMC, respectively.

Double-cropped annual forages following corn silage provide opportunities for additional gain on growing calves with greater forage production than high-moisture corn and no apparent impacts on subsequent cash crop yields.

Key words: corn silage, double-cropped forages, high-moisture corn, ADG

Introduction

Grazing fall planted double-cropped annual forages offer opportunities for livestock producers looking to extend their grazing season and add BW before feedlot placement or looking for additional forage between grazing summer range and winter residue, such as cornstalks. Additionally, agronomic advantages are available for land owners through economic incentives (grazing rent) and possible improvements in soil characteristics.

Koch et al. (2002), in a 10-yr study near Powell, WY, determined that forage production of brassicas, seeded after July 20th, declined by 770 kg / ha per week. Researchers concluded that planting date was the single largest factor in fall double-cropped forage production. In Nebraska, corn and soybeans are the most common cash crops. Unfortunately, dry corn and soybean grain production offer limited opportunities in growing degree days for double-cropped forage production. Harvesting corn as corn silage or high-moisture corn is an opportunity for Nebraska producers to utilize double-cropped annual forages in the fall. Fae et al. (2009) conducted a 2-yr study grazing annual ryegrass and a winter rye-oat mix following corn silage and evaluated dairy heifer gain, forage production, and subsequent corn silage yield. Heifers gained 0.81 kg / d with no differences between forages. Additionally, the winter rye-oat mix resulted in 38-73% greater yield offering an additional 37 d of grazing. Authors attributed the increase in spring growth from the winter rye-oat mix to the additional yield and grazing days. Furthermore, there were no differences in subsequent yield of corn silage due to the double-cropped forage or implementation of grazing. Additionally, Ulmer et al. (2016) conducted a 2-yr study looking at the effects of double-cropped oats or an oat-turnip mix following corn silage and high-moisture corn harvest on steer gains, forage production, and subsequent cash crop yield. Following corn silage, oats and the oat-turnip mix averaged 2,124 kg DM / ha of forage by late-October with steers gaining 0.59 kg / d. Following high-moisture corn, forage production averaged 537 kg DM / ha by late-October with steers gaining 0.33 kg / d. Steers grazed for 62 d in year 2 only. No differences were found for subsequent corn silage or high-moisture corn yield.

This research suggests that early harvested corn production systems provide adequate forage production from fall double-cropped forages for favorable calf gains. Thus, the objective of this study was to determine calf gains and forage production of oats following corn silage and high-moisture corn and the effect on subsequent yield.

Materials and Methods

The University of Nebraska-Lincoln Institutional Animal Care and Use Committee approved all animal care and management procedures.

Field details

An irrigated field located at the Eastern Nebraska Research and Extension Center near Mead, NE was utilized to determine calf gains and forage production from oats following corn silage (CS) and high-moisture corn (HMC) harvest and the effects on subsequent cash crop yield. The 42-hectare field was split in half in a corn (21-ha) and soybean (21-ha) rotation. Corn and soybeans were planted with 76-cm row spacing. The half of the field planted to corn was split again into CS (11-ha) and HMC (10-ha). Each treatment (n = 6) contained 3 reps for cash crop sampling and 2 reps for forage sampling. Replications were different between cash crop and forage sampling in order to increase statistical power in the crop sampling for a soil experiment not presented here and to provide larger paddocks for grazing. Treatments included no cover/no graze (NC-NG), cover/no graze (Cov-NG), and cover/graze (Cov-G) for both CS and HMC. Treatments were initially applied in 2013; however, only data from 2016 will be reported. In 2013, corn was planted on the west half, double-cropped with wheat, and grazed according to treatment. Soybeans were planted on the east half. In 2014, corn was planted on the east half, double-cropped with an oat-brassica mix, and not grazed due to a herbicide restriction. Soybeans were planted on the west half. In 2015, corn was planted on the west half, double-cropped with oats, and grazed according to treatment. Soybeans were planted on the east half. In 2016, corn was planted on the east half, double-cropped with oats, and grazed according to treatment. Soybeans were planted on the west half. Horsepower oats were drilled at 108 kg / ha on September 6, 2016 and September 20, 2016 following CS and HMC harvest, respectively. Following seeding of oats, 32% urea-ammonium nitrate was applied at a rate of 44.8 kg / ha.

Forage production measures

Initial forage biomass was sampled on October 25, 2016 to calculate forage production and determine stocking rates. Randomly selected areas (0.91 x 0.57 m) were sampled for each treatment (2 rep / treatment) with cover (CS Cov-NG, CS Cov-G, HMC NC-NG, HMC Cov-NG, and HMC Cov-G). Grazed treatments (4.6 ha / rep) were sampled at 5 locations / rep and no graze treatments (0.3 ha / rep) were sampled at 3 locations / rep due to differences in paddock size. Forage was clipped at ground level. All samples were then dried for 48 h in a 60°C oven and weighed. Initial available corn stover was estimated based on previous research (Wilson et al., 2004); assuming 3.63 kg of leaf and husk residue per 25.4 kg of total corn plant biomass with a corn yield of 13,860 kg per hectare. After the grazing period, forage biomass was sampled and transects taken. Final forage biomass was sampled the same as initial forage biomass. Additionally, corn stover was sampled on the HMC side to account for the amount of total residue removed. Transects were taken using a 30.5 m tape stretched across randomly selected areas in each treatment. At each 0.30 m, soil was either determined to be covered or not, these were then averaged to give a percentage cover at each area. Similar to biomass samples, 5 transects / rep were taken in the grazed treatments and 3 transects / rep were taken in the no graze treatments.

Because planting date differed by treatment, growing degree days (GDD) were calculated for each treatment. Growing degree days are used to determine the number of days a plant has to grow based off the average temperature. Therefore, the calculation for GDD is the average daily temperature (^{o}C) minus 10 and then summed across every day. The summation of these GDD was from seeding date to sampling date. Additionally, the summation of GDD then had to be divided by 0.5556 to adjust for the non-linear relationship between ^{o}F and ^{o}C because the GDD calculation is based on ^{o}F.

Forage quality samples were taken on October 25, 2016 for each treatment (2 rep / treatment) containing oats (CS Cov-NG, CS Cov-G, HMC Cov-NG, and HMC Cov-G). Samples were taken by randomly clipping oats from the ground level uniformly across each paddock. Samples were then freeze dried and ground through a 1-mm screen in a Wiley Mill. Furthermore, samples were dried at 100^{o}C for 24 h to determine DM and burned in a cool muffle furnace at 600^{o}C for 6 h to determine OM. Additionally, samples were analyzed for NDF as described by Van Soest et al. (1991) and ADF as described by

Van Soest (1963). Sodium sulfite was added to all samples at 0.5 g. Lastly, samples were analyzed using a TrueSpec micro analyzer (LECO Corp.) to determine CP.

Cash crop yield

Corn and soybean yields were collected by hand harvest methods (Lauer, 2002) to determine subsequent cash crop yields following the imposed treatments. Treatments were the same as previously stated (NC-NG, Cov-G, and Cov-NG) for both CS and HMC with 3 reps / treatment. Hand harvest of corn occurred on August 31, 2016 and September 12, 2016 for CS and HMC, respectively. Hand harvest of soybeans occurred on October 14, 2016. Corn silage was hand harvested at the first node level for 5.33 m at 3 locations per replicate for each treatment. Rows sampled were alternated within each replicate. Corn ears were shucked, weighed wet, shelled, dried for 48 h in a 60^{o}C oven, and weighed to determine corn and cob DM. Cob weights were included in the dry stover yields. The rest of the corn plant was ground through a chipper shredder (model #D11334 AC, Troy Built, MTD Products, Valley, City, OH), weighed wet, and sub-sampled. Sub-samples were dried for 48 h in a 60^{o}C oven and weighed to determine stover DM to calculate corn silage yield per hectare.

Similarly, HMC was hand harvested at the second node level for 5.33 m at 3 locations per replicate for each treatment. Rows were alternated within each replicate. Corn ears were shucked and weighed; the rest of the corn plant was then weighed without the ears. Three corn plants and three ears were dried for 48 h in a 60^{o}C oven to determine stover DM. Kernel counts were done on all three ears before being shelled and further dried to determine corn and cob dry matter. Cob weights were included in the dry stover yields. Dry matters were used to calculate corn grain yield and stover yield per hectare.

Harvest index was calculated based on the percentage of the entire plant that was dry grain.

Soybeans were hand harvested at ground level for 5.33 m at 3 locations / rep / treatment. Samples were then bundled and dried at 60°C until threshing. During threshing, grain and stover were collected, weighed wet, and dried for 48 h in a 60°C oven to determine DM. Dry matters were used to calculate soybean grain and stover yield per hectare.

Animal Management

Fifty-five steer calves (initial BW = 228 kg; SD = 13 kg) were limit fed a common diet of 50% Sweet Bran (Cargill Wet Milling) and 50% alfalfa hay for 5 d and weighed for 3 consecutive d at the beginning of the study to limit differences in BW due to gut fill and establish initial BW (Watson et al., 2013). Calves were stratified by BW and assigned randomly to paddocks with 14 steers / paddock, except for one CS group that had 13 steers due to stocking rate calculation. On November 2nd, steers were implanted with 36 mg zeranol (Ralgro, Merck Animal Health, Madison, NJ) and turned out into their respective paddocks. Steers grazed for 42 d and were pulled off on December 14th due to limited forage in the HMC treatments.

Stocking rates were calculated using a predetermined 70 d grazing season with a 60% grazing efficiency, intakes estimated at 2.5% of BW, and initial biomass measurements of kg DM / ha within each paddock. Steers grazing CS were allocated 819 kg oat DM / animal. Steers grazing HMC were allocated 187 kg oat DM / hd and 617 kg corn stover DM / animal. After the grazing period, steers were limit fed on the same common diet for 8 d and weighed for 3 consecutive d to limit differences in BW due to gut fill and establish final BW (Watson et al., 2013).

Statistical Analysis

Data were analyzed using the GLIMMIX procedure of SAS. Paddock was the experimental unit for steer performance and forage quality data. Treatment was analyzed as a fixed effect for steer performance and soybean yields. Since animals were not grazed in 2014, treatments could not be analyzed as a fixed effect for subsequent corn yields. Therefore, Cov-G and Cov-NG treatment means were combined into a cover treatment with 6 replications and compared to the no cover treatment (NC-NG) with 3 replications. Crop type was analyzed as a fixed effect for annual forage quality and production data. Data were determined to be significantly different at $P \leq 0.05$.

Results and Discussion

Forage production and quality

Forage biomass production of oats was greater ($P < 0.01$) following CS than HMC with 2,547 kg DM / ha compared to 597 kg DM / ha, respectively (Table 4.1). Interestingly, the corn stover from the HMC provided 1,973 kg DM / ha making total kg DM / ha between the treatments similar. Furthermore, GDD were 583 and 331 for oats following CS and HMC, respectively. The difference in GDD between the treatments and cover from the HMC residue were likely the reasons forage production was significantly greater for oats following CS. Forage production declined by 975 kg DM / ha for each week planting was delayed comparing oats following CS to HMC. This is similar to findings in forage production of brassicas declining by 770 kg / ha per week after July

20th (Koch et al. 2002). The larger decline during this study may be due to differences in winter hardiness of oats compared to brassicas, as well as the significant amount of residue cover in the HMC treatment possibly affecting oat emergence. Additionally, similar relationships were found in forage production of oats and an oat-turnip mix following CS and HMC with an average forage production of 2,124 kg DM / ha and 537 kg DM / ha, respectively over 2 years (Ulmer et al., 2016). Furthermore, Fae at al. (2009) reported average fall forage production of an oat-winter rye mix or annual ryegrass following CS at 3,178 kg DM / ha and 2,896 kg DM / ha, respectively. Similarly, Cox et al. (2016) seeded an oat-turnip-radish mix following CS and reported 3,758 kg DM / ha of forage production.

Forage quality of oats were similar whether following CS or HMC harvest. Organic matter of the oats was not different ($P = 0.13$) whether it was seeded behind CS or HMC (88.8% or 88.2%, respectively; Table 4.3). However, CP was greater ($P < 0.01$) in the oats seeded behind HMC compared to CS at 24.8 and 18.9%, respectively. As illustrated in total forage production, the oats following HMC were less mature than the oats following CS, which likely explains the greater percentage of CP. Furthermore, the maintenance requirement for MP of a 250 kg growing calf is 239 g / d (NASEM, 2016). Assuming calves average intake was 2.5% of BW and RUP content of the oats was approximately 25%, it can be presumed that the oats provided a sufficient amount of MP in order to meet and exceed the maintenance requirement for MP with most of the requirement likely provided from the RUP portion of the oats. Both NDF and ADF were greater ($P < 0.01$) for oats following CS compared to HMC (41.0 vs 37.8% and 25.5 vs 22.6%, respectively). The increased NDF content of the oats in the CS treatment is logical due to the earlier planting date. Wiedenhoeft and Barton (1994) illustrated that earlier planted forages will have higher NDF content compared to forages planted later. Similarly, ADF content increases as the plant matures due to increasing proportions in structural components of the plant (cellulose and lignin; Van Soest, 1963). In previous research, Ulmer et al. (2016) reported increased OM with no differences in CP, NDF, or ADF when comparing oats seeded after CS compared to HMC. Fae et al. (2009) reported increased NDF and decreased NDF digestibility with no difference in CP when comparing an oat-winter rye mix to annual ryegrass, seeded at the same time.

Lastly, percentage ground cover, estimated using transects, was different between CS and HMC with a crop by treatment interaction ($P < 0.01$; Table 4.2). Looking at the simple effects of percentage ground cover, Cov-NG and NC-NG treatments within HMC had the greatest percent ground cover at 93.5 and 92.5%, respectively. It is logical that the HMC treatments would have more cover due to the corn residue. Additionally, the limited amount of growth from the oats seem to have a limited impact on ground cover. Furthermore, the NC-NG treatment within the CS had the least percent ground cover at 30.5%. The Cov-G and Cov-NG treatments within CS, as well as the Cov-G treatment within HMC were intermediate with 85.5, 82.5, and 78.5% ground cover, respectively. Additionally, the Cov-G treatment within CS did not differ from the NC-NG treatment within HMC. Understandably, the presence of oats had a more profound effect on ground cover within the CS treatments compared to the HMC treatments. Ground cover was also not impacted by grazing within the CS treatments; whereas, the implementation of grazing lowered the percentage ground cover within the HMC treatments. This impact could potentially be due to the difference in total biomass remaining at the end of the grazing period. The oats following CS produced more forage and therefore had more remaining after the grazing period.

Cash crop yields

Subsequent soybean yields were not different ($P \geq 0.11$) between treatments (Cov-G, Cov-NG, and NC-NG; Table 4.4). Soybean grain yields averaged 4,566 kg DM / ha and stover yields averaged 3,270 kg DM / ha across all treatments. Furthermore, subsequent corn yield could not be compared across treatment since animals were not grazed in 2014 due to a herbicide restriction. Therefore, subsequent corn yield of CS and HMC was a comparison between either cover or no cover from an oat-brassica mix planted in 2014. Subsequent yields were not different ($P \geq 0.35$) for CS yield, HMC grain yield, or HMC stover yield with or without cover applied in 2014. Averaged across treatment (cover or no cover), CS yielded 18,375 kg DM / ha, HMC grain yielded 14,663 kg DM / ha, and HMC stover yielded 8,655 kg DM / ha. Previous research has shown no impact on subsequent cash crop yield from double-cropped annual forages with or without concurrent grazing of the forage (Ulmer et al., 2016 and Fae et al., 2009).

Calf performance

Steers grazing oats following CS had greater ADG than steers grazing oats following HMC ($P = 0.05$) with an ADG of 1.10 and 0.84 kg / d, respectively (Table 4.1). Ending BW was greater for steers on the CS treatment compared to the HMC treatment ($P = 0.04$). However, gain per hectare was not different between treatments with an average gain of 129 kg / ha. Previous research illustrated no difference in ADG between steers grazing oats following CS and HMC with ADG of 0.59 and 0.33 kg / d, respectively (Ulmer et al., 2016). Unlike the Ulmer et al. (2016) study, this study grazed an additional 20 d with 653 kg DM / ha greater forage production on the CS treatment and similar forage production on the HMC treatment, inferring that steers may have started to lose BW in last 20 d due to limited forage availability. Fae et al. (2009) reported an ADG of 0.81 kg / d for dairy heifers grazing annual ryegrass or an oat-winter rye mix. Additionally, Cox et al. (2016) reported an ADG of 1.02 kg / d over 71 d grazing an oat-turnip-radish mix.

In summary, double-cropping oats following CS offers producers an opportunity to add additional weight to weaned calves, as well as add economic incentive to their cropping system with no impacts on subsequent crop yield. The data have shown less desirable gains from oats seeded after HMC due to the lack of GDD, in turn, leading to a substantial decrease in forage production. Interestingly, Tibbitts et al. (2016) reported that calves grazing corn residue with no supplement lost 0.10 kg / d, suggesting that oats following HMC still provide value. The quality of the forage, whether seeded after CS or HMC, provides sufficient amounts of protein and energy for growing calves and may be an opportunity for stocking other classes, such as replacement heifers or fall calving cows, as well.

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Table 4.1. Calf performance grazing oats seeded after corn silage or high-moisture corn harvest, forage production, growing degree days, and soil cover

	Treatment			
Item	CS[1]	HMC[2]	SEM	*P*-value
Calf Performance				
Initial BW, kg	228	228	0	0.42
Ending BW, kg	274	263	2	0.04
ADG, kg	1.10	0.84	0.04	0.05
Gain, kg / ha	144	113	9	0.14
Forage Production				
Biomass, kg / ha[3]	2,547	597	46	<0.01
GDD[4]	583	331	-	-
Cover, %[5]	66.2	88.2	1.3	<0.01

[1] Calf performance and forage production of oats seeded after corn silage harvest
[2] Calf performance and forage production of oats seeded after high-moisture corn harvest
[3] Biomass determined before grazing period on October 25th
[4] GDD (growing degree days of oats) = [average daily temperature (ºC) – 10] summed from d oats seeded to d initial oat biomass sampled / .5556
[5] Percent cover determined by transects after the grazing period. Crop x treatment interaction (*P* < 0.01)

Table 4.2. Simple effects of percentage ground cover of oats after corn silage or high-moisture corn production[1]

	Corn Silage			High-Moisture Corn				
Item	Cov-G[2]	Cov-NG[3]	NC-NG[4]	Cov-G[2]	Cov-NG[3]	NC-NG[4]	SEM	*P*-value
Forage Production								
Cover, %	85.5^{bc}	82.5^{c}	30.5^{d}	78.5^{c}	93.5^{a}	92.5^{ab}	2.2	<0.01

[1] Crop x treatment interaction ($P < 0.01$)

[2] Cov-G = oats seeded after corn silage or high-moisture corn and grazed

[3] Cov-NG = oats seeded after corn silage or high-moisture corn and not grazed

[4] NC-NG = no oats seeded or grazing

Table 4.3. Forage quality of oats planted after corn silage and high-moisture corn harvest

Item[1]	Treatment		SEM	*P*-value
	CS[2]	HMC[3]		
OM	88.8	88.2	0.2	0.13
CP	18.9	24.8	0.5	<0.01
NDF	41.0	37.8	0.4	<0.01
ADF	25.5	22.6	0.2	<0.01

[1] All treatment means are percentages

[2] Nutrient content of oats seeded after corn silage harvest

[3] Nutrient content of oats seeded after high-moisture corn harvest

Table 4.4. Subsequent soybean yields (kg DM / hectare) following a double-cropped annual forage with and without grazing[1]

	Treatments[2]				
Item[3]	Cov-G	Cov-NG	NC-NG	SEM	*P*-value
Soybean Grain Yield	4,576	4,404	4,719	99	0.11
Soybean Stover Yield	3,078	3,346	3,387	228	0.59

[1] Soybean yields from 2016 following a double-cropped annual forage of wheat in 2013 and oats in 2015 each forage was seeded after corn silage or high-moisture corn harvest; field was planted to soybeans in 2014

[2] Cov-G = grazed oats, Cov-NG = ungrazed oats, NC-NG = ungrazed without oats drilled

[3] All treatment means are kg DM / hectare, HMC = high-moisture corn

Table 4.5. Subsequent corn yields (kg DM / hectare) following an oat-brassica cover crop[1]

Item[2]	Cover[3]	SEM	No Cover[4]	SEM	*P*-value
Corn Silage Yield	17,161	1,386	19,588	1,960	0.35
HMC Grain Yield	14,772	442	14,553	625	0.78
HMC Stover Yield	8,724	156	8,585	220	0.62

[1] Corn yields from 2016 following an oat-brassica cover crop in 2014; field was rotated with soybeans being planted in 2013 and 2015

[2] All treatment means are kg DM / hectare, HMC = high-moisture corn

[3] Subsequent corn yield following cover in 2014

[4] Subsequent corn yield following no cover in 2014