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Distillers Grains with Solubles for Feedlot Cattle - Finishing Performance, Lipid Metabolism, and Ethanol Greenhouse Gas Balance

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DISTILLERS GRAINS WITH SOLUBLES FOR FEEDLOT CATTLE – FINISHING PERFORMANCE, LIPID METABOLISM, AND ETHANOL GREENHOUSE GAS BALANCE

by

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Previous University of Nebraska feedlot research trials have characterized the feed value of wet distillers grains plus solubles (WDGS). These trials were summarized with meta-analysis methodology and indicated the feed value of WDGS interacts with corn processing type, cattle age (calf-fed or yearling), and inclusion level. Two steer finishing studies and a metabolism study were conducted to understand the impact of different lipid sources in WDGS on WDGS feed value. A biphasic lipid extraction procedure was developed to analyze feed samples from these trials that was more effective than Goldfisch ether extraction at lipid analysis of byproduct feds. These trials indicated the lipid content of WDGS partially accounted for WDGS feed value being greater than corn. Diets containing WDGS to supply up to 8% of diet DM as lipid may be fed without depressing cattle performance. However, feeding diets containing 8% dietary lipid with corn oil depresses cattle performance. The difference in rumen metabolism of these two lipids is due to partial physical protection of WDGS lipid from metabolism by rumen microbes. However details for the mechanisms for the improved feed value of WDGS relative to corn are still unknown.

Key Words: Beef cattle, Byproducts, Distillers grains, Lipid

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May God bless you greatly!

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INTRODUCTION

Cattle and other livestock have been fed byproducts of ethanol production for about a century. Initially the byproducts were from the beverage alcohol industry. The majority of ethanol industry byproducts are now sourced from the production of fuel grade ethanol. Livestock producers have been, and still are, trying to understand the dollar value of these products, how to best implement the products in production diets, and what level of DMI, ADG, and G:F when the products are fed. This interest spurred research on feeding these products to livestock at universities, especially at the University of Nebraska – Lincoln. The research has shown these products to be acceptable and sometimes superior feeds to corn. Not all byproducts are created equal though. The differences in livestock DMI, ADG, and G:F when fed the different products have become a focused area of byproduct feed research. Individual trials have reported improved G:F of cattle fed DGS of different moisture contents with different inclusion levels with different corn processing types. Many years of research were required to develop a large enough database of knowledge to evaluate these effects, not to mention the interaction of them. However, the mechanisms for the effects and interactions have remained elusive.

The reason DGS are available for livestock feed is due to the improved environmental impact of ethanol versus gasoline. Both the ethanol and gasoline life cycles are made of complex interacting components. A detailed understanding of both systems is needed to accurately compare their differences in environmental impact. Accurate livestock ADG and G:F when fed different DGS are needed to calculate the feeds offset when DGS displaces corn and protein in livestock diets.

A review of literature on feeding DGS to livestock, especially feedlot cattle, was conducted to better understand current research on feeding DGS and the important factors to consider when comparing the environmental impact of ethanol relative to gasoline.

REVIEW OF LITERATURE

General Information on Distillers Grains

Distillers Grains Production. Wet or dry distillers grains plus solubles (DGS) are composed of the nonfermentable portion of corn grain and are the byproduct from dry-mill corn-ethanol production. By definition, the DGS must contain a minimum of 75% of the unfermentable solids produced by a dry-mill ethanol plant (AAFCO, 2002). The DGS produced must be at least 10% condensed corn distillers solubles (CCDS). Dry-mill biorefineries powered by natural gas currently represent nearly 90% of U.S. grain-ethanol production capacity (Liska et al., 2009). Corn starch fermented to ethanol represents roughly 73% of grain dry matter and about 67% of the energy content. The remaining protein, lipid, cellulose, lignin, and ash make up about 27% of grain dry matter and 33% of the energy. As such, the energy content of byproducts is a sizable portion of total energy output of the corn-ethanol life cycle.

Three main types of DGS are produced by most dry-mill ethanol biorefineries. Wet distillers grains with solubles (WDGS; 65% water) are produced by adding CCDS back to the solid unfermentable portion of the corn grain (WDG) after fermentation. Distillers solubles are the water soluble fraction of post-distillation stillage that are separated via centrifugation. An alternate product, modified distillers grains with solubles (MDGS; 55% water) are produced when the WDGS is partially dried before additional CCDS are added. If the CCDS and grains are mixed together and dried more completely, dried distillers grains with solubles (DDGS; 10% water) are produced. Producing byproducts with less moisture requires energy input at the biorefinery (Liska et al., 2009).

Target market livestock populations and DGS transportation costs are drivers of the quantity of WDGS produced and how WDGS is processed at the ethanol plant (Buckner et al., 2008). Drying WDGS improves shelf life and decreases shipping costs due to less moisture being hauled. Drying DGS allows access to markets unattainable with WDGS. Export markets, the swine industry, and livestock industries in other regions of the US are available with DDGS. This flexibility comes at a cost. In addition to the decrease in energy concentration relative to corn of DDGS relative to WDGS, the fixed and variable cost of owning and operating a dryer in an ethanol plant are significant (Baumel, 2008). Ethanol plant decisions on DGS moisture management also impact the greenhouse gas (GHG) balance of ethanol produced. This emphasizes making ethanol production decisions that are economically and environmentally sound.

The term feeding value relative to corn provides a simplistic way to compare the energy content of multiple byproducts relative to corn. The following calculation is a reference point for the generalized term “feeding value” utilized throughout this review. Feeding value of DGS relative to corn from actual cattle performance G:F when both DGS and corn only diets were fed in the same trial. Feeding value of a specific dietary inclusion level of DGS was calculated as ((((DGS level G:F) – (0% DGS G:F))/(0% DGS G:F))/(0% DGS G:F))/(diet DM % DGS))+1. This calculation assumes that the difference in G:F of the control diet and the test diet is due to DGS inclusion replacing corn.

***Coexistence of Cattle and Distillers Grains*.** Pre-gastric fermentation of low quality feedstuffs into protein provides the beef industry with an opportunity to compete with more efficient food protein producing industries such as poultry and fish. DGS is used not only as a protein source but also as an energy source (NRC, 1996; Klopfenstein et al., 2008a). Ruminants are able to utilize the fat, fiber, and protein components of DGS. Fractionation of DGS products for biodiesel production from the fat component and cellulosic ethanol production of the fiber fraction may result in future byproduct feeds containing copious amounts of protein (greater than 40% of DM). The GHG balance of ethanol and other byproducts produced from fractionated corn processes may be significantly different from the current systems analyzed due to uses of byproducts produced, change in corn processing, and environmental costs of implementing the technology. The feeding value of future products may also be reduced. Furthermore, exploitation of fibrous biomass fermentation for ethanol production would directly compete for the resource niche that cattle currently utilize. Although ethanol production has altered the availability of corn for livestock production, the use of DGS as livestock feed has helped to maintain the synergistic relationship between the livestock and corn production industries.

These data indicate that beef producers have the opportunity to utilize many different byproducts in different production situations. Changes in the ethanol production process may impact cattle ADG and G:F, feed available to beef producers, and the environmental impacts of both cattle production and ethanol use.

Distillers Grains in Feedlot Finishing Diets

University of Nebraska Studies. Wet DGS has been fed to feedlot cattle in at least 20 feedlot cattle finishing trials with 350 pen means and representing 3,365 steers fed at the University of Nebraska (Larson et al., 1993; Ham et al., 1994; Al-Suwaiegh et al., 2002; Vander Pol et al., 2005; Godsey et al., 2008a, 2008b; Meyer et al., 2008; Wilken et al., 2008; Corrigan et al., 2009; Rich et al., 2009; Vander Pol et al., 2009; Loza et al., 2010; Luebbe et al., 2010; Moore et al., 2010; Nuttelman et al., 2010; Rich et al., 2010; Sarturi et al., 2010). Modified DGS for feedlot cattle has been evaluated in at least 4 trials with 85 pens representing 680 steers (Adams et al., 2007; Huls et al., 2008; Luebbe et al., 2010; Nuttelman et al., 2010). Dried DGS for feedlot cattle has been evaluated in at least 4 trials with 66 pens representing 581 steers (Ham et al., 1994; Buckner et al., 2010; Nuttelman et al., 2010; Sarturi et al., 2010).

Griffin et al. (2007) has described and analyzed the management system utilized for the calf-feds and yearlings fed as part of these studies. The UNL feedlot purchases spring born, predominately black, crossbred steers weaned in the fall for research trials. After an initial receiving period, the largest steers are fed as calf-feds in the winter, the medium steers are fed as short-yearlings in the summer after wintering on corn stalks, and the smaller steers are wintered on corn stalks, grazed on grass the following summer, and finished in the fall to market by 24 months of age.

All trials evaluated feeding corn DGS replacing dry-rolled corn (DRC), high-moisture corn (HMC), or a blend of the two corn types. All HMC contained a minimum of 27% moisture. Individual animal carcass data were collected on all steers and feeding performance was calculated from a carcass adjusted final weight. Trials evaluated feeding from 0 to 50% of diet DM as a single byproduct in the diet. Distillers grains replaced corn and urea nitrogen in the finishing diets (Klopfenstein et al., 2008a). In 2000, a survey of beef cattle nutritionists found urea to be the primary source of supplemental protein in feedlot diets (Galyean and Gleghorn, 2001). By 2007, however, ethanol byproducts were widely used as a low-cost protein source for feedlot cattle (Vasconcelos and Galyean, 2007). All trials were conducted under similarly managed feedlot research settings across multiple years at University of Nebraska Beef Research Feedlots.

This compilation of studies indicates that there is an opportunity to collectively analyze the results from the individual studies. However, these data have never been collectively summarized. The consistent management strategy utilized across trials offers the opportunity to analyze cattle feeding performance and carcass characteristics when fed DGS with Meta-analysis methodology to predict future cattle performance.

Feedlot Industry Distillers Grains Use. Experimental data have demonstrated that up to 50% of diet dry matter may be replaced with DGS in feedlot diets and improve cattle performance (Klopfenstein et al., 2008b). Nutritionists' surveys indicated the current average DGS inclusion rate is 20% (dry matter basis) with a range of 5 to 50% of the diet DM (Vasconcelos and Galyean, 2007). In the Corn Belt, survey data suggest that beef producers feeding DGS use an average dietary inclusion of 22 to 31% on a wet basis (approximately 15 to 20% of diet DM) (NASS, 2007).

Respondents to both the feedlot nutritionist survey (Vasconcelos and Galyean, 2007) and a Nebraska feedlot industry survey (Waterbury et al., 2009) reported that DGS are the most common ethanol byproduct used by cattle feeders. The Nebraska survey indicated 53 and 29% of Nebraska feedlots feed WDGS and MDGS, respectively. The nutritionist survey indicated 69% of the 29 nutritionists were feeding DGS as the primary byproduct in the diet, and these beef nutritionists were responsible for formulating diets for nearly 70% of cattle on feed in the United States. Results from the two surveys documented that proportionately more DGS are fed in the United States feedlot industry than corn gluten feed.

Klopfenstein et al. (2008a) documented improved performance of DGS when substituted for corn, and an additional benefit of WDGS compared to DDGS. Moreover, the feeding value of each type of DGS was affected by the proportion of substitution in the diet. Hence, the type and level of DGS fed affected cattle DMI, ADG, and G:F.

These data indicate that that beef producers are interested in feeding DGS. However, differences in cattle performance make the decision on which byproduct to feed and level of inclusion may be perplexing. Prediction equations from biological data are needed to help producers understand the opportunities with feeding DGS.

Feeding Distillers Grains of Different Moisture Contents. A decrease in steer G:F as moisture is removed from WDGS has been noted by trials evaluating both WDGS and DDGS in the same trial (Ham et al., 1994; Nuttelman et al., 2010; Sarturi et al., 2010). The three trials evaluated feeding WDGS or DDGS and found the energy content of WDGS to be greater than DDGS. Nuttelman et al. (2010) conducted the first trial to evaluate feeding multiple dietary inclusion levels of WDGS, MDGS, and DDGS in the same trial. The MDGS and DDGS were sourced from the same ethanol plant. The researchers noted the energy value of WDGS being greater than MDGS and both being greater than DDGS. Steer DMI increased as DGS moisture decreases with equal ADG. This may indicate cattle fed dryer DGS products eat to a constant energy intake.

Mechanism of WDGS Performance Response

Paradox. The biological mechanisms responsible for the superior feeding value of WDGS relative to corn have been elusive. The mechanism is perplexing due to the WDGS paradox . The paradox is that most of the energy in corn (starch) is removed to create WDGS which has greater feeding value than corn with lower digestibility than corn (Corrigan et al., 2009;Vander Pol et al., 2009). In addition, NRC (1996) predicted cattle performance when fed WDGS is less than the values calculated in this summary of WDGS feeding trials. NRC (1996) inputs from conventional WDGS laboratory nutrient assays do not accurately predict cattle performance.

NDF digestibility. Three trials have reported WDGS diet NDF digestibility to be numerically greater (significantly greater in one of the trials) than corn diet NDF digestibility (Ham et al., 1994; Corrigan et al., 2009; Vander Pol et al., 2009). Therefore, roughly double the amount of NDF is digested by steers fed WDGS as compared to steers fed corn. Ham et al. (1994) also found that steers fed 20% of diet DM as thin stillage had similar NDF digestibility as corn fed steers. Vander Pol et al. (2009) also found diet NDF digestibility of steers fed a corn diet containing 3.4% corn oil to be similar to NDF digestibility of steers fed a corn diet, however DMI of steers fed the corn oil diet was much less than corn and WDGS DMI. Passage rate may have been affected by DMI and influenced extent of NDF digestion.

The site of NDF digestion of WDGS may be post-ruminal. Corrigan et al. (2009) evaluated ruminal corn bran NDF digestion with 22 h ruminal in situ incubation and found no difference in corn bran NDF digestion when steers were fed a corn control or a

40% WDGS diet. Ruminal digestibility of corn bran was low and averaged 29.9% and 27.8% for steers fed WDGS or corn, respectively. Vander Pol et al. (2009) reported 56 and 71% pre-duodenal diet NDF digestibility for corn and WDGS fed steers, respectively. The in vivo NDF digestibility calculations of Vander Pol et al. (2009) indicated greater ruminal NDF digestibility of corn and WDGS than the in situ corn bran digestibility data of Corrigan et al. (2009). Inherent errors exist within both in situ and in vivo ruminal NDF digestibility calculations. Therefore, it is unclear what fraction of WDGS NDF is digested ruminally.

Ruminal Volatile Fatty Acid Profile Shift. A proposed biological mechanism of the superior feeding value of WDGS relative to corn is a shift of acetate to propionate production in the rumen of steers fed WDGS (Corrigan et al., 2009; DiLorenzo and Galyean, 2010). Vander Pol et al. (2009) and Corrigan et al. (2009) found reduced acetate-to-propionate ratio (A:P) of cannulated steers when fed 40% WDGS diets compared to a corn control diets. However, trials by Ham et al. (1994) found that feeding 40% of diet DM as wet distillers grains with or without solubles had similar or increased A:P relative to DRC fed steers.

It has been hypothesized that the decreased A:P is due to low ruminal pH of WDGS fed steers causing increased hemicelluloses fermentation relative to cellulose fermentation (Murphy et al., 1982; DiLorenzo and Galyean, 2010). The results of Ham et al. (1994), Corrigan et al. (2009), and Vander Pol et al. (2009) do not indicate a significant reduction in average ruminal pH. However, those three trials did report numerically lower average ruminal pH for steers fed WDGS relative to corn. This agrees with the findings of Corrigan et al. (2009) and Vander Pol et al. (2009) who noted no significant difference in time spent below pH 5.6 for both WDGS and corn. However, they both found WDGS fed steers to have numerically more time below pH 5.6.

Metabolism trials of Ham et al. (1994) indicated that feeding thin stillage or CCDS replacing corn decreased A:P ratio relative to DRC. In three trials, Hanke and Lindor (1983) evaluated feeding thin stillage (CCDS prior to moisture removal) in place of drinking water to finishing cattle and found 5.7 and 11.0% improvements in ADG and G:F, respectively, with reduced DMI when thin stillage was fed. Rust et al. (1990) evaluated feeding up to 20% of diet DM as CCDS and observed improved G:F when CCDS was fed relative to corn control fed cattle. Trenkle (1997 and 2002) evaluated feeding 0 to 8% of diet DM as CCDS replacing DRC in finishing diets and noted improved G:F when CCDS was fed. These trials collectively indicate that CCDS contains greater feeding value than dry-rolled corn. The difference in A:P of the different metabolism trials may be due to the ratio of wet grains to CCDS in WDGS.

Importance of Lipid in WDGS on Feeding Value. The theoretical energy benefit of fat relative to starch is more significant for ruminant animals than monogastric animals due to ruminal energy loss from microbial heat production and gaseous energy loss. Lodge et al. (1997) evaluated feeding a simulated WDGS product from a combination of wet corn gluten feed, tallow, and corn gluten meal. The feeding value of the WDGS composite was decreased from 124 to 118% of DRC when the tallow was removed. The relative ratio of wet grains to CCDS in WDGS influences the dietary lipid contribution of WDGS. Farlin et al. (1981) evaluated feeding WDG at 42.5% of diet DM and observed 9.9 and 10.6% improvements in ADG and G:F relative to corn control fed cattle. Firkins et al. (1985) also observed a linear improvement in ADG and G:F when dietary inclusion of wet distillers grains without solubles (WDG) increased from 0 to 25 and 50% of diet DM. Godsey et al., 2008a evaluated feeding combinations of wet distillers grains (10.0% ether extract) and CCDS (27.8% ether extract) with 100:0, 85:15, or 70:30 ratios of wet grains to CCDS at either 20 or 40% of diet DM. They found no interaction of byproduct level with CCDS level and G:F numerically improved as proportionately more CCDS were fed and as dietary inclusion of byproduct increased. In addition to lipid content differences between the WDG and WDGS diets in these two studies, the CCDS in the WDGS treatments also provided protein from yeast cells in addition to other components. These studies collectively indicate that the feeding value of WDG is at least equal to corn and may be greater than corn.

Optimization of cattle performance is a balance of both diet caloric density and quantity of intake. Based on greater caloric density of lipid versus starch and protein, it is logical to replace a portion of lesser energy starch or protein from feedlot diets with lipid (Lodge et al., 1997). Vander Pol et al. (2009) replaced corn with 2.5% corn oil or 20% WDGS to create diets with 6.4% total diet ether extract. Both the 2.5% corn oil diet and 20% WDGS diets resulted in similar feeding performance relative to the corn diet for individually fed heifers. When total diet ether extract was increased to 8.8% with either 5% corn oil or 40% WDGS, G:F was greater for the 40% WDGS diet relative to 20% WDGS. The 5% corn oil diet resulted in decreased G:F relative to the corn diet. In a second finishing trial, Vander Pol et al. (2009) evaluated replacing corn with 1.3 or 2.6% tallow or 20 or 40% DDGS in diets containing 20% wet corn gluten feed (WCGF). Feeding performance was similar for all treatments. Maximum dietary ether extract was 6.0 and 5.0% for tallow and DDGS diets, respectively. These results indicate that feeding a 5% ether extract diet containing 2.6% of diet DM as tallow was not enough saturated lipid to depress cattle performance with 20% WCGF diets. The differences in metabolism of different lipid sources may result in different dietary lipid content optimums.

Previous lipid metabolism research has focused on traditional lipids such as beef tallow and vegetable oil (Vander Pol et al., 2009). Some of the results reported in these studies may be misleading in ad libitum feeding situations due to lipid digestibility being reported from limit fed cattle (Plascencia et al., 2003). Ruminal lipid biohydrogenation and total tract lipid digestibility of ethanol industry byproducts such as WDGS and CCDS may differ from tallow and vegetable oil due to lipid matrix (Vander Pol et al., 2009).

Vander Pol et al. (2009) has shown that a portion of WDGS fatty acids are protected from ruminal biohydrogenation. This results in a portion of WDGS fatty acids reaching the small intestine for absorption as unsaturated fatty acids. Unsaturated fatty acids may be more efficiently absorbed than saturated fatty acids (Plascenscia et al., 2003). Increased absorption of WDGS fatty acids in the unsaturated form has been verified by increased proportion of polyunsaturated fatty acids in steaks from steers fed WDGS diets (de Mello et al., 2007).

Sweet Bran ® WCGF (Cargill Inc., Blair, NE), with limited lipid content, and WDGS with greater lipid content have been shown to be complementary feed ingredients in finishing diets (Loza et al., 2010). The lipid content of CCDS without WDG may also be complementary to WCGF. However, there are limited data collected on feeding CCDS in finishing diets, and no data collected on feeding CCDS with WCGF. Loza et al.

(2010) conducted two studies to evaluate feeding 30% WCGF with WDGS for finishing cattle. One trial evaluated feeding 0, 10, 15, 20, 25, and 30% WDGS in diets containing 30% WCGF and found ADG to decrease quadratically and a trend for DMI to decrease quadratically that resulted in no significant change in G:F as WDGS level increased. A second trial evaluated diets containing 30% WCGF with or without 30% WDGS and noted decreased DMI and ADG that resulted in greater G:F for steers fed the diet containing WCGF and WDGS. The findings of Loza et al. (2010) indicated that feeding combinations of WCGF and WDGS instead of WCGF alone should not depress G:F. However, ADG may be depressed by feeding the combination.

The response to feeding WDGS in diets containing WCGF is different than the response to feeding WDGS as the single byproduct in a diet (Klopfenstein et al., 2008a). Replacing corn with WDGS alone in finishing diets has resulted in quadratic improvements in DMI, ADG, and G:F that resulted in decreased days on finishing diet to reach a similar degree of finish. The lack of improvement when adding WDGS to diets containing WCGF creates a perplexing situation. The undegradable intake protein (UIP), NDF, and lipid content characteristics of WDGS may be of limited value in WCGF diets. This is intriguing since WCGF contains significantly less UIP and lipid than WDGS. The commonality between the two feedstuffs is greater NDF and containing fermentation end products. The WCGF and WDGS may both fill a similar metabolic niche.

A review of current research on why DGS fed cattle have superior ADG and G:F relative to corn fed cattle results in more questions than answers. Proposed hypotheses recognize that fiber, protein, and lipid components of DGS are important. However, no clear mechanisms are evident.

Distillers grains interaction with cattle type and corn processing method

Cattle Type and Wet Distillers Grains. Differences in cattle type (calf-feds or yearlings) and corn processing method, DRC or HMC, have been shown to influence cattle performance. A 98-pen summary of feeding similar sourced calf-feds and yearlings demonstrated calf-feds have lower daily DMI, ADG, and greater days on feed than yearlings (Griffin et al., 2007). However, calf-feds have greater G:F than yearlings. Previous research has also evaluated feeding WDGS to winter calf-feds and summer yearlings in a confinement barn (Larson et al., 1993). The trials were replicated over two years. The researchers reported a greater feeding value of WDGS replacing 40% of diet DM as DRC for yearlings than calf-feds, 151 and 134% the feeding value of DRC, respectively.

Corn Processing and Wet Distillers Grains. Corn WDGS has greater feeding value than DRC or a blend of DRC and HMC (Klopfenstein et al., 2008b). Research has also evaluated feeding WDGS with DRC, HMC, or a blend of both corn types (Vander Pol et al., 2008; Corrigan et al., 2009). In the Vander Pol et al. (2008) feeding trial, 30% WDGS (DM basis) was fed and G:F was numerically superior for steers fed HMC compared to DRC or a DRC and HMC blend. However, in this trial 0% WDGS diets were not fed to evaluate the response to WDGS from different corn processing types. The Corrigan et al. (2009) trial evaluated the response to feeding 0, 15, 27.5, and 40% WDGS (DM basis) with either DRC or HMC. A greater response to WDGS was observed with less intensely processed DRC compared to HMC. However, G:F for HMC fed steers was superior to G:F of DRC fed steers with up to 40% of diet DM as WDGS.

Practical Benefit of Wet Distillers Grains and High Moisture Corn. Feeding HMC with WDGS offers feedlots an opportunity to capitalize a cheap, localized supply of corn. As United States corn production increases, harvesting and storing the larger crop has logistical limitations due to environmental factors and a semi-fixed amount of storage (Cassman and Liska, 2007). Feedlot use of HMC offers farmers an increased window of opportunity to harvest corn without incurring drying costs of wet corn harvested early in the harvest season (Macken et al., 2006). In a time of greater price volatility in inputs to operate a feedlot, owning the physical corn commodity may offer a risk management strategy to the feedlot. Pricing the corn in the fall when supply is greatest may allow purchase of corn at a price below the marketing year average. Some feedlots and corn producers may prefer to risk manage this cost in other ways, including but not limited to, pricing a portion of the corn on a monthly basis to spread out farmer income and allowing farmers to "store" the corn at the feedlot without drying cost to price for future payment. The feedlot may risk manage this cost by hedging the purchase when the physical commodity arrives in the yard. Minimizing storage costs and product shrink losses are also important management factors. Managing a physical inventory of HMC may lock a feedlot into feeding a certain level of corn in the diet that may not allow them to take advantage of future byproduct opportunities. These strategies are provided to demonstrate that innovative options are available to manage the cost of owning the physical HMC inventory.

Mechanism of WDGS and Corn Processing Type Interaction. Increasing degree of corn processing has been shown to increase the proportion of corn starch digested in the rumen. The increased quantity of starch reaching the small intestine with the less processed corn is a theoretical improvement in starch utilization efficiency (Huntington et al., 2006). However, the limitation to this efficiency may be the ability of the small intestine to digest and absorb glucose from dietary starch. This digestion may be limited by alpha amylase activity. Increasing amounts of post-ruminal infusion of partially hydrolyzed starch or glucose in cannulated steers fed a forage diet has been shown to decrease pancreatic alpha amylase secretion (Swanson et al., 2002). Results of Richards et al. (2002 and 2003) indicated that small intestine protein supply is important in stimulating pancreatic alpha-amylase secretion to improve starch digestion in the small intestine. Wet distillers grains with solubles provides a significant amount of UIP to the small intestine that may stimulate pancreatic alpha amylase secretion (Klopfenstein et al., 2008a). Research by Ham et al. (1994) showed an improvement in total tract starch digestion for steers fed a diet containing wet distillers without solubles compared to a DRC based diet. However, metabolism trials by Vander Pol et al. (2009) and Corrigan et al. (2009) found no difference in total tract apparent digestibility of diet DM, OM, NDF, and starch of steers fed a DRC diet or a 40% WDGS diet. In addition, Corrigan et al. (2009) found no interaction of feeding DRC or HMC with or without 40% WDGS on apparent total tract digestibility of DM, OM, NDF, or starch. These total tract digestibility measurements do not indicate partitioning of starch digestion between ruminal and post-ruminal fractions. Corrigan et al. (2009) did find that ruminal in-situ digestion of DRC DM and starch was greater for steers fed 40% WDGS than for steers fed corn diets without WDGS. This may indicate that feeding WDGS actually decreases the quantity of starch available for metabolism in the small intestine relative to DRC fed steers.

These data indicate that DGS inclusion level may interact with cattle type and corn processing method. However, due to an unknown mechanism the reason why is not completely understood. Therefore, a summary of research evaluating DGS inclusion with different cattle types and corn processing methods may be useful for producers to predict steer performance and to help elucidate the complex interactions of these factors

Distillers Grains for Dairy and Swine

Distillers Grains Use in Dairy Cattle Diets. A recent meta-analysis of dairy feed rations includes data from numerous research trials to estimate current DGS feeding practices for dairy production (Schingoethe, 2008). The nutrient composition of DGS makes it a good energy and protein source for dairy cows when dietary lipid contribution from DGS is managed, and diets fed to dairy cows may contain DGS to replace corn, protein, and forages (Janicek et al., 2008). It is more common, however, to replace corn and protein without replacing forage (Schingoethe, 2008). Results from published feeding studies are not consistent with regards to dairy cow milk production response to DGS inclusion. Some studies found no change in milk production when DGS were added to lactating dairy cow diets (Schingoethe et al., 1999). Other studies reported a dilution of milk components when DGS were fed (Nichols et al., 1998; Leonardi et al., 2005), or an increase in milk production from feeding DGS (Anderson et al., 2006; Kleinschmit et al., 2006). When all available research data were combined and evaluated in a meta-analysis, no production response to DGS feeding was evident, and milk composition was not affected by substituting DGS for corn.

Distillers grains have been fed up to 30% of diet DM to lactating dairy cows without negative effects on milk production when replacing corn and soybean meal

(Schingoethe, 2008). Survey data suggest that the inclusion of DGS in dairy diets is 10 to 22% (approximately 10% of DM) (NASS, 2007). At this relatively low inclusion level, DGS are primarily used as a protein supplement to replace soybean meal. The byproduct credit for DGS inclusion in dairy cow diets based on the direct replacement of corn and soybean meal is 0.45 kg of corn and 0.55 kg of soybean meal DM for each kilogram of DGS DM added to the diet (Schingoethe et al., 1999; Anderson et al., 2006; Kleinschmit et al., 2006).

Distillers Grains Use in Swine Diets. A recent review of swine research on feeding DDGS to finishing pigs is based on numerous studies (Stein, 2008). Finishing pigs are the main class of swine to use DDGS, and their feeding performance was not affected when each kg of DDGS replaced 0.57 kg corn and 0.43 kg of soybean meal in the diet. There were a few examples where reduced performance was observed when DDGS were fed. The reduced performance may have resulted from suboptimal diet formulation, the use of low-quality DDGS, or decreased palatability of DDGS diets to the pigs (Stein, 2008). Research has shown that DDGS may be included in grow-finish diets up to 27% of diet dry matter without decreasing ADG or G:F. When DDGS are added to swine diets, corn and soybean meal are replaced at the rate of 0.57 kg of corn and 0.43 kg of soybean meal dry matter per kilogram of DDGS dry matter (Stein, 2007). Because commercial swine feeding systems are developed to deliver dry feed (< 15% moisture) to finishing pigs, feeding WDGS has logistical challenges for use in these large-scale swine operations.

These data indicate that DGS is a feed for dairy cows and finishing swine in addition to beef cattle. However, dairy cows and swine to not have superior ADG and

G:F relative to corn fed cows and swine. Therefore, DGS is a direct replacement of corn and protein in these diets.

Operations Feeding Distillers Grains

A recent NASS survey of beef, dairy, and swine operations reported ethanol byproduct use for livestock feed in the U.S. Corn Belt (NASS, 2007). In 2006, the region contained 11.3 million cattle in 1000+ head feedlots, 3.2 million dairy cattle, and 64.1 million grow-finish pigs representing 50, 33, and 70% of U.S. beef, dairy, and pork production, respectively (NASS, 2008). The survey reported that 36, 38, and 12% of Corn Belt beef, dairy, and swine operations, respectively, were feeding byproducts in 2006. Estimating average corn-ethanol byproduct use, however, may be misleading when based on number of operations using byproducts. The data indicated that large-scale producers were more likely to use byproducts (NASS, 2007; Waterbury et al., 2009). Adjusting for operation size based on byproduct use (NASS, 2007and 2008), 63, 49, and 40% of finishing beef, dairy cows, and finisher pigs in the Corn Belt, respectively, were fed byproducts in 2006. These byproduct numbers are representative of the major DGS producing region of the United States. Use of DGS would likely be different in other regions of the United States. These data indicate that the beef, dairy, and swine industries are all adapting to the availability of DGS for diet formulation. However, not all livestock industries and producers within the respective industries are utilizing DGS equally.

Modeling Corn-Ethanol-Livestock Life Cycle Emissions

Corn DGS are an important part of the corn-ethanol-livestock life cycle when comparing GHG emissions of ethanol to gasoline. Distillers grains contains a significant quantity of energy and offsets corn, urea and soybean meal in livestock diets. The corn and protein replacement value of DGS is dependent on DGS moisture level, dietary inclusion level, and livestock class fed. Ethanol plant energy use and associated GHG emissions are impacted by moisture content of DGS produced.

While byproducts from corn grain-ethanol production are an important source of animal feed and additional income for biorefineries, byproduct production, processing, transport, and end-use also have a large impact on net GHG emissions from the corn-ethanol life cycle (Farrell et al., 2006; Klopfenstein et al., 2008a; Liska et al., 2009). State and federal regulations under development will require life cycle GHG emissions from biofuels to achieve minimum reduction levels compared to transportation fuels derived from petroleum. For example, the Energy Independence and Security Act of 2007 requires that corn-ethanol, cellulosic ethanol, and advanced biofuels reduce life cycle GHG emissions by 20, 60, and 50%, respectively (Liska et al., 2009). Because GHG-credits for byproducts have been previously estimated to offset 19 to 38% of positive life cycle emissions from corn production and biorefining (Liska et al., 2009), it is critical that these credits are accurately estimated to determine the net anthropogenic impact of corn-ethanol production on the atmosphere. Furthermore, such knowledge should be accurately captured by life cycle assessment (LCA) methods used in the regulatory process for biofuels.

Recent changes in byproduct use as livestock feed suggest that previous estimates of byproduct GHG credits are no longer representative of current industry practices

(NASS, 2007; Klopfenstein et al., 2008a). For example, recent estimates of substitution rates between byproducts and conventional feed (Arora et al., 2008) do not consider the impact of changing byproduct uses in livestock diets on the magnitude of the byproduct GHG credit, and its impact on the life cycle of corn-ethanol. Furthermore, varying rates of byproduct substitution in different livestock feeding settings requires a dynamic byproduct crediting model to determine the GHG credit attributable to each of the main livestock feeding systems.

The most widely used and accurate method for allocating byproduct GHG and energy credits to the corn-ethanol life cycle is through the displacement method in the context of "system expansion" (Kodera, 2007). This method assumes that byproducts from corn-ethanol production substitute for other feed components and offset fossil fuel use and associated GHG emissions required to produce the replaced feed components (Kodera, 2007; Liska et al., 2009). Alternative approaches to byproduct allocation include mass basis, energy content, and market value (Kim and Dale, 2002; Kodera, 2007). Although these alternative methods may be less data-intensive than the displacement method, they are not sensitive to the different livestock feeding values of corn-ethanol byproducts and therefore do not accurately represent changes in GHG emission profiles.

Estimating the displacement credit for an individual corn-ethanol biorefinery requires quantification of the different types of byproducts produced by the ethanol plant, identification of the products to be displaced in livestock diets (and displacement ratios), and calculation of the fossil fuel energy and GHG emissions attributable to the life cycle production of the displaced products (Wang, 1999; Graboski, 2002). Recent byproduct credit estimates assumed DGS displaced corn, urea, soybean meal, and oil, at a 15% inclusion level in feedlot cattle diets, as well as other variable substitutions (NRC, 2000; Graboski, 2002; Kodera, 2007).

These data collectively indicate that the corn-ethanol-livestock life cycle is a complex system. Decisions within the system may impact the environmental impact of the system relative to gasoline. Accurate predictions of livestock performance are needed to model the environmental impact of this system.

Gasoline Reference to Compare Corn-Ethanol-Livestock Cycle. The evaluation of ethanol relative to gasoline not only requires accurate evaluation of the ethanol production cycle, but also an accurate reference point for the GHG-intensity of gasoline. Gasoline emissions not only include combustion emissions, but also upstream emissions from crude oil recovery, refinery emission, and flaring losses (Brandt and Farrell, 2007). Emissions due to military security associated with acquisition of Middle Eastern petroleum, changes in the composition of petroleum supplies toward more GHG-intensive fuels, and other additional emissions from petroleum processing must also be considered (Liska and Perrin, 2009). The GHG emissions directly and indirectly related to cleaning up the recent BP oil spill in the Gulf of Mexico should also be charged to the GHG balance of gasoline. Indirect GHG emissions from military security for maritime oil transit are estimated to raise the GHG intensity of gasoline from the Middle East by roughly 20% over the conventional baseline (Liska and Perrin 2010).

Ethanol production does not displace average gasoline, but displaces a marginal unit of gasoline that may have a much greater environmental cost than average gasoline

(US EPA, 2010). As the proportion of gasoline derived from more energy intense processes increases, the GHG life cycle reference point of gasoline should be updated to compare a marginal liter of gasoline to an equal energy quantity from ethanol. The GHG-intensity of gasoline is increasing due to depletion of efficiently accessible deposits (Brandt and Farrell, 2007). Unconventional and less efficiently processed sources of petroleum such as tar sands, coal-to-liquids, and oil shale will likely be used to fill the difference between current petroleum supply and energy demand. In fact, Canadian tar sands could supply 20% of US gasoline by 2020 (Liska and Perrin, 2009).

Indirect GHG impacts of ethanol and gasoline. Indirect impacts of ethanol and gasoline production are of interest in addiction to direct impacts. Evaluation of indirect GHG emissions from ethanol and gasoline is immensely complex (Liska and Perrin, 2009; US EPA, 2010). A methodology to incorporate both reasonably accurate scientific knowledge about direct life cycle emissions and relatively diffuse and uncertain scientific knowledge concerning potentially significant indirect emissions must be developed to fully evaluate the GHG mitigation potential of ethanol (Liska and Perrin, 2009; US EPA, 2010). This is especially true when the indirect effects may provide a large impact on the life cycle being analyzed.

Some organizations have proposed to add the single indirect emission from land use change due to increased ethanol production (e.g. as done by the California Air Resources Board), yet land use change is only one significant indirect GHG emission among many. Other significant indirect emissions include military security emissions, changes in rice cultivation, and changes in livestock globally (Liska and Perrin, 2009; Liska and Perrin 2010; US EPA, 2010). The indirect environmental impact of oil drilling is also becoming a significant source of concern with acquiring energy. Further research is needed before we can have reasonable confidence in the net effects of indirect GHG emissions of both biofuels and petroleum fuels (Liska and Perrin, 2009). A comprehensive assessment of the total GHG emissions implications of substituting ethanol for petroleum needs to be completed before the impact of indirect GHG emissions from land use change alone can be accurately determined.

Indirect land use change is only associated with future expansion of the ethanol industry. Emissions from existing ethanol production facilities are limited to direct emissions, given whatever indirect emissions were associated with initiating ethanol production at these facilities has already occurred. Because of this, biofuels use now from existing facilities not only reduces GHG emissions from transportation fuel use compared to petroleum, but also supports national security goals of decreased dependence on foreign oil and rural development objectives to increase employment opportunities and improve the sustainability of rural communities. Evaluation of these additional policy objectives are not considered in GHG emissions modeling frameworks, but are important considerations when comparing fuels.

These data collectively indicate that calculation of the environmental impact of gasoline is as complex as for ethanol. Some impacts from both the gasoline and ethanol systems may be so complex that many years are required to develop conclusive evidence on their environmental impacts.

Conclusion

A review of current DGS feeding data indicate several trials have been conducted feeding DGS to beef cattle, however they have not been effectively summarized to predict cattle DMI, ADG, and G:F when fed DGS. The moisture content, inclusion level, corn processing type replace, and cattle type all interact with DGS inclusion in the diet. These individual trial data need to be summarized to provide more meaningful cattle performance predictions when fed DGS. The mechanisms for these interactions are not understood, based on current knowledge of feeding DGS. An understanding of the lipid metabolism characteristics of steers fed DGS may offer some insight into the mechanisms responsible for DGS feeding value superior to corn. These conclusions have resulted in the development of the following research objectives.

Objectives of Research

1) Create updated cattle performance prediction equations when fed distillers grains with the most complete data available and to evaluate the impact of DGS moisture and inclusion level in livestock diets on ethanol GHG emissions from the corn-ethanol-livestock life cycle relative to gasoline.

2) Evaluate the interactions of cattle type and corn processing method on cattle performance with WDGS inclusion level.

3) Optimize the performance of a new lipid analysis procedure for ethanol industry feedstuffs.

4) Evaluate cattle performance and metabolism characteristics of feedlot diets containing traditional and byproduct lipid sources.

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Distillers grains, corn processing, and cattle type

Meta-Analysis of Feeding Calf-Feds or Yearlings Fed Wet Distillers Grains with Different Corn Processing Types[1]

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ABSTRACT

Feedlot cattle performance data from 20 trials (n = 350 pen means; representing 3,365 steers) evaluating dietary inclusion of corn wet distillers grains plus solubles (WDGS) were summarized with two meta-analyses. The objective of this study was to evaluate the effects of WDGS inclusion level with dry-rolled corn (DRC) or a blend of DRC and high-moisture corn (HMC) for either calf-feds or yearlings on WDGS feeding value. The feeding value of 10 to 40% of diet DM as WDGS was superior to corn and averaged 150-130% of the corn replaced. Feeding WDGS with diets containing HMC resulted in G:F superior to steers fed DRC with or without WDGS. The feeding value of WDGS was greater when WDGS replaced DRC compared with a DRC and HMC blend. The feeding value of WDGS was greater when fed to yearlings than for calf-feds. The biological mechanisms responsible for WDGS feeding value with different corn processing types is not well understood.

Keywords: Cattle, Corn Processing, Distillers Grains, Feedlot

INTRODUCTION

Cattle type (calf-feds or yearlings) and corn processing method (dry-rolled corn (DRC) or high-moisture corn (HMC)) have been shown to influence cattle performance. A 98-pen summary of feeding similar sourced calf-feds and yearlings demonstrated that calf-feds have lower daily DMI, ADG, and greater days on feed than yearlings (Adams et al., 2007; Griffin et al., 2007). However, calf-feds have greater G:F than yearlings. Research has also shown that steers fed a finishing diet with HMC have lower DMI, similar ADG, and improved G:F relative to cattle fed DRC (Stock and Erickson, 2009).

Corn wet distillers grains plus solubles (WDGS; 32% DM) has a greater feeding value compared to DRC or a blend of DRC and HMC (Klopfenstein et al., 2008b). In a trial reported by Vander Pol et al. (2008), 30% WDGS (DM basis) was fed and G:F was numerically superior for steers fed HMC compared to DRC or a DRC and HMC blend. However, 0% WDGS diets were not fed to evaluate the response to WDGS from different corn processing types. The Corrigan et al. (2009) trial evaluated the response to feeding 0, 15, 27.5, and 40% WDGS (DM basis) with either DRC or HMC. A greater G:F response to WDGS was observed with DRC than HMC. However, G:F for HMC-fed steers was greater than G:F of DRC-fed steers with up to 40% of diet DM as WDGS. Previous research has also evaluated feeding WDGS to winter calf-feds and summer yearlings in a confinement barn (Larson et al., 1993) over two years. The researchers reported a greater feeding value of WDGS replacing 40% of diet DM as DRC for yearlings than calf-feds, 151 and 134% the feeding value of DRC, respectively.

Previous research has evaluated the main effects of corn processing type, cattle type, and WDGS inclusion level on cattle performance. However, the interaction of these three factors has not been evaluated. Therefore, a pen level meta-analysis of University of Nebraska research was conducted to evaluate the interactions of cattle type and corn processing method on cattle performance when cattle consume WDGS.

MATERIALS AND METHODS

Cattle Performance Data

All trials included in the analyses evaluated feeding corn WDGS as an energy source replacing DRC, HMC, or a blend of the two. All WDGS was sourced from a single ethanol plant within trial and contained condensed corn distillers solubles (CCDS). All HMC contained a minimum of 27% moisture. Corn gluten meal was added as an undegradable protein (UIP) source early in the feeding period when steers were calculated to be UIP deficient by NRC (1996). All trials had a corn control diet formulated to meet minimum NRC (1996) UIP and degradable intake protein (DIP) requirements. As WDGS level increased, urea was removed from the supplement and limestone was added to balance calcium to phosphorus ratio. Individual animal carcass data were collected on all steers and feeding performance was calculated from carcass adjusted final weight with a common 62 or 63% dress within trial. Trials evaluated feeding from 0 to 50% of diet DM as WDGS with no other co-product in the diet. All trials were conducted under similarly managed feedlot research settings across multiple years at the University of Nebraska Beef Research Feedlots. Animal use procedures were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee.

Griffin et al. (2007) described and analyzed the management system utilized for the calf-feds and yearlings fed as part of this study. The UNL feedlot purchased spring-born, predominately black, crossbred steers weaned in the fall for research trials. After an initial receiving period, the heaviest steers were fed as calf-feds in the winter, the medium steers were fed as short-yearlings in the summer after wintering on corn stalks, and the lightest steers were wintered on corn stalks, grazed on grass the following summer, and finished in the fall to market by 24 months of age.

Performance predictions of WDGS fed cattle were developed from 20 feedlot cattle finishing trials with 350 pen means representing 3,365 steers fed (Larson et al., 1993; Ham et al., 1994; Al-Suwaiegh et al., 2002; Vander Pol et al., 2005, 2009; Godsey et al., 2008a, 2008b; Meyer et al., 2008; Wilken et al., 2008; Corrigan et al., 2009; Rich et al., 2009, 2010; Loza et al., 2010; Luebbe et al., 2010; Moore et al., 2010; Nuttelman et al., 2010; Sarturi et al., 2010). Winter calf-feds were fed in seven trials, summer yearlings were fed in ten trials, and fall long yearlings were fed in three trials. Steers were fed DRC in 11 trials and a blend of DRC and HMC in 9 trials (1:1 ratio of DRC:HMC for 6 trials and 2:3 ratio of DRC:HMC for 3 trials), and HMC as the only corn source in one trial.

The results of the current analysis were compared to similarly conducted meta-analyses conducted on similarly managed cattle when fed modified distillers grains plus solubles (MDGS; 46% DM) or dried distillers grains plus solubles (DDGS; 90% DM) (Bremer et al., 2010b). Cattle performance predictions of MDGS fed steers were developed from four UNL feedlot trials with 85 pens representing 680 steers (Adams et al., 2007; Huls et al., 2008; Luebbe et al., 2010; Nuttelman et al., 2010). Cattle performance predictions of DDGS steers were developed from 4 UNL feedlot trials with 66 pens representing 581 steers (Ham et al., 1994; Buckner et al., 2010; Nuttelman et al., 2010; Sarturi et al., 2010).

Data Analysis

Meta-analysis methodology for integrating quantitative findings from multiple studies was utilized for data analysis of WDGS inclusion level and corn processing type with either calf-feds or yearlings (St-Pierre, 2001). This method accounts for the random effect of individual trial with a structured iterative analytical process utilizing the PROC

MIXED procedure of SAS (SAS Inst., Inc., Cary, NC, USA). Pen mean was the experimental unit of analysis. Trials were weighted by number of WDGS levels evaluated to prevent artificial linear responses from trials with only two levels of WDGS fed. Biological performance equations were developed based on significant model variables. The intercepts (0% DGS diet) of the MDGS and DDGS predicted performance equations of Bremer et al. (2010b) were scaled to the intercept of the WDGS prediction equations from the current analysis to compare differences in cattle performance relative to a common 0% DGS diet. The equation adjustment allowed the evaluation of how an individual steer would perform if given one of the three products relative to a common corn diet base point.

Two meta-analyses of the data were conducted. The initial analysis was for the overall effect of WDGS inclusion level regardless of cattle type and corn processing method to update previously reported WDGS feeding values. This analysis was then compared to the MDGS and DDGS cattle performance reported by Bremer et al. (2010b). The second analysis evaluated the effect of corn processing method and WDGS inclusion level on G:F of calf-feds or yearlings.

Feeding value of distillers grains (DGS) relative to corn was calculated from G:F output. Feeding value of a specific dietary inclusion level of DGS was calculated as ((((DGS level G:F) – (0% DGS G:F))/(0% DGS G:F))/(diet DM % DGS))+1. This calculation assumes that the difference in G:F of the control diet and the test diet is due to DGS inclusion replacing corn.

RESULTS AND DISCUSSION

20 Trial Wet Distillers Grains Finishing Summary

Replacement of corn up to 40% of diet DM as WDGS resulted in superior ADG and G:F compared to cattle fed no WDGS (Table 1). These data agree with a previous meta-analysis of Klopfenstein et al. (2008a). Dry matter intake, ADG, G:F, 12th rib fat, and marbling score were increased quadratically ($P < 0.01$) as WDGS inclusion level increased. The feeding value of WDGS was consistently greater than corn when WDGS was included up to 40% of diet DM. The feeding value was greater at lower WDGS inclusion levels and decreased as inclusion level increased, but was still better than 0% WDGS. Feeding value of WDGS was 150 to 130% of corn for 10 to 40% of diet DM as WDGS. These values are consistent with the 142 to 131% of corn for 20 to 40% of diet DM as WDGS values reported by Klopfenstein et al. (2008a). The current study expanded upon the 9-trial, 34-treatment mean meta-analysis of Klopfenstein et al. (2008a) by accounting for additional trial to trial variation with pen mean performance as the observational unit and increased number of trials included in the analysis.

The results from the current WDGS meta-analysis combined with the DDGS and MDGS meta-analyses of Bremer et al. (2010b) indicate the following combined conclusions. Steer DMI increased quadratically as DGS inclusion level increased, regardless of DGS moisture content (Table 1). The greatest numeric increase in DMI occurred when DDGS replaced corn. The DMI response to MDGS inclusion was intermediate to DDGS and WDGS. Maximum DMI of steers fed DDGS occurred at a greater level of DGS inclusion than MDGS, and the maximum DMI intake of steers fed WDGS occurred at the lowest level of DGS inclusion of the three DGS moisture products. Quadratic increases in ADG and G:F were observed when steers were fed

WDGS or MDGS. Steer ADG and G:F improved linearly as DDGS replaced corn in the diet. Steer ADG was similar for the three DGS moisture products. The DGS products all contained greater feeding value than corn. The feeding values of WDGS, MDGS, and DDGS, when fed at 10 to 40% of diet DM, were 150 to 130, 128 to 117, and a constant 112% of corn (DM basis), respectively. The G:F of DGS fed steers decreased as moisture level decreases. The feeding value of WDGS and MDGS decreased as inclusion level increases. The feeding value of DDGS was a constant 112% of corn DM.

Distillers Grains Moisture Level and Cattle Performance

Integration of the findings from the current meta-analysis was combined with the DDGS and MDGS meta-analyses of Bremer et al. (2010b). The greatest DMI occurred when DDGS was the byproduct replacing corn and at the higher inclusion levels (Table 1). The DMI response to MDGS inclusion was intermediate to DDGS and WDGS. Maximum DMI of steers fed DDGS occurred at a greater level of DGS inclusion than the maximum DMI of MDGS fed steers. The maximum DMI intake of steers fed WDGS occurred at the lower levels of DGS inclusion (10 and 20%). Quadratic increases in ADG ($P < 0.01$) and G:F ($P = 0.05$) were observed when steers were fed increasing levels of WDGS or MDGS. Steer ADG and G:F improved linearly ($P < 0.01$) as DDGS replaced corn in the diet. Steer ADG was similar for the three DGS moisture products. The DGS products all contain greater feeding value than corn. The feeding values of WDGS, MDGS, and DDGS, when fed at 10 to 40% of diet DM, were 150 to 130, 128 to 117, and a constant 112% of corn (DM basis), respectively. The feeding value of DGS decreased as DGS moisture level decreased.

Decreased steer feeding performance as moisture is removed from WDGS is in agreement with individual trials evaluating both WDGS and DDGS in the same trial (Ham et al., 1994; Nuttelman et al., 2010; Sarturi et al., 2010). Nuttelman et al. (2010) conducted the first trial to evaluate feeding multiple dietary inclusion levels of WDGS, MDGS, and DDGS in the same trial. The MDGS and DDGS were sourced from the same ethanol plant. The researchers noted the feeding value of WDGS being greater than MDGS and both being greater than DDGS. Similar ADG of steers fed WDGS, MDGS, or DDGS with different DMI may indicate cattle fed dryer DGS products eat to a constant energy intake.

The feeding value of DGS is derived from ethanol plant management decisions on drying DGS and the ratio of grains to CCDS in the DGS produced. Supply and demand for DDGS, MDGS, WDGS, and CCDS ultimately drive the marketing decisions of the ethanol plant. Available livestock populations, DGS transportation costs, and availability of competeing feedstuffs are drivers of these marketing decisions (Buckner et al., 2008; Bremer et al., 2010c). Drying WDGS improves shelf life and decreases shipping costs due to less moisture being hauled. Drying WDGS allows access to export markets, the swine industry, and livestock industries in other regions of the US. This flexibility comes at a cost. In addition to the decrease in feeding value of DDGS relative to WDGS, the fixed and variable costs of owning and operating a dryer in an ethanol plant are significant (Baumel, 2008). Ethanol plant decisions on DGS moisture management also impact the GHG balance of ethanol produced. Ethanol plants producing DDGS require 167% as much energy and produce 145% of the GHG emissions of ethanol plants producing WDGS (Bremer et al., 2010c). This emphasizes the importance of making ethanol production decisions that are environmentally sound.

Inherent error of calculated feeding values may increase as test ingredient inclusion level decreases. This increase in error may be caused by increased variation in cattle performance due to greater corn starch load with low DGS inclusion level diets that may limit dietary acidosis control (Stock and Erickson, 2009). The cattle performance variation may then be magnified by numerically smaller devisors from low DGS inclusion in the feeding value equation.

Control Diet Impact on Feeding Value

Calculated feeding value of a feed ingredient is impacted by both the performance of the cattle fed the WDGS diet and performance of cattle fed the control diet. Acidosis control, interaction of diet ingredients fed, and cattle management influence the relative difference in cattle performance when fed the two diets. The replacement of corn and urea with WDGS has allowed for the evaluation of feeding performance due to the test ingredient without directly confounding other dietary factors. However, both the control diet and the test diet may not have been completely optimized in terms of cattle performance due to differences in diet characteristics provided by the test ingredient.

Optimal corn processing type may be different for the control diet relative to a diet containing 30% WDGS. Utilizing ground HMC may complement low starch WDGS and provide superior cattle performance. However, if similarly processed HMC is used for the control diet, acidosis management may be a concern that hinders control cattle performance and induces error in the comparison of WDGS to corn.

Effect of Corn Processing Method

The feeding values of DRC and a blend of DRC and HMC were similar for 0% WDGS fed steers within cattle type (Table 2). The feeding value of WDGS was greater when WDGS replaced DRC as compared to a corn blend at any inclusion level of WDGS.

Only one trial has evaluated feeding WDGS replacing HMC or DRC with WDGS in diets within the same trial (Corrigan et al., 2009). The trial evaluated replacing each corn type with up to 40% of diet DM as WDGS. The DRC 0% WDGS cattle performed similar to the winter DRC fed cattle in the meta-analysis. The HMC had 115% the feeding value of DRC in their trial. The improvement in G:F of increasing WDGS from 0 to 40% WDGS in HMC diets is less than the improvement in G:F of DRC or corn blend due to HMC having a greater feeding value than DRC. As HMC was replaced by WDGS, the feeding value differential was less than the feeding value differential of WDGS and DRC because HMC feeding value is greater than DRC. These data suggest the combination of 47.5% of diet DM as HMC and 40% of diet DM as WDGS has a feeding value equal to 122% of DRC.

Feeding HMC with WDGS offers feedlots an opportunity to capitalize on a cheap, localized supply of corn. As United States corn production increases, harvesting and storing the larger crop has logistical limitations due to environmental factors and a semi-fixed amount of storage (Cassman and Liska, 2007). Feedlot use of HMC offers farmers an increased window of opportunity to harvest corn without incurring drying costs of wet corn harvested early in the harvest season (Macken et al., 2006). In a time of greater price volatility in inputs to operate a feedlot, owning the physical corn commodity may offer a risk management strategy to the feedlot. Pricing the corn in the fall when supply is greatest may allow purchase of corn at a price below the marketing year average. Some feedlots and corn producers may prefer to risk manage this cost in other ways, including but not limited to, pricing a portion of the corn on a monthly basis to spread out farmer income and allowing farmers to “store” the corn at the feedlot without drying cost to price for future payment. The feedlot may risk manage this cost by hedging the purchase when the physical commodity arrives in the yard. Minimizing storage costs and product shrink losses are also important management factors. Managing a physical inventory of HMC may lock a feedlot into feeding a certain level of corn in the diet that may not allow them to take advantage of future feed product opportunities. The ability to transfer ownership and use of HMC to other feedlots is also less than dry corn, in the event a feedlot decides marketing corn is more profitable than feeding cattle. These strategies are provided to demonstrate that innovative options are available to manage the cost of owning the physical HMC inventory, although, risk of commodity ownership must also be accounted for.

Calf-feds and Yearlings

We realize that season of feeding and steer age are confounded in the previously discussed UNL feedlot system. However, the confinement barn study of Larson et al. (1993) provided a moderate environment for both winter and summer steer feeding, and cattle were fed as either calf-feds or yearlings in two consecutive years. Their study indicated greater feeding value of WDGS for yearlings than calf-feds. Therefore, we conclude the effect of steer age is more important than season of feeding on cattle performance.

As expected, calf-feds were more efficient than yearlings ($P < 0.01$; Table 2). The feeding value of WDGS, regardless of corn processing type, was greater for yearlings than for calf-feds. The feeding value of WDGS was a constant 136% of DRC and a constant 124% of a DRC and HMC blend for calf-feds due to linear improvement in G:F as WDGS replaced each corn processing type. Yearling performance improved quadratically as WDGS level increased, regardless of corn processing type ($P < 0.01$). The feeding value of WDGS for yearlings decreased in both DRC and blended corn diets. Feeding value of WDGS replacing 10 to 40% of diet DM for yearlings decreased from 167 to 143% of DRC and from 154 to 131% for a blend of DRC and HMC.

Practical application of these findings may include increasing WDGS inclusion level for yearling cattle fed in the summer. Feedlots may be able to capture value from both purchasing WDGS below yearly average prices and greater corn replacement with WDGS for yearlings than calf-feds in summer months. The relative demand of WDGS compared to WDGS supply may be more favorable in summer months relative to winter due to decreased cattle on feed (Erickson et al., 2008).

Mechanism of WDGS Performance Response

The biological mechanisms responsible for the superior feeding value of WDGS relative to corn have been elusive. The mechanism is perplexing due to the WDGS paradox. The paradox is that most of the energy in corn (starch) is removed to create WDGS which has greater feeding value with lower DM digestibility than corn (Vander

Pol et al., 2009; Corrigan et al., 2009; Bremer et al., 2010a). In addition, NRC (1996) predicts lower G:F when WDGS is fed than feeding trials indicate. NRC (1996) inputs from conventional WDGS laboratory nutrient assays do not accurately predict cattle performance.

A proposed biological mechanism for the superior feeding value of WDGS relative to corn is a shift of acetate to propionate production in the rumen of steers fed WDGS (Corrigan et al., 2009; DiLorenzo and Galyean, 2010). Vander Pol et al. (2009) and Corrigan et al. (2009) found reduced acetate-to-propionate ratio (A:P) when cannulated steers were fed 40% WDGS diets compared to a corn control diets. However, trials by Ham et al. (1994) and Bremer et al. (2010a) found that feeding 40% of diet DM as wet distillers grains without solubles, 40% WDGS with 37.5% of WDGS DM as CCDS, or 56% diet DM as WDGS had similar or increased A:P relative to DRC-fed steers.

It has been hypothesized that the decrease in A:P ratio is due to low ruminal pH of WDGS fed steers causing increased hemicelluloses fermentation relative to cellulose fermentation (Murphy et al., 1982; DiLorenzo and Galyean, 2010). Both the hemicellulose and cellulose fractions of corn are concentrated when the corn starch is removed during fermentation. The better understanding of WDGS NDF digestion is needed to evaluate this hypothesis. We do not have a clear understanding for why hemicellulose fermentation would be favored over cellulose fermentation in WDGS diets has not been elucidated at this point in time. Of the five metabolism trials discussed where WDGS was fed relative to a corn control, WDGS did not significantly reduce average ruminal pH. However, four of the five trials reported numerically lower average ruminal pH. Three trials reported the amount of time ruminal pH was less than 5.6. Two of the three trials reported that steers fed WDGS had a greater time ruminal pH was below 5.6 than for steers fed a corn diet. The other trial indicated numerically greater average pH and less time with ruminal pH less than 5.6 for WDGS fed steers.

Feeding thin stillage or CCDS replacing DRC in finishing diets has consistently shown a decrease in A:P ratio relative to feeding DRC (Ham et al., 1994 and Bremer et al., 2010a). In three trials, Hanke and Lindor (1983) evaluated feeding thin stillage (CCDS prior to moisture removal) in place of drinking water to finishing cattle and found 5.7 and 11.0% improvements in ADG and G:F, respectively, with reduced DMI when thin stillage was fed. Rust et al. (1990) evaluated feeding up to 20% of diet DM as CCDS and observed improved G:F when CCDS was fed relative to corn control. Trenkel (1997 and 2002) evaluated feeding 0 to 8% of diet DM as CCDS replacing DRC in finishing diets and noted improved G:F when CCDS was fed. Godsey et al., 2008a evaluated feeding combinations of wet distillers grains (10.0% ether extract) and CCDS (27.8% ether extract) with 100:0, 85:15, or 70:30 ratios of wet grains to CCDS at either 20 or 40% of diet DM. They found no interaction of byproduct level with CCDS level and G:F numerically improved as proportionately more CCDS were fed. In addition Bremer et al. (2010a) found that CCDS had a feeding value equal to HMC in diets containing 35% Sweet Bran® wet corn gluten feed (Cargill Inc., Blair, Nebraska). These findings indicate difference in A:P of the different metabolism trials may be due to different ratios of wet grains to CCDS in WDGS.

Intake of NDF is roughly two times greater with WDGS diets than corn control diets. Evaluation of ruminal NDF digestion with 22 or 24 h ruminal in-situ incubation of corn bran has shown no difference in corn bran NDF digestion when steers were fed a corn diet or a 40 to 56% WDGS diet (Corrigan et al., 2009; Bremer et al., 2010a). In both studies, ruminal digestibility of corn bran was low and averaged 29 and 21% for Corrigan et al. (2009) and Bremer et al. (2010a), respectively. Vander Pol et al. (2009) reported 56 and 71% ruminal diet NDF digestibility for corn and WDGS fed steers, respectively. The in vivo NDF digestibility calculations of Vander Pol et al. (2009) indicate greater ruminal NDF digestibility of corn and WDGS when fed to steers than the in situ corn bran digestibility data of Corrigan et al. (2009) and Bremer et al. (2010a). Inherent errors exist within both in situ and in vivo ruminal NDF digestibility calculations. Therefore, it is unclear what fractions of WDGS versus forage NDF are digested ruminally. Total tract WDGS diet NDF digestibility has been reported from four trials to be numerically greater (significantly greater in one of the trials) than corn diet NDF digestibility (Ham et al., 1994; Corrigan et al., 2009; Vander Pol et al., 2009; Bremer et al., 2010a). Therefore, roughly double the amount of NDF is digested by WDGS fed steers as compared to corn control fed cattle. The differential in total tract digestibility of corn starch and WDGS NDF may explain a portion of the decrease in digestibility of WDGS diets relative to corn control diets in the metabolism studies.

Steers consuming diets containing 40% WDGS consume more than twice the amount of lipid as control corn fed steers. Extent of fatty acid digestion is not depressed by the high dietary lipid content relative to a corn control diet with or without added lipid from corn oil, tallow, or CCDS (Bremer et al., 2010a). Therefore, steers fed 40% WDGS metabolize twice the amount of lipid as steers fed corn diets without additional fat. Vander Pol et al. (2009) and Bremer et al. (2010a) have shown that a portion of WDGS fatty acids are protected from ruminal biohydrogenation. This results in a portion of WDGS fatty acids reaching the small intestine for absorption as unsaturated fatty acids. Unsaturated fatty acids may be more efficiently absorbed than saturated fatty acids (Plascenscia et al., 2003). Increased absorption of WDGS fatty acids in the unsaturated form has been verified by increased proportion of polyunsaturated fatty acids in steaks from steers fed WDGS diets (de Mello et al., 2007).

The theoretical energy benefit of fat relative to starch is more significant for ruminant animals than monogastric animals due to ruminal energy loss from microbial heat production and gaseous energy loss. Lodge et al. (1997) evaluated feeding a simulated WDGS product from a combination of wet corn gluten feed, tallow, and corn gluten meal. The feeding value of the WDGS composite was decreased from 124 to 118% of DRC when the tallow was removed. The relative ratio of wet grains to CCDS in WDGS influences the dietary lipid contribution of WDGS. Research has shown no difference (Godsey et al., 2008a) or improved feeding value of WDGS (Bremer et al., 2010a) with increased ratio of CCDS to wet grains in WDGS. Godsey et al., 2008a evaluated feeding combinations of wet distillers grains (10.0% ether extract) and CCDS (27.8% ether extract) with 100:0, 85:15, or 70:30 ratios of wet grains to CCDS at either 20 or 40% of diet DM. They found no interaction of wet distillers grains by CCDS level interaction or CCDS level response. Bremer et al. (2010a) evaluated feeding 35% of diet DM as wet distillers grains with no CCDS (6.7% lipid) or traditional WDGS (13.0% lipid). They found the wet grains and WDGS to have 102 and 127% the feeding value of a DRC and HMC blend, respectively. The difference in findings from these two studies may be due to the greater lipid content of the wet distillers grains without solubles in the

Godsey et al. (2008a) trial. In addition to lipid content differences between the wet grains and WDGS diets in these two studies, the CCDS in the WDGS treatments also provided protein from yeast cells in addition to other nutrients.

Mechanism of WDGS and Corn Processing Type Interaction

Increasing degree of corn processing has been shown to increase the proportion of corn starch digested in the rumen. The increased quantity of starch reaching the small intestine with the less processed corn is a theoretical improvement in starch utilization efficiency (Huntington et al., 2006). However, the limitation to this efficiency may be the ability of the small intestine to digest and absorb glucose from dietary starch. This digestion may be limited by alpha amylase activity. Increasing amounts of post-ruminal infusion of partially hydrolyzed starch or glucose in cannulated steers fed a forage diet has been shown to decrease pancreatic alpha amylase secretion (Swanson et al., 2002). Results of Richards et al. (2002 and 2003) indicate that intestinal protein supply is important in stimulating pancreatic alpha-amylase secretion to improve starch digestion in the small intestine. Wet distillers grains with solubles provides a significant amount of UIP to the small intestine that may stimulate pancreatic alpha amylase secretion (Klopfenstein et al., 2008a). Research by Ham et al. (1994) observed an improvement in total tract starch digestion for steers fed a diet containing wet distillers grains without solubles compared to a DRC based diet. However, Vander Pol et al. (2009) and Corrigan et al. (2009) found no difference in total tract apparent digestibility of diet DM, OM, NDF, and starch of steers fed a DRC diet or a 40% WDGS diet. In addition, Corrigan et al. (2009) found no interaction of feeding DRC or HMC with or without 40% WDGS on apparent total tract digestibility of DM, OM, NDF, or starch. These total tract digestibility measurements do not indicate partitioning of starch digestion between ruminal and post-ruminal fractions. Corrigan et al. (2009) did find that ruminal in-situ digestion of DRC DM and starch was greater for steers fed 40% WDGS than for steers fed corn diets without WDGS. This may indicate that feeding WDGS actually decreases the quantity of starch available for metabolism in the small intestine relative to DRC-fed steers.

The protein, fiber, and lipid components of WDGS and WDGS moisture content have been investigated to determine why cattle gain more efficiently when fed WDGS in the place of corn. The current summary of research also indicates that the feeding value of WDGS interacts with corn processing method and cattle age. However, current WDGS cattle metabolism data do not indicate a clear mechanism for the improved feeding value of WDGS relative to DRC or HMC based on theorized mechanisms of feeding value improvement.

IMPLICATIONS

The performance response clearly shows WDGS to be an excellent cattle feed and to be superior in feeding value to MDGS and DDGS. Many years of research were required to develop a large enough database to evaluate these effects. New laboratory analytical procedures are needed to efficiently evaluate the feeding value of byproduct feeds in the future. The development of these laboratory procedures may be futile until the mechanisms responsible for cattle performance when fed WDGS are clearly understood. Without laboratory procedures to evaluate byproduct feeding values, the extended time frame required to capture live animal performance of new byproducts will be a constriction in cattle industry utilization of byproduct feeds.

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Table 1. Finishing steer performance when fed different dietary inclusions of corn wet distillers grains plus solubles (WDGS), modified distillers grains plus soluble (MDGS) or dried distillers grains plus soluble (DDGS) replacing dry rolled and high moisture corn.

	DGS Inclusion[1]						
Item	0DGS	10DGS	20DGS	30DGS	40DGS	Lin[2]	Quad[2]
WDGS[3]							
DMI, kg/d	10.4	10.6	10.6	10.4	10.2	0.01	< 0.01
ADG, kg	1.60	1.71	1.77	1.78	1.75	< 0.01	< 0.01
G:F	0.155	0.162	0.168	0.171	0.173	< 0.01	< 0.01
Feeding value, %[4]		150	143	136	130		
12th rib fat, cm	1.22	1.32	1.37	1.40	1.40	< 0.01	0.01
Marbling score[5]	528	535	537	534	525	0.19	< 0.01
MDGS[6]							
DMI, kg/d	10.4	10.8	10.9	10.9	10.6	0.95	< 0.01
ADG, kg	1.60	1.71	1.77	1.78	1.74	< 0.01	< 0.01

G:F	0.155	0.159	0.162	0.164	0.165	< 0.01	0.05
Feeding value, %[4]		128	124	120	117		
DDGS[6]							
DMI, kg/d	10.4	10.9	11.2	11.3	11.3	< 0.01	0.03
ADG, kg	1.60	1.66	1.72	1.77	1.83	< 0.01	0.50
G:F	0.155	0.156	0.158	0.160	0.162	< 0.01	0.45
Feeding value, %[4]		112	112	112	112		

[1] Dietary treatment levels (DM basis) of distillers grains plus solubles (DGS), 0DGS = 0% DGS, 10DGS = 10% DGS, 20DGS = 20% DGS, 30DGS = 30% DGS, 40DGS = 40% DGS.

[2] Estimation equation linear and quadratic term t-statistic for variable of interest response to DGS level.

[3] WDGS data presented are summarized from Larson et al., 1993; Ham et al., 1994; Al-Suwaiegh et al., 2002; Vander Pol et al., 2005; Godsey et al., 2008a, 2008b; Meyer et al., 2008; Wilken et al., 2008; Corrigan et al., 2009; Rich et al., 2009; Vander Pol et al., 2009; Loza et al., 2010; Luebbe et al., 2010; Moore et al., 2010; Nuttelman et al., 2010; Rich et al., 2010; Sarturi et al., 2010.

[4] Feeding value is relative to a blend of dry-rolled corn and high-moisture corn and calculated from DGS inclusion level G:F relative to 0WDGS G:F for each WDGS inclusion level. Feeding value for any level of DGS inclusion = ((((DGS level G:F) – (0% DGS G:F))/(0% DGS G:F))/(diet DM % DGS))+1.

[5] 500 = Small^0.

[6] MDGS and DDGS steer performance, summarized by Bremer et al., 2010b, were scaled to the WDGS intercept for equal comparison across byproduct types. This process was validated by the results of Nuttelman et al., 2010.

Table 2. Finishing steer performance when calf-feds or yearlings were fed different dietary inclusions of wet distillers grains plus solubles (WDGS) replacing dry rolled corn (DRC) or a blend of DRC and high moisture corn (HMC).

	WDGS inclusion[1]						
Item	0WDGS	10WDGS	20WDGS	30WDGS	40WDGS	Lin[2]	Quad[2]
Winter calf-feds							
DRC diet, G:F	0.162	0.168	0.174	0.180	0.186	< 0.01	0.18
Feeding value, % of DRC[2]		136	136	136	136		
DRC and HMC blend[3], G:F	0.162	0.166	0.170	0.174	0.178	< 0.01	0.18
Feeding value, % of corn blend[2]		124	124	124	124		
Summer yearlings							
DRC diet, G:F	0.148	0.158	0.165	0.171	0.174	< 0.01	< 0.01
Feeding value, % of DRC[2]		167	159	151	143		
DRC and HMC blend[3], G:F	0.148	0.156	0.162	0.165	0.166	< 0.01	< 0.01
Feeding value, % of corn blend[2]		154	146	138	131		

[1]Dietary treatment levels (DM basis) of wet distillers grains plus solubles (WDGS), 0WDGS = 0% WDGS, 10WDGS = 10% WDGS, 20WDGS = 20% WDGS, 30WDGS = 30% WDGS, 40WDGS = 40% WDGS.

[2] Percent of respective corn processing type feeding value, calculated from predicted G:F relative to 0WDGS G:F, divided by WDGS inclusion. Feeding value for any level of DGS inclusion = ((((DGS level G:F) – (0% DGS G:F))/(0% DGS G:F))/(diet DM % DGS))+1.

[3]The trials included in this analysis evaluated WDGS inclusion replacing either a 1:1 or 2:3 ratio of DRC to HMC.

Running Header: Byproduct lipid and NDF analysis

Technical note: Method for lipid and NDF analysis of ethanol byproduct feedstuffs[1]

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ABSTRACT: Four experiments were conducted to evaluate the performance of a new biphasic lipid and NDF analytical procedure for byproduct feeds. Exp. 1 and 2 were conducted to optimize the hours of sample incubation in solvent and solvent ratio of diethyl ether to hexane for a biphasic byproduct lipid analytical procedure. Exp. 3 compared condensed corn distillers soluble (**CCDS**) lipid extraction with a 5 h Goldfisch diethyl ether procedure to extraction with a biphasic procedure developed from Exp. 1 and 2. Exp. 4 evaluated the NDF content of corn dried distillers grains (**DDG**) with differing levels of CCDS addition with and without pre-NDF lipid extraction. Exp. 1 and 2 indicated that a 10 h incubation of samples with a 1:1 ratio of diethyl ether to hexane was appropriate for the biphasic lipid extraction procedure. Increased solvent proportion of diethyl ether extracted non-lipid material from byproduct samples ($P < 0.01$). Exp. 3 indicated the ratio of GLC analyzed fatty acids quantity to mass of lipid extract was lower for the Goldfisch procedure ($P = 0.01$) than for the biphasic extraction, indicating that non-lipid material was being extracted with the Goldfisch procedure. The Goldfisch procedure extracted 3 to 10% of CCDS DM as non-lipid material. Exp. 4 indicated decreased DDG NDF values with pre-NDF lipid extraction compared to no pre-NDF extraction ($P < 0.01$). Values were 33.9 and 35.6% NDF, respectively. This indicates lipid interferes with determination of NDF. Collectively these results suggest a 10 h incubation of samples with a 1:1 diethyl ether:hexane solvent for biphasic extraction of feedstuff lipids has increased accuracy relative to Goldfisch diethyl ether extraction, especially for CCDS. A pre-NDF lipid extraction must be completed before analyzing feeds high in lipid (> 7% of sample DM) for NDF. Combining the biphasic lipid

procedure with NDF analysis is an effective way to analyze both components and fatty acid profiles in high-lipid DDG.

Key words: byproducts, distillers grains, lipid, NDF

INTRODUCTION

The Goldfisch lipid extractor (Laboratory Construction Company, Kansas City, MO), utilizes a continuous reflux of diethyl ether over a suspended sample to dissolve non-polar compounds into a collection beaker. Following reflux, excess solvent is distilled to quantify ether extract in the collection flask. This extraction method has been utilized to estimate the lipid content of feedstuffs (AOAC, 1965). The limitations of this procedure include exposure of volatile solvent to heat, limited throughput, tedious manipulation of the collection beakers for fatty acid quantification, and the potential for extraction of non-fatty acid.

Biphasic extractions have been utilized to extract lipids from biological samples (Folch et al., 1957). Biphasic extractions utilize differing densities and polarities of solvents to select soluble sample components for analysis with removal of non-lipid contaminants from the extracts (Christie, 1993). Selection of proper solvents for complete extraction of lipid material is important for accurate lipid analysis. Many extraction procedures utilize combinations of solvents of differing polarity to optimize lipid extraction from biological samples.

Corn ethanol industry byproducts such as distillers grains with solubles (**DDG**) contain a significant quantity of lipid (about 12% of DM) that may interfere with NDF analysis and cause an upward bias in the estimate of NDF (Buckner et al., 2010;

Mertens, 2002). This is because the lipid extraction capacity of neutral detergent solution may not completely dissolve all lipids (Van Soest et al., 1991). Therefore, a convenient method to extract lipid prior to analysis of NDF is needed.

Therefore, three experiments were conducted to optimize the performance of a new lipid analytical procedure for ethanol industry feedstuffs. The first and second experiments evaluated the effect of sample incubation length on quantity of extract and extraction efficiency with different ratios of diethyl ether and hexane, respectively. The third experiment evaluated the lipid content of condensed corn distillers solubles (**CCDS**) lipid content with both the new procedure and the Goldfisch procedure. The fourth experiment evaluated the new lipid procedure as a lipid extraction method prior to DDG NDF determination.

MATERIALS AND METHODS

Experiment 1

This experiment evaluated proper incubation time of DDG samples with a new biphasic lipid extraction procedure to optimize quantity of lipid extract compared to a Goldfisch diethyl ether extraction. Five corn DDG samples were analyzed in duplicate for 0.1, 2, 4, 6, 8, 10, or 12 h at 50 degrees C. The biphasic extraction utilized 0.38 g of DDG DM incubated with 4 mL of a 50:50 ratio of diethyl ether to hexane (Fisher Scientific, Pittsburgh, PA) in 16 by 125 mm screw top test tubes (Fisher Scientific, Pittsburgh, PA). After incubation, 3 mL of dilute hydrochloric acid water (0.125 mL of 37.1% hydrochloric acid solution per 40 mL distilled water) was added to each tube to elevate the solvent and lipid extract layer above the feed sample. The tubes were recapped and vigorously hand-shaken for approximately 2 s to facilitate solvent removal from feed particles. The tubes were then centrifuged at 900 x *g* for 6 min to separate aqueous and solvent phases. The upper solvent phase containing lipid was transferred by glass pipette to a pre-weighed test tube. An additional 2 mL of solvent were added to the original tube, shaken, centrifuged, and transferred to the same corresponding tube with the same glass pipette. Solvent was distilled off at 50^{o} C under nitrogen and lipid residue was weighed.

The Goldfisch lipid extractor utilized 1.2 g of DDG suspended in a thimble. Thirty-five mL of diethyl ether was continuously refluxed through samples for 4 h. The solvent was then evaporated from the extract. Extract was dried in a 100^{o} C oven for 1 h and then weighed.

Experiment 2

This experiment evaluated the effect of diethyl ether:hexane ratio on efficiency of lipid extraction from DDG, modified distillers grains, wet distillers grains, dry rolled corn, corn germ meal, and CCDS samples. Five diethyl ether to hexane ratios were evaluated (0:100, 25:75, 50:50, 75:25, and 100:0) with a 9 h biphasic incubation procedure based of the results of Exp. 1. Lipid extracts were prepared as fatty acid methyl esters for GLC analysis with a methanolic boron trifluoride procedure using heptadecanoic fatty acid as internal standard for 12 to 20 carbon fatty acid quantification (Metcalfe et al., 1966).

Experiment 3

This experiment compared CCDS lipid extraction with the Goldfisch method to the new biphasic procedure. Three CCDS samples were lyophilized and pulverized using a mortar and pestle. The three samples were analyzed in triplicate for each of four methods.

Method 1: The Goldfisch apparatus was the same as described in Exp. 1. The solvent was evaporated, and the lipid residue was weighed in pre-weighed beakers. Hexane was then added to the extract to separate the lipids from the hexane insoluble materials and transferred to a test tube, hexane was evaporated under nitrogen at 50^{o} C, and lipids were methylated for fatty acid analysis by GLC.

Methods 2 & 3: Samples were extracted using a biphasic extraction procedure with a 10 h incubation procedure based on the results of Exp. 1 and 2with either a 50:50 ratio of diethyl ether to hexane (Method 2) or diethyl ether alone (Method 3). The lipid fractions were methylated for GLC fatty acid analysis.

Method 4: Samples were refluxed with the Goldfisch diethyl ether procedure as described in Method 1. However, instead of evaporating the diethyl ether upon completion of the reflux period, the diethyl ether extract mixture was transferred to a screw top test tube. Three mL of dilute hydrochloric acid solution from Exp. 1 was added to the tubes. Tubes were shaken and the diethyl ether fraction was quantitatively transferred to an additional tube. Two additional mL of diethyl ether was added to the original tubes and a second quantitative transfer was performed. The diethyl ether and water were evaporated from the respective tubes, and each tube was weighed to calculate diethyl ether and water soluble CCDS fractions. The diethyl ether fraction was methylated for fatty acid analysis by GLC.

Experiment 4

The NDF procedure included weighing 0.5 g of DDG sample into a tall-form 600 mL beaker, adding 100 mL of neutral detergent, refluxing for 1 h, filtering the residue, and drying the filter. Two methods were compared to evaluate lipid contamination of DDG when measuring NDF. These methods included: 1) this methodology with an acetone rinse of residue at filtering and 2) a biphasic lipid extraction, outlined as Method 2 of Exp. 3, prior to refluxing. Half a gram of sodium sulfite (Fisher Scientific, Pittsburgh, PA) and 0.5 mL alpha-amylase (20,350 liquefon/ mL, ANKOM Technology, Macedon, NY) were used for each beaker. The 5 DDG samples analyzed in triplicate contained varying levels of CCDS (Corrigan et al., 2009). The samples were represented as 0, 33, 67, 100, and 110% of normal CCDS incorporation at an individual ethanol plant (Otter Creek Ethanol, Ashton, IA). The DDG with 100% of the normal CCDS inclusion was calculated to contain 19.1% CCDS on a DM basis (Corrigan et al., 2009).

Statistics

The PROC MIXED procedure of SAS with Tukey adjusted mean separation (SAS Institute Inc., Cary, NC) was utilized to evaluate incubation time of Exp. 1, solvent ratio of Exp. 2, extraction method of Exp. 3, and NDF analytical methodology of Exp. 4. Sample was used as a covariate for the four experiments.

RESULTS AND DISCUSSION

Experiment 1

Amount of lipid extract increased ($P < 0.05$) as incubation time increased from 0.1 to 12 h in Exp. 1 (Table 1). The 0.1 h incubation extracted the least amount of lipid of all levels evaluated ($P < 0.05$). The 12 h incubation extracted a significantly greater amount of lipid than the intermediate (6 h or less) incubation times ($P < 0.05$). However, 12 h incubation lipid extract amount was not significantly different from the extract amount of 8 and 10 h incubations. The extract at 10 h yielded 12.2 ± 0.14% lipid, which was similar to the Goldfisch ether extract which averaged 12.2% extract. This experiment indicated that a 10 h incubation was an acceptable incubation time for the biphasic procedure.

Experiment 2

Gravimetric quantification of the lipid extraction increased as proportion of diethyl ether increased in the solvent mixture (Table 2). Solvents with a diethyl ether concentration equal to, or greater than, hexane had increased lipid extract ($P < 0.05$). However, when the extracts were methylated and analyzed by GLC, there were no differences in % total fatty acids ($P > 0.30$) among solvent compositions. The ratio of GLC-analyzed extract to gravimetric extract decreased as solvent diethyl ether content increased above hexane content. The 0.90 GLC:gravimetric ratio for the 0:100, 25:75, and 50:50 ratios of diethyl ether to hexanes was greater than the 0.80 GLC:gravimetric ratio for 75:25 and 100:0 ratios of diethyl ether to hexanes ($P < 0.05$). The expected GLC-analyzed to gravimetric ratio is approximately 0.90 due to ~ 10% non-fatty acid glycerol molecular mass content of triglycerides. Increased inclusions of diethyl ether extracted non-lipid material from the samples, as indicated by the reduced

GLC:gravimetric ratio. This experiment indicated that a 50:50 ratio of diethyl ether to hexane was an acceptable solvent combination for the biphasic extraction procedure.

Experiment 3

Gravimetric CCDS lipid extraction was numerically greatest for the Goldfisch extraction method in Exp. 3 (Table 3). Biphasic lipid extraction with a 50:50 ratio of diethyl ether to hexane (Method 2) was numerically similar to lipid extraction when water soluble impurities were removed with biphasic extraction from the Goldfisch extract (Method 4). The CCDS lipid contents with Methods 2 and 4 were 17.6 and 17.5%, respectively. The Goldfisch procedure CCDS non-lipid extract ranged from 3 to 10% of sample and averaged 5.8% of CCDS DM. There were no significant differences in CCDS % GLC-analyzed fatty acids. The ratio of GLC: gravimetric extract was lowest for the Goldfisch procedure ($P < 0.05$) and similar for the other three procedures indicating that non-lipid material was being extracted with the Goldfisch procedure. The percentage of CCDS DM in the water soluble fraction of Method 4 averaged 6.2%, which is similar to the difference in extraction between the Goldfisch and the 50:50 ratio of diethyl ether to hexane methods. Our current laboratory hypothesis is that these impurities are of yeast origin from the ethanol fermentation process and are not from phospholipids, glycerol, or starch origin.

Experiment 4

There was a complex interaction of CCDS inclusion level with pre-NDF lipid extraction ($P = 0.02$). All NDF values for the pre-NDF lipid extracted material were less than NDF values of samples not receiving pre-extraction (Table 4). We hypothesized that lipid content would interfere with DDG NDF content more at lower CCDS inclusion levels than greater CCDS inclusion levels. However, the data indicate that the least lipid interference was observed for intermediate levels of CCDS. The biological basis of this interference is unclear. The physical form of lipid in the CCDS and grains fraction of the DDG samples is different (Bremer et al., 2010). The material in CCDS originates from the unfermentable liquid fraction of dry-mill ethanol production. The grains fraction are solids that may contain a lipid form that is more likely to physically interfere with NDF analysis either by physically creating artifact NDF or inhibiting removal of non-NDF material from DDG. Utilizing the pre-NDF lipid extraction reduced the DDG NDF content from 35.6 to 33.9% of DDG DM ($P < 0.01$). Therefore, combining the biphasic lipid procedure with NDF analysis provides an effective way to analyze both nutrients for high-lipid byproduct feeds (Van Soest et al., 1991; Mertens, 2002).

These results indicate that the biphasic procedure developed with these experiments may be utilized for lipid analysis of feedstuffs. The procedure has convenience superior to the Goldfisch procedure for feedstuff fatty acid analysis. This procedure may also be useful for removing lipid from feeds for NDF analysis.

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Table 1. Average lipid content of five DDG samples incubated for different times utilizing a new biphasic lipid extraction procedure of Exp. 1[1].

	h of Incubation								
Item	0.1	2	4	6	8	10	12	SEM	P-value
DDG lipid, % of DM[2]	11.1[a]	11.9[b]	12.0[b]	12.0[b]	12.1[b,c]	12.2[b,c]	12.3[c]	0.14	0.01

[1] DDG = lyophilized distillers grains plus solubles samples.

[2] Samples were also analyzed with the Goldfisch method and averaged 12.2% ether extract.

[a,b,c] Means with unlike superscripts differ at $P < 0.05$.

Table 2. Average lipid content of six feedstuffs incubated with different ratios of diethyl ether to hexane with a new biphasic lipid extraction procedure of Exp. 2[1].

	Ratio of diethyl ether to hexane						
Item	0:100	25:75	50:50	75:25	100:0	SEM	P-value
Gravimetric extract, % of DM	12.4[a]	12.6[a]	12.7[a]	13.8[b]	14.2[c]	0.13	0.01
GLC fatty acids, % of DM	11.0	11.3	11.4	11.2	11.3	0.11	0.31
GLC:Gravimetric	0.90[b]	0.90[b]	0.90[b]	0.81[a]	0.79[a]	0.01	0.01

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[1] GLC = gas chromatography analysis of 12 to 20 carbon length fatty acids with heptadecanoic acid as internal standard and GLC:Gravimetric = the ratio of GLC analyzed fatty acids to gravimetric extract.

[a,b,c] Means within a row with unlike superscripts are different at $P < 0.05$.

Table 3. Average lipid content of three lyophilized condensed corn distillers solubles samples with four different laboratory procedures of Exp. 3[1].

	Method					
	1	2	3	4		
Item	GFISH	50:50	100:0	GFISH+50:50	SEM	P-value
Gravimetric extract, % of DM	23.4	17.6	20.0	17.5	1.3	0.06
GLC fatty acids, % of DM	14.9	15.5	16.8	15.2	0.5	0.15
GLC:Gravimetric	0.64[a]	0.88[b]	0.84[b]	0.87[b]	0.03	0.01

[1] 1-GFISH = Goldfisch extraction with diethyl ether, 2-50:50 = biphasic extraction with 50:50 ratio of diethyl ether to hexane, 3-100:0 = biphasic extraction with diethyl ether, 4-GFISH + 50:50 = Goldfisch extraction with subsequent biphasic extraction, GLC = gas chromatography analysis of total fatty acids with heptadecanoic acid as internal standard, GLC:Gravimetric = the ratio of GLC analyzed fatty acids to gravimetric extract.

[a,b] Means within a row with unlike superscripts are different at $P < 0.05$.

Table 4. Percentage NDF for five DDG samples with different condensed corn distillers solubles levels with or without pre-NDF analysis lipid extraction of Exp. 4.

	Treatment[1]				
DDGS[2]	NONE	EXTRACT	Unit	SEM	P-value
0	43.4	41.0	2.4		
33	38.1	36.8	1.3		
67	33.6	32.8	0.8		
100	31.3	30.1	1.2		
110	31.8	28.8	3.0		
Average	35.6	33.9	1.7	1.19	0.01

[a,b] Methods with unlike superscripts differ ($P < 0.01$).

[1] NONE = 100mL neutral detergent solution with acetone rinse at filtering, EXTRACT = use residue remaining after biphasic lipid extraction with 100 mL neutral detergent solution and acetone rinse at filtering.

[2] DDGS = dried distillers grains with solubles. 0, 33, 67, 100, and 110 represent the percentage of a single ethanol plant's normal condensed corn distillers solubles added to the wet grains fraction. The samples contained 7.1, 9.2, 10.8, 13.8, and 13.9% lipid, respectively, as analyzed with the biphasic lipid extraction method.

Feedlot cattle performance when fed multiple byproducts and metabolism characteristics of diets containing traditional and byproduct lipid sources[1]

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ABSTRACT

Three experiments evaluated cattle performance and metabolism characteristics of feedlot diets containing traditional and byproduct lipid sources. In Exp. 1, 96 crossbred steers (399 ± 52 kg of BW) were used in a RCBD experiment to evaluate performance when fed 0 or 35% of diet DM as wet distillers grains (WDG) or WDG with condensed corn distillers solubles (CCDS; WDGS) replacing corn. Final BW, HCW, and ADG increased for steers fed WDGS compared to steers fed corn or WDG ($P < 0.05$). Steers fed WDG or corn diets had similar DMI, ADG, and G:F. In Exp. 2, 279 crossbred steers (457 ± 27 kg of BW) were used in a RCBD experiment to evaluate steer performance when 0, 6.7, 13.3, or 20% of diet DM as CCDS or 0, 13.3, 26.7, or 40% of diet DM as WDGS replaced corn in diets containing 35% wet corn gluten feed (Sweet Bran). Replacement of corn with WDGS decreased ADG linearly ($P < 0.01$), tended to linearly decrease DMI ($P = 0.06$), and did not affect G:F ($P > 0.10$). When CCDS replaced corn, no difference in steer performance was observed ($P > 0.10$). In Exp. 3, 5 ruminally fistulated steers (520 ± 41 kg of BW) were used in a 5-period Latin square design to evaluate effects of 8.5% lipid finishing diets containing 4.8% corn oil (OIL) or beef tallow (TAL), 25.5% CCDS, 56% WDGS or no added lipid diet (CORN) on metabolism characteristics of finishing steers. The unsaturated to saturated fatty acid ratio of omasal samples of steers fed WDGS was greater than for other treatments ($P = 0.01$). Apparent total tract fatty acid digestibility was greater than 93.9% and similar for all treatments ($P = 0.22$). Apparent total tract diet NDF digestibility was least for OIL fed steers ($P = 0.04$) and similar for all other treatments. Ruminal pH was least for CCDS fed steers and greatest for OIL fed steers. Molar proportion of acetate was least for CCDS and greatest for WDGS and OIL. The lipid content of distillers grains with CCDS partially accounts for feeding value being greater than corn. Diets containing distillers grains to supply up to 8% of diet DM as lipid may be fed without depressing cattle performance. However, feeding diets containing 8% dietary lipid with corn oil depresses cattle performance. The difference in rumen biohydrogenation between OIL and WDGS is due to physical protection of lipid in distillers grains, and CCDS does not hinder rumen fermentation like OIL.

Key words: byproducts, cattle, distillers grains, lipid, lipids, solubles

INTRODUCTION

Optimization of cattle growth performance is a balance of both diet caloric density and quantity of intake. Based on greater caloric density of lipid versus starch and protein, it is logical to replace a portion of starch or protein from feedlot diets with lipid (Lodge et al., 1997). Previous lipid research has focused on traditionally fed lipids such as beef tallow and vegetable oil (Vander Pol et al., 2009). Because in some other studies animals were limit fed, some of the results reported in these studies may be misleading for ad libitum feeding situations (Plascencia et al., 2003). The differences in rumen availability of different lipid sources may influence the maximum different dietary lipid content optimums (Zinn, 1994; Vander Pol et al., 2009). Ruminal lipid biohydrogenation characteristics of ethanol industry byproducts such as wet distillers grains (**WDG**) and condensed corn distillers solubles (**CCDS**) may differ from tallow and vegetable oil (Vander Pol et al., 2009).

Wet corn gluten feed (**WCGF**), with 4% lipid content, and WDG with CCDS (**WDGS**), with 12% lipid content, have been shown to be compatible feed ingredients in finishing diets (Loza et al., 2010). The lipid content of CCDS without WDG may also be complementary to WCGF. However, there are limited data on feeding CCDS in finishing diets, and no data collected on feeding CCDS with WCGF.

The lipid content of WDG, CCDS, and WDGS accounts for a significant portion of energy from each feedstuff (Lodge et al., 1997). It is unknown if there are differences in ruminal biohydrogenation and fatty acid absorption of these lipid sources when fed to finishing steers. For this reason, two feedlot studies and a metabolism study were conducted to evaluate cattle growth performance and lipid biohydrogenation and digestibility characteristics of feedlot diets containing traditional lipid sources compared to byproducts.

MATERIALS AND METHODS

All animal use procedures were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee. Upon arrival at the feedlot, all steers were individually identified, vaccinated with Bovi-Shield Gold 5 and Somubac (Pfizer Animal Health, New York, NY), and injected with Dectomax Injectable (Pfizer Animal Health). Steers were revaccinated approximately 16 d after initial processing with Bovi-Shield Gold 5, Somubac, and Ultrachoice 7 (Pfizer Animal Health). These procedures were performed before initiation of the experiments. In Exp. 1 and Exp. 2, feedbunks were assessed at approximately 0630 h and managed so that only traces of feed were left in the bunk each morning at feeding time. Accumulated feed refusals were removed from feedbunks as needed and were dried for 48 h at 60°C in a forced-air oven to determine DM. Diets were fed once daily. Steers in the two feedlot studies were harvested at a commercial abattoir (Greater Omaha Pack, Omaha, NE). On d of harvest, HCW was collected. After a 48-h chill, marbling score, 12^{th} rib fat thickness, and LM area data were collected. All carcass data were collected by trained personnel from the University of Nebraska-Lincoln. Final carcass adjusted BW, ADG and G:F were calculated by dividing HCW by a common dressing percentage of 63%. All post trial lipid and NDF analyses were conducted according to the biphasic lipid extraction and NDF analytical procedures of Bremer et al. (2010a).

Exp. 1

Seven d before initiation of the experiment, steers were limit-fed (2% of BW daily) a diet containing 33% DRC, 33% wet corn gluten feed, 33% alfalfa hay, and 1% supplement (DM basis). Steers were weighed on d 0 and 1 of the experiment, and the average of the two measurements was used as initial BW. Ninety-six crossbred yearling steers (399 ± 52 kg) were stratified and blocked by BW and assigned randomly to pen within block based on d 0 BW, and pens assigned randomly to one of three treatments. Treatments included a corn control with no byproduct (**CON**), low lipid WDG (**LFAT**), and normal lipid WDGS (**NFAT**). Twelve pens were used resulting in four replications per treatment. A 1:1 ratio of dry-rolled corn (**DRC**), and high-moisture corn (**HMC**) was replaced with WDG containing 31.4% DM, 34.8% CP, 6.7% lipid, and 0.85% sulfur or WDGS containing 34.1% DM, 34.5% CP, 12.9% lipid, and 0.94% sulfur at 35% of the diet DM (Table 1). All diets contained 10% sorghum silage and 5% supplement (DM basis). The CON diet was formulated to provide 12.5% CP by including 0.75% urea in the diet. Soypass (LignoTech USA, Inc., Rothschild, WI) was also included in the CON diet at 1.0% of diet DM for the first 40 d to meet the metabolizable protein requirement of the steers (NRC, 1996). Therefore, any response to WDG or WDGS will be attributed to an energy response (NRC, 1996). Thiamine was provided at 150 mg per steer daily in the LFAT and NFAT diets. All diets were formulated to provide 30 g/ton DM monensin (Elanco Animal Health, Greenfield, IN) and 90 mg per steer daily tylosin (Elanco Animal Health). Monthly composites of feed ingredient samples were analyzed for DM, CP, sulfur, and lipid. Ingredient DM was analyzed by drying at 60^{o}C for 48 h. Ingredient CP and sulfur were analyzed using a combustion type N and S analyzer (Leco N and S Autoanalyzer, Leco, St. Joseph, MI). Ingredient lipid content was analyzed with a biphasic lipid extraction procedure of Bremer et al. (2010a). Steers were slaughtered in two weight blocks at either 102 or 131 d on feed. Cattle performance and carcass characteristics were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was considered the experimental unit in this RCBD study.

Exp. 2

An 82-d finishing study utilized 279 crossbred steer calves (457 ± 27 kg) in a RCBD experiment. Steers received a Synovex Choice implant (Pfizer Animal Health) and a dose of Durasect ll anthelmentic (Pfizer Animal Health) and were fed a common finishing diet for 100 d before study initiation that contained 25% HMC, 50% WCGF, 15% corn silage, 5% corn stalks, and 5% of a dry supplement (DM basis). Steers were limit-fed the common WCGF based diet at 1.8% of BW for 5 d to capture three d average initial BW. The average BW from the first two d was used to block the steers into three blocks, stratify steers by BW within block, and assign steers randomly within block to pens. Pens were then assigned randomly within block to one of 7 dietary treatments with 5 pens per treatment and 8 steers per pen. Dietary treatments (Table 2) consisted of 35% WCGF with 0% WDGS or CCDS; 13.3, 26.7, or 40% WDGS, or 6.65, 13.35, or 20% CCDS replacing HMC in the diet (DM basis). All diets contained 5% ground cornstalks and 5% dry supplement. The WDGS and CCDS were sourced from Abengoa Bioenergy, York, NE. The WCGF (Sweet Bran®) was sourced from Cargill, Inc., Blair, NE. The HMC was processed through a roller mill at harvest, ensiled in a bunker silo 166 d prior to study initiation, and averaged 30% moisture. Steers were adapted to finishing diets over 6 d. Steers were implanted with Synovex Choice (Pfizer Animal Health) at trial initiation. All diets provided 350 mg monensin (Elanco Animal Health), 127 mg thiamine, and 88 mg of tylosin (Elanco Animal Health) per steer daily. Individual feed ingredient samples were collected weekly and composited by month to evaluate DM, lipid, CP, and S with procedures similar to Exp. 1. Ingredient NDF content was analyzed with the method outlined by Bremer et al. (2010a). Steers were slaughtered on d 83. Yield grade was calculated using the carcass measurements and the formula of Boggs and Merkel (1993). Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc.) and tested for linear, quadratic, and cubic effects of WDGS or CCDS inclusion level. Seven pens of cattle were removed from the analysis due to incorrect feeding for 2 d during the study. This resulted in three complete blocks of treatments and two incomplete blocks of treatments.

Exp. 3

Five ruminally cannulated steers (520 ± 41 kg) were utilized in a five-period Latin square designed experiment. Each steer was assigned randomly to one of five balanced treatment sequences. Treatments were five diets with different dietary lipid sources (Table 3). The negative lipid addition control diet contained no added lipid sources (**CORN**). The positive lipid control diets contained 4.8% of diet DM as corn oil (**OIL**) or beef tallow (**TAL**), respectively. The byproduct diets contained added lipid in the form of CCDS or WDGS. The four diets with added lipid were formulated to be isolipid with total diet lipid at 8.5% of diet DM. All diets contained monensin (Elanco Animal Health), thiamine, and tylosin (Elanco Animal Health) fed at the rates of 309, 112, and 77 mg per steer daily, respectively.

Steers were fed 6 times daily with automatic feeders (ANKOM Technology, Macedon, NY) for ad libitum intake and offered ad libitum access to fresh water. The CCDS and WDGS were from a single load of each commodity for the entire trial from the same ethanol plant (Abengoa Bioenergy).

Period duration was 21 d and consisted of a 12 d adaptation period. Continuous pH data were collected with intraruminal pH probes on d 15 to 20. Chromic oxide (7.5 g/dose) was dosed intraruminally at 0800 and 1600 h daily on d 13 to 20. Omasal and fecal samples were collected at 0800 and 1600 h on d 16 to 20. Omasal samples were collected with a modified procedure of Huhtanen et al. (1997) described by Lundy, III et al. (2004). Briefly, omasal samples were collected via tygon tubing (16 mm i.d.) that was passed through the ruminal cannula and inserted into the reticulo-omasal orifice. A hand-operated vacuum pump was attached to a filter flask, and 250 ml of omasal contents were retrieved. Rumen fluid samples were collected at 0800 and 1600 h on d 19 and 20 for volatile fatty acid analysis according to procedures outlined by Erwin et al. (1961).

In situ bags containing corn bran were ruminally incubated for 0, 12, 24, or 48 h on d 13 to 15. Quadruplicate bags were incubated in each steer per time point. Bags were inserted at staggered times. All bags were removed the morning of d 15, and machine washed in 39°C water for 5 cycles of 1 min of agitation and 2 min of spin per cycle (Whittet et al., 2003). Bags incubated 0 h were used to determine the amount of the sample that washed out without incubation. In situ bags were dried for 48 h at 60°C in a forced-air oven to determine in situ DM digestibility. All feed, feed refusals, omasal, and fecal samples were ground through a 1 mm screen using a Cyclotech 1093 Sample Mill (Foss Tecator, Eden Prairie, MN) prior to analysis. Omasal and fecal samples were composited by d, lyophilized, ground, and composited by animal within period and analyzed for lipid, fatty acid, and NDF content according to the procedures outlined by Bremer et al. (2010a). Samples of feeds and feed refusals were dried for 48 h at 60°C in a forced-air oven, ground and analyzed for lipid, fatty acid, and NDF content (Mertens, 2002; Bremer et al., 2010a). Feed ingredients were also analyzed for sulfur content by combustion (S632 Sulfur Determinator, Leco Corp., St. Joseph, MI). Omasal and fecal samples were analyzed for chromium concentration using an atomic absorption spectrophotometer (Varian Spectra AA-30; Williams et al., 1962) to determine total fecal output. Individual feed ingredients, omasal, and fecal composites were analyzed via GLC for fatty acid profile and quantification according to Bremer et al. (2010a).

Data were analyzed as a Latin square design using the GLIMMIX procedures of SAS (SAS Inst. Inc.). A Kenward-Rogers denominator degrees of freedom adjustment was utilized. The pH data were analyzed with the GLIMMIX procedure of SAS (SAS Inst. Inc.) utilizing direct regression. Models included the fixed effects of period, day, and treatment. A Cholesky covariance structure was utilized for pH repeated measures analysis. Corn bran in situ data, ruminal volatile fatty acid profile, DM digestibility, and nutrient digestibility data were analyzed utilizing the MIXED procedure with fixed effects of period and treatment and the random effect of steer. Treatment differences were evaluated when overall significance was less than $P = 0.10$.

RESULTS AND DISCUSSION

Exp. 1

Steer DMI was similar for CON, LFAT, and NFAT treatments (Table 4). Steer ADG, HCW, and carcass adjusted final BW were greater for steers fed NFAT relative to the other diets ($P < 0.05$). Steers fed NFAT gained an average of 0.13 kg per day more than control and LFAT fed steers which resulted in 11 kg greater HCW. No differences in ADG, HCW, and carcass adjusted final BW were observed ($P > 0.05$) between steers fed CON or LFAT. Steers fed NFAT had numerically greater G:F than steers fed CON or LFAT. No differences were observed across treatments for marbling score and 12th rib fat thickness ($P > 0.25$).

The numerically improved G:F of WDGS resulted in a calculated feeding value equal to 127 % of a DRC and HMC blend. The feeding value of 35% WDGS in the current study is within 6 percentage units of the 133% WDGS meta-analysis predicted feeding value of Bremer et al. (2010b). The feeding value of WDG was 102% of the control. Lodge et al. (1997) evaluated feeding a simulated WDGS composite from a combination of WCGF, tallow, and corn gluten meal. The feeding value of the composite was decreased from 124 to 118% of DRC when the lipid source was removed.

Farlin et al. (1981) evaluated feeding WDG at 42.5% of diet DM and observed 9.9 and 10.6% improvements in ADG and G:F relative to corn control fed cattle. Firkins et al. (1985) also observed a linear improvement in ADG and G:F when dietary inclusion of WDG increased from 0 to 25 and 50% of diet DM. Godsey et al. (2008) evaluated feeding combinations of WDG (10.0% ether extract) and CCDS (27.8% ether extract) with 100:0, 85:15, or 70:30 ratios of WDG to CCDS at either 20 or 40% of diet DM replacing a 1:1 ratio of DRC and HMC. They found no interaction of byproduct level with CCDS level and G:F numerically improved as proportionately more CCDS were fed and as dietary inclusion of byproduct increased.

In addition to lipid content differences between the WDG and WDGS diets in these two studies, the CCDS contained with WDGS provided protein from yeast cells in addition to other nutrients. These studies collectively indicate that the G:F and calculated feeding value of WDG is at least equal to corn and may be greater than corn. The feeding value of CCDS in diets containing WDG is not clearly understood when comparing the results of the current trial with previous research. Godsey et al. (2008) did not find a response to CCDS inclusion level with WDG in the diet as in the current study.

Exp. 2

The levels of WDGS and CCDS were formulated to provide equal lipid addition from either product assuming CCDS contained 25% lipid and WDGS contained 12.5% lipid, based on lipid analysis with a Goldfisch ether extract procedure (Bremer et al., 2010a). After trial initiation, it was discovered that the Goldfisch lipid extraction procedure over-estimates lipid values for CCDS due to extracting non-lipid material in the extraction process (Bremer et al., 2010a). Therefore, a new procedure to accurately measure lipid content of byproducts that utilizes a biphasic extraction of lipid material with a 1:1ratio of hexane to diethyl ether solvent was developed (Bremer et al., 2010a) Upon trial completion, the new lipid analysis indicated CCDS contained 15% lipid and WDGS contained 12.4% lipid. Therefore, the treatments did not produce equal levels of lipid addition from the WDGS and CCDS sources.

As level of WDGS increased in the diets with 35% WCGF, ADG decreased linearly (P < 0.01), DMI tended to decrease linearly (P = 0.06), and G:F was not affected by treatment (Table 5). Twelfth rib fat thickness also tended to decrease linearly (P = 0.07) as level of WDGS increased in the diet, however there were no significant differences in HCW, LM area, 12th rib fat, yield grade, or marbling score. Loza et al. (2010) conducted a study to evaluate feeding 30% WCGF with WDGS for finishing cattle. The trial evaluated feeding 0, 10, 15, 20, 25, and 30% WDGS in diets containing 30% WCGF and found ADG to increase quadratically and a trend for DMI to increase quadratically as WDGS level decreased that resulted in no significant change in G:F at the different WDGS levels.

Steers fed up to 20% CCDS with 35% WCGF had similar DMI, ADG, G:F, HCW, 12th rib fat, LM area, and yield grade as steers fed 35% WCGF with no CCDS (Table 6). There was a significant (P = 0.04) cubic effect of CCDS inclusion level on marbling score, however this effect is difficult to explain and probably not biologically significant. No other trials have evaluated feeding CCDS in combination with WCGF, however, other trials have evaluated feeding CCDS as a single dietary byproduct relative to corn. In three trials, Hanke and Lindor (1983) evaluated feeding thin stillage (CCDS prior to moisture removal) in place of drinking water to finishing cattle and found 5.7 and 11.0% improvements in ADG and G:F, respectively, with reduced DMI when thin stillage was fed. Rust et al. (1990) evaluated feeding up to 20% of diet DM as CCDS and observed improved G:F when CCDS was fed relative to corn control fed cattle. Trenkle (1997; 2002) evaluated feeding 0 to 8% of diet DM as CCDS replacing DRC in finishing diets and noted improved G:F when CCDS was fed.

The trial of Loza et al (2010) and the current study indicate that feeding combinations of WCGF and WDGS instead of WCGF alone does not depress G:F. However, ADG may be depressed by feeding the combination. The collective data on feeding CCDS indicate that CCDS fed steers have ADG, G:F, and feeding value equal to HMC. The feeding value of CCDS may interact with WCGF level due to no improvement in G:F as CCDS was added to diets containing 35% WCGF. The feeding value of WDGS may also interact with WCGF level due to less than expected G:F for steers fed WCGF diets with WDGS compared to feeding WDGS alone.

The steers fed 20% CCDS performed similar to the steers fed 26.7% WDGS. These two diets contained similar levels of lipid (6.2 and 5.9% lipid for the 20% CCDS and 26.7% WDGS diets, respectively). The S levels were also similar for the two diets, with 0.45 and 0.44% S in the 20% CCDS and 26.7% WDGS diets, respectively. When the level of WDGS was increased to 40% of diet DM (6.9% lipid and 0.52% S), steer performance decreased. Previous research (Vander Pol et. al., 2005) suggests that the lipid level in the 40% WDGS diet was not great enough to depress DMI or ADG. However, one of the first signs of excessive S in the diet is depressed DMI with decreased ADG (Sarturi et al., 2010). The cattle on the 40% WDGS with 35% WCGF may have had depressed DMI due to dietary S. It should be noted that no steers on this trial were observed with symptoms of polioencephalomalacia.

Vander Pol et al. (2009) replaced corn with 2.5% corn oil or 20% WDGS to create diets with 6.4% total diet ether extract. Both the 2.5% corn oil diet and 20% WDGS diets resulted in similar feeding performance relative to the corn diet for individually fed heifers. When total diet ether extract was increased to 8.8% with either 5% corn oil or 40% WDGS, G:F was greater for the 40% WDGS diet relative to 20% WDGS. The 5% corn oil diet resulted in depressed DMI, ADG, and G:F relative to the corn diet. This trial indicated that 8.8% diet lipid from 5% corn oil was detrimental to rumen function, but not if WDGS was the lipid source. In a second finishing trial, Vander Pol et al. (2009) evaluated replacing corn with 1.3 or 2.6% tallow or 20 or 40% DDGS in diets containing 20% WCGF. Feeding performance was similar for all treatments. Maximum dietary ether extract was 6.0 and 5.0% for tallow and DDGS diets, respectively. These results suggest that feeding a 5% ether extract diet containing 2.6% of diet DM as tallow did not depress cattle performance with 20% WCGF diets. The results of Exp. 2 indicate replacing corn in 35% WCGF diets with either CCDS or WDGS resulted in diets containing 6.2 and 6.9% diet lipid, respectively. The combined interpretation of the Vander Pol et al. (2009) studies and Exp. 2 indicates that CCDS does not depress feeding performance like corn oil. These data substantiate that the form of lipid in distillers grains, CCDS and tallow have different feeding values and effects on rumen function compared to vegetable oils.

Exp. 3

Post-trial analysis indicated the OIL, TAL, CCDS, and WDGS diets were 8.2 to 8.6 % dietary lipid on a DM basis. Dry matter intake was numerically greatest for CORN, intermediate for the saturated fatty acid TAL diet and WDGS, and least for the more unsaturated fatty acid OIL and CCDS diets (Table 7). This is similar to the metabolism trial results of Vander Pol et al. (2009) that indicated a decreased DMI of metabolism steers fed a corn based diet containing 3.4% corn oil relative to a corn control diet. Vander Pol et al. (2009) also indicated that DMI of steers fed 40% WDGS was numerically less than corn fed steers. Ham et al. (1994) found DMI of metabolism steers fed 15% CCDS to be similar to corn fed steers. Apparent total tract DM digestibility was greatest for CORN and least for WDGS diets with OIL, TAL, and CCDS diets being intermediate. These findings agree with Corrigan et al. (2009) and Vander Pol et al. (2009) who found DM digestibility of WDGS diets to be at least numerically less than DM digestibility of corn control diets. Vander Pol et al. (2009) also found the DM digestibility of the corn oil containing diet to be less than the corn control diet.

Lipid and fatty acid intake were similar for lipid supplemented diets and roughly two times greater ($P < 0.10$) for lipid supplemented diets than for CORN. The omasal fatty acid profile of steers fed the WDGS diet was less saturated than other treatments due to proportionately greater C18:1 and C18:2 and less C18:0 ($P < 0.01$). This indicates that CCDS is minimally protected from ruminal biohydrogenation unlike WDGS. The results of Vander Pol et al. (2009) support these findings. They reported that duodenal fatty acid profile of WDGS fed steers was less saturated than corn and corn oil diet fed steers. Increased absorption of WDGS fatty acids in the unsaturated form has been verified by increased proportion of polyunsaturated fatty acids in steaks from steers fed

WDGS diets (de Mello et al., 2007). In Exp. 3, apparent total tract lipid digestibility was greatest for TAL and least for CORN and WDGS diets ($P < 0.03$). However, apparent digestibility of fatty acids reaching the omasum was similar for all treatments. All apparent total tract lipid digestibilities were greater than 89% and fatty acid digestibilities were greater than 93.9%. This indicates that fatty acid absorption at the small intestine was not decreased with the high lipid diets. These findings contradict the findings of Plascencia et al. (2003) who reported unsaturated fatty acids may be more efficiently absorbed than saturated fatty acids.

Diet NDF intake was roughly two times greater ($P < 0.10$) for WDGS fed steers than for the steers fed other diets due to the increased NDF content of WDGS relative to the other feed ingredients fed. Seventy percent of diet NDF consumed by WDGS fed steers originated from WDGS. Apparent total tract NDF digestibility was least for OIL ($P < 0.10$) and similar among all other treatments. The lower NDF digestibility for the OIL diet may be due to corn oil lipid limiting ruminal fermentation of NDF by limiting microbial interaction with oil coated feed particles or microbial population modification (Zinn et al., 2000). Total tract NDF digestibility for diets containing WDGS has been reported by three other trials to be numerically greater (significantly greater in one of the trials) than corn-based diets. (Ham et al., 1994; Corrigan et al., 2009; Vander Pol et al., 2009). Therefore, roughly double the amount of NDF is digested by WDGS fed steers as compared to corn control fed cattle. Ham et al. (1994) also found that steers fed 20% of diet DM as thin stillage had similar NDF digestibility as corn fed steers. Vander Pol et al. (2009) also found corn oil diet NDF digestibility to be similar to corn diet NDF digestibility, however corn oil diet intake was much less than corn and WDGS diet intakes and passage rate may have been affected more than in the current study.

Post-ruminal digestion of WDGS NDF may be greater than ruminal WDGS NDF digestion. Ruminal in situ corn bran NDF digestibility was generally poor for all treatments and averaged 12.7, 19.7, and 26.7 for 12, 24, and 48 h incubations, respectively (Table 8). Total tract NDF digestibility values were roughly 2 to 3 times greater than in situ corn bran digestibility values, indicating that either the in situ values are artificially low or significant post-gastric NDF digestion occurred. The NDF digestibility values may be low due to dietary lipid clogging pores on the Dacron bags and preventing microbial contact with corn bran samples. This argument is supported by CORN (lowest lipid diet) having the numerically greatest in situ NDF digestibility ($P > 0.10$; Table 7) at all three time points. Corrigan et al. (2009) evaluated ruminal corn bran NDF digestion with 22 h ruminal in situ incubation and found no difference in corn bran NDF digestion when steers were fed a corn control or a 40% WDGS diet. Ruminal digestibility of corn bran was low and averaged 29.9% for WDGS fed steers and 27.8% for corn fed steers. Using duodenally fistulated steers Vander Pol et al. (2009) reported 56 and 71% ruminal diet NDF digestibility for corn and WDGS fed steers, respectively. The in vivo NDF digestibility calculations of Vander Pol et al. (2009) indicated greater ruminal NDF digestibility of corn and WDGS fed steers than the in situ corn bran digestibility data of Corrigan et al. (2009) and the current study. Inherent errors exist within both in situ and in vivo ruminal NDF digestibility calculations. In addition, ruminal in situ corn bran NDF digestibility may not be indicative of WDGS NDF digestibility. Particle size differences between corn bran NDF and corn NDF in WDGS may impact rate and extent of NDF digestion. Therefore, it is unclear what fraction of WDGS NDF is digested ruminally.

Ruminal average pH was lowest for CCDS and highest for OIL ($P < 0.10$; Table 8). Time of ruminal pH below 5.6 was greatest for CCDS and least for OIL and TAL ($P < 0.10$). Ruminal average pH of WDGS fed steers was numerically greater than average ruminal pH of corn fed steers, but not statistically different ($P > 0.10$). Time spent below pH 5.6 was numerically less for WDGS fed steers compared to time spent below pH 5.6 for corn fed steers. These results are consistent with the findings of Ham et al. (1994), Corrigan et al. (2009), and Vander Pol et al. (2009) who did not find a significant reduction in average ruminal pH. However, those three trials did report numerically lower average ruminal pH for steers fed WDGS relative to corn fed steers. The numerically lower pH of WDGS fed steers may be due to similar (Vander Pol et al., 2009) or increased (Corrigan et al., 2009) diet DMI of WDGS fed steers relative to corn fed steers.

It has been hypothesized that the decrease in acetate to propionate ratio (**A:P**) is due to lower ruminal pH of WDGS fed steers causing proportionately greater hemicellulose fermentation relative to cellulose fermentation (Murphy et al., 1982; DiLorenzo and Galyean, 2010). Both the hemicellulose and cellulose fractions of corn are concentrated when the corn starch is removed with fermentation. The corn bran in situ NDF digestibility data discussed above indicate that ruminal WDGS NDF digestion may be limited; however, total tract NDF digestibility may be similar to a corn diet. A better understanding of NDF digestion of WDGS is needed to evaluate this hypothesis.

The numerically greater average pH of steers in the current trial may be influenced by the use of timed feeders in the current trial. Steers fed CCDS had the greatest time spent with ruminal pH less than 5.6 and OIL and TAL had the least time spent less than pH 5.6 ($P < 0.10$). The WDGS fed steers were similar to CORN fed steers. This agrees with the findings of Corrigan et al. (2009) and Vander Pol et al. (2009) who noted no significant difference in time spent below pH 5.6 for both WDGS and corn fed steers. However, they both found WDGS fed steers to have numerically more time below pH 5.6.

Ruminal volatile fatty acid profile proportion for acetate was greatest for OIL and WDGS and least for CCDS ($P < 0.10$). Volatile fatty acid profile proportion of propionate was numerically greatest for CCDS. This resulted in the CCDS having numerically the lowest A:P. A proposed biological mechanism of the superior feeding value of WDGS relative to corn is a shift of acetate to propionate production in the rumen of steers fed WDGS (Corrigan et al., 2009; DiLorenzo and Galyean, 2010). Vander Pol et al. (2009) and Corrigan et al. (2009) found reduced A:P when steers were fed 40% WDGS diets compared to a corn control diets. However, trials by Ham et al. (1994) and the current study found that feeding 40% of diet DM as WDG, 40% WDGS with 37.5% of WDGS DM as CCDS, or 56% diet DM as WDGS had similar or increased A:P relative to DRC fed steers. Metabolism trials of Ham et al. (1994) and the current study indicate feeding thin stillage or CCDS replacing corn decreases A:P ratio relative to DRC fed steers. The difference in A:P of the different metabolism trials may be due to ratio of WDG to CCDS in WDGS.

In conclusion, diets containing wet or dry distillers grains to supply up to 8% of diet DM as lipid may be fed without depressing cattle performance. However, feeding diets containing 8% dietary lipid with corn oil depresses cattle performance. Corn oil, CCDS, and DGS lipids originate from corn, but the differences in rumen metabolism of these lipids may be due to physical protection from digestion by rumen microbes. Due to an unknown mechanism, CCDS does not limit ruminal metabolism like corn oil, which impacts feeding values.

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Table 1. Diet composition and nutrient analysis of finishing diets fed in Exp. 1[1]

	Treatment[2]		
Item	CON	LFAT	NFAT
Ingredient			
Dry-rolled corn	42.5	25.0	25.0
High-moisture corn	42.5	25.0	25.0
Wet distillers grains	-	35.0	-
Wet distillers grains plus solubles	-	-	35.0
Sorghum silage	10.0	10.0	10.0
Dry supplement	5.0	5.0	5.0
Fine-ground corn	0.426	2.831	2.831
Limestone	1.430	1.638	1.638
Urea	1.540	-	-
Soypass[3]	1.000	-	-
Salt	0.300	0.300	0.300
Tallow	0.125	0.125	0.125
Potassium chloride	0.087	-	-
Trace mineral premix[4]	0.050	0.050	0.050
Rumensin-80 premix[5]	0.019	0.019	0.019
Vitamin A-D-E premix[6]	0.015	0.015	0.015
Thiamine premix[7]	-	0.014	0.014
Tylan-40 premix[8]	0.008	0.008	0.008
Nutrient composition[9]			
CP	13.6	17.9	17.8
Lipid[10]	3.64	4.72	6.91
Sulfur	0.12	0.37	0.41

[1] Values presented as a percentage of diet DM.
[2]Where CON = 0% byproduct, LFAT = 35% wet distillers grains without solubles, and NFAT = 35% wet distillers grains with solubles; inclusion of byproducts replaced a 1:1 ratio of dry-rolled corn and high-moisture corns.
[3]Soypass included at 1.0% of diet DM during the first 40 d, then replaced with fine ground corn.
[4]Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, 0.05% Co.
[5]Premix contained 176 g of monensin·kg^{-1} (Elanco Animal Health, Greenfield, IN).
[6]Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E·g^{-1}.
[7]Premix contained 88 g of thiamine·kg^{-1}.
[8]Premix contained 88 g of tylosin·kg^{-1} (Elanco Animal Health).
[9]Based on analyzed nutrients for each ingredient.
[10]Analyzed with a biphasic lipid extraction procedure with 1:1 ratio of hexanes:diethyl ether Bremer et al. (2010a).

Table 2. Diet composition and nutrient analysis of finishing diets fed in Exp. 2[1]

	Treatment[2]						
Item	Control	13.3WDGS	26.7WDGS	40WDGS	6.7CCDS	13.3CCDS	20CCDS
Ingredient							
High-moisture corn	55.0	41.7	28.3	15.0	48.3	41.7	35.0
Wet corn gluten feed	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Wet distillers grains plus soluble	-	13.3	26.7	40.0	-	-	-
Condensed corn distillers soluble	-	-	-	-	6.7	13.3	20.0
Corn stalks	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Dry supplement	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fine-ground corn	3.078	2.991	2.750	2.512	2.970	2.711	2.452
Limestone	1.683	1.770	2.011	2.249	1.791	2.050	2.309
Tallow	0.130	0.130	0.130	0.130	0.130	0.130	0.130
Trace mineral premix[3]	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Rumensin-80 premix[4]	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Vitamin A-D-E premix[5]	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Thiamine premix[6]	0.014	0.014	0.014	0.014	0.014	0.014	0.014
Tylan-40 premix[7]	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Nutrient composition[8]							
CP	15.6	18.8	21.9	25.1	16.8	17.9	19.1
NDF	23.3	26.7	30.2	33.6	22.8	22.3	21.8
Lipid[9]	4.1	5.0	5.9	6.9	4.8	5.5	6.2
Sulfur	0.26	0.35	0.44	0.52	0.33	0.39	0.45

[1] All values expressed on a DM basis.

[2] WDGS = wet distillers grains plus solubles, CCDS = dry mill condensed corn distillers solubles, 13.3WDGS = 13.3% WDGS, 26.7WDGS = 26.7% WDGS, 40WDGS = 40% WDGS, 6.7CCDS = 6.7% CCDS, 13.3CCDS = 13.3% CCDS, and 20CCDS = 20% CCDS; inclusion of WDGS or CCDS replaced high-moisture corn.

[3]Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, 0.05% Co.
[4]Premix contained 176 g of monensin·kg^{-1} (Elanco Animal Health, Greenfield, IN).
[5]Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E·g^{-1}.
[6]Premix contained 88 g of thiamine·kg^{-1}.
[7]Premix contained 88 g of tylosin·kg^{-1} (Elanco Animal Health).
[8]Based on analyzed nutrients for each ingredient.
[9]Analyzed with a biphasic lipid extraction procedure with 1:1 ratio of hexanes:diethyl ether Bremer et al. (2010a).

Table 3. Diets fed to metabolism steers of Exp. 3 (DM basis)[1]

Item	Treatment[2]				
	CORN	OIL	TAL	CCDS	WDGS
Ingredient					
Dry-rolled corn	80.0	82.7	82.7	62.0	31.5
Grass hay	7.5	7.5	7.5	7.5	7.5
Molasses	7.5	-	-	-	-
Corn oil	-	4.8	-	-	-
Tallow	-	-	4.8	-	-
Condensed corn distillers soluble	-	-	-	25.5	-
Wet distillers grains plus soluble	-	-	-	-	56.0
Dry supplement	5.0	5.0	5.0	5.0	5.0
Fine-ground corn	2.525	2.525	2.525	2.728	2.728
Urea	1.280	1.280	1.280	-	-
Limestone	0.793	0.793	0.793	1.870	1.870
Sodium Chloride	0.300	0.300	0.300	0.300	0.300
Trace mineral premix[3]	0.050	0.050	0.050	0.050	0.050
Rumensin-80 premix[4]	0.017	0.017	0.017	0.017	0.017
Vitamin A-D-E premix[5]	0.015	0.015	0.015	0.015	0.015
Thiamine premix[6]	0.012	0.012	0.012	0.012	0.012
Tylan-40 premix[7]	0.008	0.008	0.008	0.008	0.008
Nutrient composition[8]					
NDF	14.0	14.0	14.0	12.6	28.5
CP	11.9	11.4	11.4	12.7	22.4
Lipid[9]	3.6	8.5	8.5	8.2	8.6

Fatty Acids	3.1	7.3	6.9	6.6	7.2
Sulfur	0.15	0.11	0.11	0.45	0.58

[1] All values expressed on a DM basis.

[2] CORN = control corn diet, OIL = 4.8% corn oil, TAL = 4.8% beef tallow, CCDS = 25.5% condensed corn distillers solubles, WDGS = 56.0% corn wet distillers grains; inclusion of lipid sources replaced dry-rolled corn.

[3]Premix contained 10% Mg, 6% Zn, 4.5% Fe, 2% Mn, 0.5% Cu, 0.3% I, 0.05% Co.
[4]Premix contained 176 g of monensin·kg^{-1} (Elanco Animal Health, Greenfield, IN).
[5]Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, 3.7 IU of vitamin E·g^{-1}.
[6]Premix contained 88 g of thiamine·kg^{-1}.
[7]Premix contained 88 g of tylosin·kg^{-1} (Elanco Animal Health).
[8]Based on analyzed nutrients for each ingredient.
[9]Analyzed with a biphasic lipid extraction procedure with 1:1 ratio of hexanes:diethyl ether Bremer et al. (2010a).

Table 4. Yearling steer finishing feedlot performance when fed a control, low lipid WDG, and normal lipid WDGS diet in Exp. 1.

	Treatments[1]				
Item	Control	LFAT	NFAT	SEM[2]	P-value[3]
Performance					
Initial BW, kg	403	402	402	1	0.38
Final BW[4], kg	587[a]	587[a]	604[b]	4	0.04
DMI, kg/d	11.1	11.1	11.1	0.3	0.99
ADG, kg/d	1.55[a]	1.55[a]	1.68[b]	0.07	0.02
G:F[5]	0.139	0.139	0.152	0.004	0.12
Carcass characteristics					
HCW, kg	370[a]	370[a]	381[b]	2.2	0.04
Marbling score[6]	614	591	617	20	0.61
12th rib fat, cm	1.19	1.32	1.35	0.08	0.25
LM area, cm^2	86.45	83.22	84.52	2.19	0.62

[a,b]Means in the same row without a common superscript differ ($P < 0.05$)

[1]Where control = 0% byproduct, LFAT = 35% wet distillers grains without solubles, and NFAT = 35% wet distillers grains with solubles; inclusion of byproducts replaced a 1:1 ratio of dry-rolled corn and high-moisture corns.

[2]Each treatment mean represents 4 pens (n).

[3]Significance for *F*-test effect between treatments.

[4]Calculated from HCW, adjusted to a 63% yield.

[5]Calculated as total BW gain over total DMI.

[6]450=Slight[50], 500=Small[0].

Table 5. Main effects of wet distillers grains plus solubles (WDGS) level with 35% wet corn gluten feed on performance measurements and carcass characteristics in Exp. 2.

	Treatment[1]					P-value[2]		
Item	Control	13.3WDGS	26.7WDGS	40WDGS	SEM	Linear	Quadratic	Cubic
Performance								
Initial BW, kg	446	447	447	446	1	0.85	0.95	0.96
Final BW,[3] kg	588	587	582	577	5	0.37	0.77	0.93
DMI, kg/d	10.4	10.3	10.3	9.6	0.2	0.06	0.80	0.86
ADG, kg/d	1.72	1.71	1.65	1.56	0.06	< 0.01	0.34	0.89
G:F[4]	0.166	0.166	0.168	0.163	0.005	0.86	0.70	0.77
Carcass characteristics								
HCW, kg	370	370	367	361	3	0.38	0.76	0.93
12^{th}-rib fat, cm	1.47	1.37	1.35	1.30	0.07	0.07	0.80	0.76
LM area, cm^2	82.9	81.5	81.3	79.8	1.9	0.15	0.98	0.67
Yield grade[5]	3.34	3.31	3.26	3.25	0.11	0.44	0.99	0.97
Marbling score[6]	519	523	535	504	18	0.52	0.34	0.46

[1]WDGS = wet distillers grains plus solubles, 13.3WDGS = 13.3% WDGS, 26.7WDGS = 26.7% WDGS, 40WDGS = 40% WDGS; inclusion of WDGS replaced high-moisture corn.

[2]Single degree of freedom contrasts for linear, quadratic, and cubic effects of WDGS level in diets containing 35% wet corn gluten feed.

[3] Calculated from carcass weight, adjusted to a 63% common dressing percentage.

[4]Calculated as total BW gain over total DMI.

[5]Yield grade calculated as [2.5 + (6.35*fat thickness, cm) + (0.2* 2% KPH) + (0.0017* HCW, kg) – (2.06*LM area, cm^2)]; (Boggs and Merkel, 1993).

[6]450=$Slight^{50}$, 500=$Small^{0}$.

Table 6. Main effects of condensed corn distillers solubles (CCDS) level with 35% wet corn gluten feed on performance measurements and carcass characteristics in Exp. 2.

	Treatment[1]					P-value[2]		
Item	Control	6.7CCDS	13.3CCDS	20CCDS	SEM	Linear	Quadratic	Cubic
Performance								
Initial BW, kg	446	447	447	445	1	0.99	0.79	0.92
Final BW,[3] kg	588	587	589	587	5	0.96	0.72	0.85
DMI, kg/d	10.4	10.3	10.0	10.2	0.2	0.55	0.80	0.81
ADG, kg/d	1.72	1.71	1.73	1.72	0.06	0.92	0.72	0.73
G:F[4]	0.166	0.166	0.173	0.168	0.005	0.52	0.58	0.49
Carcass characteristics								
HCW, kg	370	370	371	370	3	0.97	0.71	0.85
12th-rib fat, cm	1.47	1.40	1.45	1.42	0.07	0.78	0.80	0.16
LM area, cm^2	82.9	81.7	81.1	78.1	1.9	0.19	0.58	0.68
Yield grade[5]	3.34	3.37	3.43	3.53	0.11	0.15	0.97	0.90
Marbling score[6]	519	516	551	519	18	0.24	0.04	0.04

[1]CCDS = condensed corn distillers solubles, 6.7CCDS = 6.7% CCDS, 13.3CCDS = 13.3% CCDS, and 20CCDS = 20% CCDS; inclusion of CCDS replaced high-moisture corn.

[2]Single degree of freedom contrasts for linear, quadratic, and cubic effects of CCDS level in diets containing 35% wet corn gluten feed.

[3] Calculated from carcass weight, adjusted to a 63% common dressing percentage.

[4]Calculated as total BW gain over total DMI.

[5]Yield grade calculated as [2.5 + (6.35*fat thickness, cm) + (0.2* 2% KPH) + (0.0017* HCW, kg) – (2.06*LM area, cm^2)]; (Boggs and Merkel, 1993).

[6]450=Slight[50], 500=Small[0].

Table 7. Effects of dietary lipid source on nutrient intake and total tract DM, lipid, fatty acids, and NDF digestibility in Exp. 3.

	Treatment[1]						
Item	CORN	OIL	TAL	CCDS	WDGS	SEM	P-value[2]
DM							
Intake, kg/d	11.2	9.6	10.3	9.9	10.6	0.7	0.43
Digestibility, %	81.3[c]	77.3[ab]	80.3[bc]	80.6[bc]	75.8[a]	2.6	0.06
Total lipid							
Intake, kg/d	0.42[a]	0.83[b]	0.86[b]	0.83[b]	0.92[b]	0.05	< 0.01
Digestibility, %	89.2[a]	90.9[ab]	92.9[c]	92.5[bc]	90.3[a]	1.2	0.03
Fatty acids							
Intake, kg/d	0.35[a]	0.74[b]	0.72[b]	0.66[b]	0.77[b]	0.05	< 0.01
Omasal fatty acid profile, % of total omasal fatty acids							
Palmitic acid (C16:0)	12.5[a]	12.4[a]	19.8[c]	14.3[b]	14.2[b]	0.6	< 0.01
Stearic acid (C18:0)	51.5[b]	57.4[c]	47.3[b]	49.4[b]	39.1[a]	2.3	< 0.01
C18:1 (all isomers)	16.0[a]	17.5[ab]	17.9[ab]	19.8[b]	25.0[c]	1.4	< 0.01
C18:2 (all isomers)	13.1[b]	7.6[a]	7.5[a]	11.4[b]	17.0[c]	1.3	< 0.01
C18:3 (all isomers)	1.0[bc]	0.9[ab]	0.8[a]	1.1[bc]	1.1[c]	0.06	0.02
Unsaturated:Saturated	0.49[a]	0.39[a]	0.40[a]	0.52[a]	0.83[b]	0.06	< 0.01
Digestiblity, % of fatty acids reaching omasum[3]							
Palmitic acid (C16:0)	93.7	95.0	96.6	97.2	96.0		
Stearic acid (C18:0)	95.6	94.9	95.5	97.4	94.9		
C18:1 (all isomers)	92.6	94.6	96.2	96.9	96.1		
C18:2 (all isomers)	88.8	84.2	91.0	92.6	92.9		
C18:3 (all isomers)	88.7	90.9	93.0	100.0	92.9		
Total	94.1	93.9	95.4	95.8	95.2	1.0	0.22

NDF							
Intake, kg/d	1.6[b]	1.4[ab]	1.5[a]	1.2[b]	3.0[c]	0.1	< 0.01
Digestibility, %	63.2[b]	49.1[a]	60.2[b]	58.3[b]	65.0[b]	4.9	0.04

[a-d] Means within a row with unlike superscripts differ (P < 0.10).

[1] CORN = control corn diet, OIL = 4.8% corn oil, TAL = 4.8% beef tallow, CCDS = 25.5% condensed corn distillers solubles, WDGS = 56.0% corn wet distillers grains; inclusion of lipid sources replaced dry-rolled corn.

[2] Significance for *F*-test effect between treatments.

[3] Calculated from the disappearance of omasal fatty acids (amount of fatty acid intake X individual fatty acid proportion of omasal profile with an assumed net zero addition of rumen biosynthesized fat) relative to actual quantity of individual fecal fatty acids.

Table 8. Effects of dietary fat source on ruminal in-situ corn bran NDF digestibility, pH, and volatile fatty acid profile parameters in Exp. 3.

	Treatment[1]						
Item	CORN	OIL	TAL	CCDS	WDGS	SEM	P-value[2]
In situ corn bran NDF digestibility, %							
12 h	15.6	9.2	11.5	13.5	13.9	1.8	0.16
24 h	22.6	17.1	21.4	18.4	19.1	2.2	0.15
48 h	31.6	29.1	22.1	26.2	24.7	2.7	0.13
Ruminal pH							
Average	5.41[ab]	5.75[c]	5.60[bc]	5.31[a]	5.56[bc]	0.09	0.01
Variance	0.07[d]	0.06[c]	0.05[b]	0.04[a]	0.04[a]	0.01	< 0.01
Time < 5.6, min/d	1091[bc]	564[a]	618[a]	1289[c]	843[ab]	147	< 0.01
Ruminal volatile fatty acids							
Total, mM	140.3	125.5	142.0	131.7	129.2	8.4	0.54
Acetate, mol/100 mol	50.5[bc]	50.9[c]	46.4[ab]	45.3[a]	52.0[c]	1.9	0.07
Propionate, mol/100 mol	34.0	32.4	38.0	40.6	32.8	2.6	0.15
Butyrate, mol/100 mol	11.8	11.1	9.4	9.8	9.7	1.0	0.21
Acetate:Propionate	1.55	1.63	1.26	1.16	1.62	1.2	0.25

[a-d] Means within a row with unlike superscripts differ (P < 0.10).

[1] CORN = control corn diet, OIL = 4.8% corn oil, TAL = 4.8% beef tallow, CCDS = 25.5% condensed corn distillers solubles, WDGS = 56.0% corn wet distillers grains; inclusion of lipid sources replaced dry-rolled corn.

[2] Significance for *F*-test effect between treatments

Emissions Savings in the Corn-Ethanol Life Cycle from Feeding Co-Products to Livestock

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ABSTRACT

Environmental regulations on greenhouse gas (GHG) emissions from corn (*Zea mays* L.)-ethanol production require accurate assessment methods to determine emissions savings from co-products that are fed to livestock. We investigated current use of co-products in livestock diets and estimated the magnitude and variability in the GHG emissions credit for co-products in the corn-ethanol life cycle. The co-product GHG emissions credit varied by more than twofold, from 11.5 to 28.3 gCO_2e per MJ of ethanol produced, depending on the fraction of co-products used without drying, the proportion of co-product used to feed beef cattle (*Bos taurus*) vs. dairy or swine (*Sus scrofa*), and the location of corn production. Regional variability in the GHG intensity of crop production and future livestock feeding trends will determine the magnitude of the co-product GHG offset against GHG emissions elsewhere in the corn-ethanol life cycle. Expansion of annual U.S. corn-ethanol production to 57 billion liters by 2015, as mandated in current federal law, will require feeding of co-product at inclusion levels near the biological limit to the entire U.S. feedlot cattle, dairy, and swine herds. Under this future scenario, the co-product GHG offset will decrease by 8% from current levels due to expanded use by dairy and swine, which are less efficient in use of co-product than beef feedlot cattle.

Because the co-product GHG credit represents 19 to 38% of total life cycle GHG emissions, accurate estimation of the co-product credit is important for determining the net impact of corn-ethanol production on atmospheric warming and whether corn-ethanol producers meet state- and national-level GHG emissions regulations.

Abbreviations: DDGS, dried distillers grains with solubles; DGS, distillers grains plus solubles; GHG, greenhouse gas; LCA, life cycle assessment; WDGS, wet distillers grains with solubles.

INTRODUCTION

WHILE co-products from maize grain-ethanol production are an important source of animal feed and additional income for biorefineries, co-product production, processing, transport, and end-use also have a large impact on net GHG emissions from the corn-ethanol life cycle (Klopfenstein et al., 2008; Liska et al., 2009; Farrell et al., 2006). State and federal regulations under development will require life cycle GHG emissions from biofuels to achieve minimum reduction levels compared to transportation fuels derived from petroleum. For example, the Energy Independence and Security Act of 2007 (EISA) requires that corn-ethanol, cellulosic ethanol, and advanced biofuels reduce life cycle GHG emissions by 20, 60, and 50%, respectively. Because GHG-credits for co-products have been previously estimated to offset 19 to 38% of positive life cycle emissions from corn production and biorefining (Liska et al., 2009), it is critical that these credits are accurately estimated to determine the net anthropogenic impact of corn-ethanol production on the atmosphere. Furthermore, such knowledge should be accurately captured by life cycle assessment (LCA) methods used in the regulatory process for biofuels.

Recent changes in co-product use as livestock feed suggest that previous estimates of co-product credits are no longer representative of current industry practices (Klopfenstein et al., 2008; NASS, 2007). For example, recent estimates of substitution rates between co-products and conventional feed (Arora et al., 2008) do not consider the impact of changing co-product uses in livestock diets on the magnitude of the co-product GHG credit, and its impact on the life cycle of corn-ethanol. Furthermore, varying rates of co-product substitution in different livestock feeding settings requires a dynamic co-product crediting model to determine the GHG credit attributable to each of the main livestock feeding systems.

Distillers grains plus solubles (DGS) are composed of the nonfermentable portion of corn grain and are the co-product from dry-mill corn-ethanol production. Dry-mill biorefineries powered by natural gas currently represent nearly 90% of U.S. grain-ethanol production capacity (G. Cooper, personal communication, 2008). Corn starch fermented to ethanol represents roughly 73% of grain dry matter and about 67% of the energy content. The remaining protein, lipid, cellulose, lignin, and ash make up about 27% of grain dry matter and 33% of the energy (Table 1). As such, the energy content of co-products is a sizable portion of total energy output of the corn-ethanol life cycle.

Three main types of distillers grains are produced by most dry mill ethanol biorefineries (NASS, 2007). Wet distillers grains with solubles (WDGS; 65% water) are produced by adding condensed distillers solubles back to the solid unfermentable portion of the corn grain after fermentation. Distillers solubles are the water soluble fraction of postdistillation stillage that are separated via centrifugation. An alternate product, modified distillers grains with solubles (MDGS; 55% water) are produced when the co-product fraction is partially dried before the condensed solubles are added. If the solubles and co-product are mixed together and dried more completely, dried distillers grains with solubles (DDGS; 10% water) are produced. Producing co-products with less moisture requires energy input at the biorefinery (Liska et al., 2009).

Livestock producers use co-products as a source of both energy and protein in beef, dairy, and swine diets. As such, they primarily substitute for corn and protein in livestock feeds (Klopfenstein et al., 2008; Schingoethe, 2008; Stein, 2008). The type of protein replaced by DGS in animal diets depends on whether beef cattle, dairy cattle, or swine are being fed, each with a distinct dietary substitution. For example, soybean meal is the major protein source replaced by DGS in dairy and swine diets (Schingoethe, 2008; Stein, 2007). In contrast, DGS substitutes for urea as a N source for protein in beef cattle diets (Klopfenstein et al., 2008). A nutritionist survey of beef cattle rations conducted in 2000 found urea to be the primary source of supplemental protein in feedlot systems (Galyean and Gleghorn, 2001). By 2007, however, ethanol co-products were widely used as a low-cost protein source for feedlot cattle (Vasconcelos and Galyean, 2007).

The most widely used and accurate method for allocating co-product GHG and energy credits to the corn-ethanol life cycle is through the displacement method in the context of "system expansion" (Kodera, 2007). This method assumes that co-products from corn-ethanol production substitute for other feed components and offset fossil fuel use and associated GHG emissions required to produce the replaced feed components (Kodera, 2007; Liska et al., 2009). Alternative approaches to co-product allocation include mass basis, energy content, and market value (Kodera, 2007; Kim and Dale, 2002). Although these alternative methods may be less data-intensive than the displacement method, they are not sensitive to the different livestock feeding values of corn-ethanol co-products and therefore do not accurately represent changes in GHG emission profiles.

Estimating the displacement credit for an individual corn-ethanol biorefinery requires quantification of the different types of co-products produced by the ethanol plant, identification of the products to be displaced in livestock diets (and displacement ratios), and calculation of the fossil fuel energy and GHG emissions attributable to the life cycle production of the displaced products (Wang, 1999; Graboski, 2002). Recent co-product credit estimates assumed DGS displaced corn, urea, soybean meal, and oil, at a 15% inclusion level in feedlot cattle diets, as well as other variable substitutions (Kodera, 2007; Graboski, 2002; NRC, 2000).

The purpose of our study was to evaluate recent changes in livestock diets due to widespread availability and use of DGS in livestock rations, and to determine the impact of current practices on the GHG emissions mitigation potential from corn-ethanol compared to gasoline. The results of this life cycle assessment were used to understand how co-product feeding practices will influence GHG emissions of corn-ethanol relative to emissions regulations in state low carbon fuel standards (LCFS) and federal EPA standards stipulated in the EISA of 2007.

MATERIALS AND METHODS

Co-Product Use in Beef Cattle Diets

Data on co-product use in feedlot cattle systems were obtained from a recent meta-analysis (Klopfenstein et al., 2008). Co-product performance in beef cattle diets was estimated from the gain-to-feed ratios that result from inclusion of DGS in feed rations. It is noteworthy that the Klopfenstein study documented improved performance of DDG when substituted for corn, and an additional benefit of WDGS compared to DDGS. Moreover, the feeding value of each type of co-product is modulated by the proportion of substitution in the diet. Hence, the type and level of DGS fed determine cattle performance. A detailed biological model, based on the co-product feeding trials of Klopfenstein et al. (2008), has been developed as a component of the Biofuel Energy Systems Simulator (BESS model, www.bess.unl.edu) to estimate animal performance and protein replacement from DGS substitution in conventional feedlot diets.

Experimental data have demonstrated that up to 50% of diet dry matter may be replaced with DGS in feedlot diets and improve cattle performance (Klopfenstein et al., 2008). Nutritionists' surveys indicate the current average co-product inclusion rate is 20% (dry matter basis) with a range of 5 to 50% of the diet (Vasconcelos and Galyean, 2007). In the Corn Belt, survey data suggest that beef producers feeding DGS have an average dietary inclusion of 22 to 31% on a wet basis (approximately 15–20% of dry matter) (NASS, 2007).

Respondents to both a feedlot nutritionist survey (Vasconcelos and Galyean, 2007) and a Nebraska feedlot industry survey (Waterbury et al., 2009) reported that DGS are the most common ethanol co-product used by cattle feeders. The Nebraska survey indicates 53 and 29% of Nebraska feedlots feed WDGS and MDGS, respectively. The nutritionist survey indicated 69% of the 29 nutritionists were feeding DGS as the primary co-product in the diet, and these beef nutritionists were responsible for formulating diets for nearly 70% of cattle on feed in the United States. Results from the two surveys document that DGS are the primary co-product used from corn-ethanol production. Therefore, DGS use in livestock rations represents the basis for estimating the co-product credit in corn-ethanol life cycle energy and GHG assessments.

Feeding values of the DGS co-products relative to corn were calculated for each feedlot inclusion level of wet, modified, and DDGS from measured biological feed efficiency values. These feeding values decrease as the level of co-product increases in the diets. Thus, as more DGS are included in the diet, they replace less corn per unit increase in the substitution rate. In addition, the relative feeding value of DDGS declines at a faster rate than WDGS as inclusion levels increase, indicating that WDGS have a higher feeding value than DDGS. Based on these differences in the amounts of urea and corn substituted by co-product relative to traditional corn-fed cattle, the resulting energy and emissions savings are calculated. When the level of co-product fed in the diet replaces all urea, the excess co-product protein is not credited to urea replacement. Energy use to produce urea is conservatively assumed to have come from natural gas (see BESS User's Guide, www.bess.unl.edu).

Co-Product Use in Dairy Cattle Diets

A recent meta-analysis of dairy feed rations includes data from numerous research trials to estimate current DDGS feeding practices for dairy production (Schingoethe, 2008). The nutrient composition of DGS makes it a good energy and protein source for dairy cows, and diets fed to dairy cows may contain DGS to replace corn, protein, and forages (Janicek et al., 2008). It is more common, however, to replace corn and protein without replacing forage (Schingoethe, 2008). Results from published feeding studies are not consistent with regard to dairy cow milk production response to DGS inclusion. Some studies found no change in milk production when DGS were added to lactating dairy cow diets (Schingoethe et al., 1999). Other studies reported a dilution of milk components when DGS were fed (Leonardi et al., 2005; Nichols et al., 1998), or an increase in milk production from feeding DGS (Anderson et al., 2006; Kleinschmit et al., 2006). When all available research data were combined and evaluated in a meta-analysis, no production response to DGS feeding is evident, and milk composition was not affected by substituting DGS for corn.

In the BESS model, DGS are assumed to directly replace corn and soybean meal in lactating dairy cow diets. Distillers grains had been fed up to 30% of diet dry matter to lactating dairy cows without negative affects on milk production when replacing corn and soybean meal (Schingoethe, 2008). Survey data suggest that the average inclusion of DGS in dairy diets is 10 to 22% (approximately 10% of dry matter) (NASS, 2007). At this relatively low inclusion level, DGS are primarily used as a protein supplement to replace soybean [*Glycine max* (L.) Merr.] meal. Based on these data, the co-product credit for DGS inclusion in dairy cow diets in the BESS model is based on the direct replacement of corn and soybean meal at a rate of 0.45 kg of corn and 0.55 kg of soybean meal dry matter for each kilogram of DGS dry matter added to the diet (Schingoethe et al., 1999; Kleinschmit et al., 2006; Anderson et al., 2006).

Co-Product Use in Swine Diets

A recent review of swine research on feeding DDGS to finishing pigs is based on numerous studies (Stein, 2008). Finishing pigs are the main class of swine to use DDGS, and their feeding performance is not affected when DDGS replace a portion of corn and soybean meal in the diet. While this was the case in the majority of experiments, there were a few examples where reduced performance was observed when DDGS were fed. The reduced performance may result from suboptimal diet formulation, the use of low-quality DDGS, or decreased palatability of DDGS diets to the pigs (Stein, 2008). Research has shown that DDGS may be included in grow-finish diets up to 27% of diet dry matter without decreasing animal performance. When DDGS are added to swine diets, corn and soybean meal are replaced at the rate of 0.57 kg of corn and 0.43 kg of soybean meal dry matter per kilogram of DDGS dry matter (Stein, 2007).

Survey data indicate relatively few swine operations use DDGS, and the average inclusion rate is 9% of diet dry matter (NASS, 2007). Because commercial swine feeding systems are developed to deliver dry feed (< 15% moisture) to finishing pigs, feeding WDGS has logistical challenges for use in these large-scale swine operations. Hence, to our knowledge, WDGS have not been studied for swine production.

Co-Product Use in Poultry Diets

The poultry industry is an insignificant consumer of DGS based on the most recent survey (NASS, 2007). Therefore, DGS use by poultry was not included in our analysis.

Current and Future Co-Product Use in Livestock Diets

A recent NASS survey of beef, dairy, and swine operations reported ethanol co-product use for livestock feed in the U.S. Corn Belt (NASS, 2007). In 2006, the region contained 11.3 million cattle in 1000+ head feedlots, 3.2 million dairy cattle, and 64.1 million grow-finish pigs representing 50, 33, and 70% of U.S. beef, dairy, and pork production, respectively (Table 2; NASS, 2008). The survey reported that 36, 38, and 12% of Corn Belt beef, dairy, and swine operations, respectively, were feeding co-products in 2006. Estimating average corn-ethanol co-product use, however, may be misleading when based on number of operations using co-products. The data indicated that large-scale producers were more likely to use co-product feeding (NASS, 2007; Waterbury et al., 2009). Adjusting for operation size based on co-product use (NASS, 2007, 2008), 63, 49, and 40% of finishing beef, dairy cows, and finisher pigs in the Corn Belt, respectively, were fed co-product in 2006. These co-product use numbers are representative of the major DGS producing region of the United States. Distillers grains utilization numbers would likely be different in other regions of the United States, and relatively little corn-ethanol is produced outside the Corn Belt. Total co-product use by each livestock class was calculated by the dietary inclusion of DGS based on data from experiments feeding co-products and survey data (Klopfenstein et al., 2008; Schingoethe, 2008; Stein, 2008; NASS, 2007). Three future feeding scenarios were developed based on co-product inclusion in livestock diets and different levels of industry use (Table 2).

Modeling Life Cycle Credits from Co-Product Feeding

Energy and GHG emissions credits from the feeding of co-products to livestock were evaluated using the BESS model, version 2009.4.0 (www.bess.unl.edu). The corn and ethanol production components of this model have been previously described, including a co-product crediting model based solely on use in beef cattle diets (Liska et al., 2009). The update of the BESS model reported here includes a more accurate depiction of DGS use by the beef, dairy, and swine industries to estimate the co-product credit. Other relatively minor changes (such as higher lime application rates, and electricity emissions factors [Liska and Cassman, 2009]) have also been updated and are described in the BESS User’s Guide 2009.4.0 (www.bess.unl.edu). State average lime rates were applied for state level scenarios. The Midwest average electricity emission factor was applied for all scenarios.

The cattle, dairy, and swine industries are assumed to operate independently of the biofuel industry because there is no evidence that livestock numbers have been affected by expansion of the biofuel industry. In fact, the U.S. beef cow herd size decreased by 1% from 2004 to 2008 (NASS, 2008). Co-product credits are determined for both energy and GHG emissions, based on a partial budget for livestock production operations that considers the difference between a conventional diet and a diet containing DGS. The model then estimates the energy and GHG emissions that result from production, processing, and transport of the feed products that were replaced by DGS.

Credits from Hauling Co-Products

There are no data available on the relative difference in transportation distances for corn and DGS delivery to livestock feeding operations. We therefore estimated these distances based on our knowledge of feedlot, corn, and DGS spatial relationships. Energy and GHG estimates for transportation are based on a loaded truck transporting a payload of 22,680 kg with a fuel efficiency of 2.55 km L^{-1} per average round trip. For feedlot cattle, corn is assumed to be sourced from nearby farmers or grain elevators with a 24 km average haul distance; average DGS haul distance is assumed to be 48 km. Corn and DGS haul distances are assumed to be the same when the feeds are fed to dairy and swine. Feed truck fuel used to feed cattle within the feedlot is based on 0.011 L diesel fuel per head per day for a traditional corn-based diet. Urea and diesel fuel energy and GHG parameters were previously described (Liska et al., 2009; see BESS 2009.4.0 User's Guide, www.bess.unl.edu). Fuel used to haul co-product to the feedlot is calculated from the amount of co-product fed, the haul distance, truck load size, and truck fuel efficiency. Water in WDGS requires more energy for transportation to feedlots compared to an equivalent amount of feed on a dry matter basis from DDGS or corn grain.

All of the energy and GHG emissions associated with DGS transportation are accounted for in the feedlot partial budget. Dairy and swine models are based on direct replacement of corn and soybean meal by DDGS; transportation fuel use for moving co-product to the livestock operation and within the operation is assumed to be equivalent to the corn and soybean meal it replaces. When DGS diets improve cattle performance relative to traditional corn-based diets, finished cattle are on feed fewer days, feed is hauled fewer days, and a credit is given to the system for the fuel saved for not hauling the corn that the co-product replaced. A debit is given to the system for the fuel expended to feed DGS.

Greenhouse Gas Emissions from Crop Production, Nitrogen, and Enteric Fermentation

The cropping system component of the BESS model estimates the energy and GHG emissions intensity of corn production (Liska et al., 2009). The efficiency of state-level corn production was calculated using previously defined parameters such as crop yields, fertilizer use, and fossil fuel use (Liska et al., 2009). Soybean meal emissions savings and production parameters were taken from Hill et al. (2006). Nitrous oxide (N_2O) emissions for soybean and corn production were determined using IPCC guidelines which are sensitive to the amount of applied N and the total amount of N in crop residues returned to soil (IPCC, 2006). Crop residue yields were estimated for corn and soybean based on average grain yields and average ratios of grain to above- and belowground crop biomass, and the N concentration in these tissues.

For cattle, DGS inclusion in diets improves growth rates and thus reduces time in the feedlot for finished cattle by several days depending on the inclusion level and whether the DGS are fed dry or wet (see above). Less time in the feedlot for finished cattle reduces fuel use for transportation of feed as well as methane emissions from cattle enteric fermentation. These savings are included in the co-product credit for the portion of DGS fed to cattle.

Enteric methane production is calculated from cattle size, projected dry matter intake, and energy content of the diet. Feed inputs are used to calculate gross energy intake by the cattle with standard animal energy equations (NRC, 1996). An average 2.9% of gross energy is lost as enteric fermentation methane by feedlot cattle (see BESS 2009.4.0 User's Guide, www.bess.unl.edu). Due to lack of data on comparison of enteric methane production from DGS vs. corn-based diets, the two feedstuffs were given the same methane production potential on a dry matter basis.

Corn-Ethanol Biorefinery Energy Efficiency and Co-Product Processing

To determine the impact of different feeding practices on the corn-ethanol life cycle, a standard natural gas-powered dry mill biorefinery is assumed in all scenarios. Data on energy use for co-product processing were obtained from survey information provided by ethanol biorefineries of this type operating in 2006–2007. Subsets of the data from these surveys have been previously reported (Perrin et al., 2009; Liska et al., 2009) and data were obtained directly from the plant managers. The surveyed biorefineries were located in Iowa, Michigan, Minnesota, Missouri, Nebraska, South Dakota, and Wisconsin. For the nine biorefineries, the date of initial operation included 2001 (*n* = 1, with plant expansion in 2007), 2004 (*n* = 1, expansion in 2006), 2005 (*n* = 6), and 2006 (*n* = 1). All yield and efficiency values are for anhydrous ethanol. Only aggregate data are shown to maintain confidentiality of individual biorefineries. Average yields and efficiencies were weighted by production capacities of biorefineries in the survey. Plant capacities represented a total production capacity of 1.83 billion L in 2006 (485 million gallons), which was about 10% of total U.S. corn-ethanol production in 2006.

The relationship between biorefinery energy use and production of the different co-product types was determined by least squares regression based on the above survey data (Table 3). The data at the bottom half of the table were used to determine an equation to estimate total natural gas use (MJ L^{-1} ethanol) at the biorefinery when producing different fractions of co-products for use in Table 4; total MJ L^{-1} = 3.42 MJ $L^{-1} \times$ % DDGS + 1.64 MJ $L^{-1} \times$ % MDGS + 4.91 MJ L^{-1}. Ethanol yields above are for 100% biofuel; 3% of the volume of the ethanol yield in the survey data was removed for exclusion of denaturant, based on statistics from the Nebraska Department of Environmental Quality that show an average denaturant level of 2.7% in 2007 in Nebraska.

Scenarios for Co-Product Production and Feed Substitution in the Corn-Ethanol Life Cycle

Twelve scenarios were developed to represent current co-product production and livestock feeding practices to evaluate DGS use (Table 4). These scenarios provide the basis for estimating energy and GHG credits from co-products in corn-ethanol systems.

The DGS credit was evaluated based on the distribution of co-product use between the beef, dairy, and swine industries (MWavg, MWdav, IAavg, NEavg, TXavg, MWfav), or only one type of co-product was assumed to be produced and fed to one type of livestock (NEdb, NEmb, NEwb, MWds, MWdd, MWdb). The six single co-product scenarios are hypothetical, as well as Midwest dry average (MWdav) and Midwest future average (MWfav). Corresponding feed substitutions were determined based on livestock type, co-product type, and inclusion level.

Co-product Composition

Scenario MWavg is based on livestock data in Table 2 and assumes swine are fed only DDGS, dairy use is 70, 15, and 15 for, DDGS, MDGS, and WDGS, respectively, and beef use is 50% of both MDGS and WDGS. IAavg is based on livestock data, where all swine use DDGS, and beef and diary are equally split between MDGS and WDGS. NEavg co-product production data are from 14 natural gas powered dry-mill biorefineries in Nebraska in 2007 (based on data from air emissions inventories, the Nebraska Department of Environmental Quality). TXavg is based on livestock data (below) and assumes all Texas DGS are produced wet due to large cattle numbers in close proximity to operating ethanol plants.

Livestock Class Composition

Livestock distribution is based on a survey of co-product use and livestock production in the Midwest (MWavg, MWdav) (NASS, 2007, 2008), and recent surveys of the livestock industry in Iowa, Nebraska, and Texas (IAavg, NEavg, TXavg, respectively) (NASS, 2009). The IAavg calculations are based on Census of Agriculture numbers

(NASS, 2008), livestock industry survey (Lain et al., 2008), and industry experts (M. Brumm, personal communication, 2009; L. Kilmer, personal communication, 2009). NEavg calculations are based on Census of Agriculture numbers (NASS, 2009), livestock industry survey (Waterbury et al., 2009), and industry experts (P. Kononoff, personal communication, 2009; D. Reese, personal communication, 2009). The TXavg calculations are based on Census of Agriculture numbers (NASS, 2009), and the remaining scenarios used hypothetical livestock class compositions as described.

Co-product inclusion rates for all scenarios are 20, 9, and 10% of diet dry matter for beef, swine, and dairy, respectively. Dietary substitutions, energy, and GHG credits were determined using the BESS model version 2009.4.0 (www.bess.unl.edu). The MWfav scenario is the projected future DGS use based on Table 2.

RESULTS

Substitutions in Livestock Diets and Greenhouse Gas Emissions Reductions

The beef finishing industry was found to be the major user of DGS with 56% of Corn Belt DGS fed to feedlot cattle on a dry matter basis. The Corn Belt dairy and swine industries use 30 and 14% of total DGS production, respectively. These three livestock classes account for 4.4 million Mg of Corn Belt DGS use, which is sufficient DGS demand to support 6.2 billion L annual ethanol production at current levels of inclusion in feed rations (Table 2). This estimate is conservative, however, because feedlot cattle numbers are based on NASS data that are only collected for feedlots greater than 1000 head; small farmer-feeders are not included. Other exclusions are calves and cows on grass, dairy heifers and nonlactating dairy cows, and sow and sow development animals that are given DGS as a nutritional supplement or feed component. In addition, there is a small amount of DGS fed to poultry, and some of the DGS is exported to other countries, both of which are not included in these estimates.

In livestock feeding systems, the co-product energy credit for the corn-ethanol life cycle is determined by the amount of fossil fuels offset from the production of substituted feeds (which is much lower than the energy derived from combustion; Tables 1 and 4). The Midwest average scenario is based on average co-product production and feeding a weighted average of DGS fed to cattle, dairy, and swine in the Midwest (MWavg). In this scenario, 1 kg of DGS dry matter replaces 0.91, 0.23, and 0.04 kg of corn, soybean meal, and urea, respectively (Table 4). Comparable average DGS replacement values were recently reported by Arora et al. (2008). These average values mask large differences in replacement values depending on types of co-product produced and how they were fed to different livestock classes. For example, substitutions were found to range from 0.45 to 1.35 kg for corn, 0 to 0.55 kg for soybean meal, and 0 to 0.07 kg for urea across WDGS, DDGS, and MDGS fed to cattle, dairy, or swine (Table 4). Energy and GHG emissions credits for the corn-ethanol life cycle are based on the above substitution rates. Dairy and swine GHG credits are calculated from the direct offset of energy inputs and associated emissions for the production of corn and soybean meal.

Greenhouse Gas Emissions Credits and Cropping Emissions Intensity

The Midwest average energy credit for ethanol was determined to be 2.16 MJ per liter, with replacement of corn, urea, and soybean meal accounting for roughly 56, 28, and 17% of the energy credit, respectively (MWavg, Table 4). Due to the multi-species approach of this co-product model, the aggregate value is less than the 4.13 MJ L^{-1} of ethanol previously reported by Farrell et al. (2006). In terms of GHG emissions, corn, soybean meal, urea, and enteric fermentation account for 63, 19, 11, and 8%, respectively, of the credit in the Midwest average scenario, with minimal impact on diesel fuel use. The average Midwest GHG credit was 15.2 gCO_2–eqiuivalent (gCO_2e) per MJ of ethanol produced.

The corn substituted by DGS is assumed to be produced locally. Because each state has a different efficiency of crop production, energy and GHG emissions credits were determined by the average emissions from crop production for the state in which the biorefinery is located (Liska et al., 2009). Based on state-level data, the GHG emissions credit increases with the GHG emissions intensity of the cropping system used to produce the grain for co-products (Fig. 1). For example, corn GHG production intensity in Iowa (274 $gCO_2e\ kg^{-1}$) is lower than Nebraska efficiency (308 $gCO_2e\ kg^{-1}$) because 70 to 75% of total corn production in Nebraska comes from irrigated systems that require energy inputs for irrigation. Texas corn production (473 $gCO_2e\ kg^{-1}$) has lower average crop yields, greater nutrient inputs, and more irrigation than Iowa. The Midwest corn production efficiency is the weighted average of 12 Corn Belt states and has an emissions intensity of 306 gCO_2e per kg grain. In states like Iowa, N_2O emissions account for half of the net emissions from corn production based on IPCC Tier I calculations (Liska et al., 2009; IPCC, 2006). The GHG credit in Iowa, Nebraska, and Texas (IAavg, NEavg, TXavg) was found to range from 12.0 to 28.3 $gCO_2e\ MJ^{-1}$, which incorporates state differences in GHG intensity of both crop and DGS production, and the use of DGS across the three categories of livestock (Table 4, Fig. 1). While we realize that a significant portion of the corn use by livestock and ethanol biorefineries in Texas is sourced from Corn Belt states, which are more energy and GHG efficient in corn production than Texas, our analysis assumed the corn for a Texas biorefiinery is obtained from local sources.

Evaluation of Individual Types of Co-Products and Livestock

Feeding scenarios in which only one type of co-product is produced by the biorefinery and used to feed one type of livestock were examined for the Midwest average and Nebraska cropping systems to evaluate the impact of drying and feeding efficiency on the GHG credit (Table 4). In these scenarios the energy credit ranged from 1.48 to 3.47 MJ L^{-1} of ethanol while the GHG emissions credit ranged from 11.5 to 20.9 gCO_2e MJ^{-1} (Table 4). The co-product credit for cattle feeding operations benefits from both energy savings when WDGS are used in place of DDGS, and also from improved cattle performance when cattle are fed WDGS, which converts to body weight more efficiently than DDGS (Klopfenstein et al., 2008). Six percent more beef can be produced per unit WDGS dry matter than when DDGS is fed–this improves the corn and urea replacement values of WDGS relative to DDGS. In addition, cattle fed WDGS require 11% fewer days on feed to reach market weight than corn-fed cattle and 4% fewer days than DDGS-fed cattle. Hence, cattle on diets with WDGS emit less methane during their life cycle in the feedlot than DDGS-fed cattle. The differences between WDGS and DDGS account for an improvement in overall feedlot energy credit of 8% and a CO_2e emissions reduction of 15%.

Feeding DDGS to cattle rather than swine or dairy will result in 53% greater reduction in GHG emissions. These savings would be even larger if the comparison was between WDGS for beef production and DDGS for swine or poultry (Table 4). Based on these results, general relationships were estimated for co-product emissions reductions in relation to the proportion of DGS fed wet vs. dry, and to cattle vs. dairy and swine (Fig. 2A). The previously mentioned differences in GHG credit due to use of WDGS vs. DDGS do not include the benefit of 41% less energy input and 29% less CO_2e emissions at the biorefinery to produce WDGS instead of DDGS.

Projected Trends in Co-Product Feeding

Future growth of the corn-ethanol industry will support more widespread adoption of co-product feeding for livestock. We evaluated several plausible future feeding scenarios to determine the impact of expected changes in feeding practices on co-product credits. If current DGS use in the livestock industry was increased to the maximum dietary inclusion level without negative impact on animal performance for each animal class, and holding total animal numbers constant, the amount of Corn Belt DGS demand could more than double to 11.3 million Mg DGS annually (dry matter basis, Table 2). If all Midwest livestock producers converted to feeding DGS based diets at maximum inclusion levels, the fed livestock would require an ethanol production capacity of 30 billion liters per year (bly). Extrapolating these Midwest DGS use estimates to the entire United States, and assuming that 100% of U.S. beef cattle, dairy cattle, and grow-finish pigs are fed at maximum inclusion levels, the dairy cattle industry becomes the largest consumer of DGS, and total DGS demand would require co-products from production of 69 bly. Current U.S. annual corn-ethanol production capacity is about 40 bly (Renewable Fuels Association, 2009), which indicates that U.S. livestock producers could use 1.7 times the amount of the DGS currently produced. If all co-products were fed at maximum biological inclusion levels, the average co-product credit would decrease for the ethanol industry from 14.6 to 13.9 $gCO_2e\ MJ^{-1}$ (MWfav, Table 4).

Greenhouse Gas Emissions Credits in the Corn-Ethanol Life Cycle

To evaluate the impact of co-product credits on the complete corn-ethanol life cycle, we assessed GHG emissions based on the performance of a standard natural gas-powered dry mill (Table 3). Average energy use by the surveyed biorefineries (7.7 $MJ\ L^{-1}$) is similar to the average energy use by the majority of natural gas powered dry mills currently operating in the Midwest (Liska et al., 2009). Production of only WDGS was estimated to require only 4.91 $MJ\ L^{-1}$, while DDGS production requires 8.33 $MJ\ L^{-1}$ due to drying (Tables 3 and 4). Biorefinery parameters (yield, natural gas efficiency, electricity efficiency) for individual facilities based on survey data and average co-product production rates were used to determine GHG emissions for each biorefinery (MWavg, Table 4). The Midwest average corn-ethanol production system was found to have an average GHG-intensity of 52.2 ± 2.8 $gCO_2e\ MJ^{-1}$ (coefficient of variation of 0.05) and a GHG reduction compared to gasoline of 46.5 ± 2.8% (CV = 0.06).

Co-product credits for the 12 feeding scenarios above were modeled as a component of a standard dry-mill natural gas biorefinery to estimate net life cycle emissions (Table 4). The co-product credit for the Midwest average scenario (MWavg) offset 23% of life cycle emissions (Table 5). Regional differences in GHG emissions associated with crop production, and the proportions of co-product fed to cattle vs. dairy and swine, result in a wide range in the co-product credit. In Texas, for example, most of the DGS is fed to cattle and the GHG intensity of corn production is high resulting in a co-product offset credit that represents 37% life cycle emissions (Fig. 1). Based on model simulations, increasing the proportion of DGS fed to beef cattle relative to other livestock types, and producing more WDGS relative to DDGS, will result in a decrease in net life cycle GHG emissions from roughly 56 to 44 $gCO_2e\ MJ^{-1}$, and resulting emissions reductions compared to gasoline increase from 43 to 55% (Fig. 2B).

DISCUSSION

A dynamic cattle feeding model was developed to assess the impact of DGS processing and feeding options on net changes in energy requirements and GHG emissions for corn-ethanol systems associated with beef, dairy, and swine production. This analysis estimated a co-product credit based on updated feeding practices and evaluated the most sensitive factors affecting the magnitude of the credit. The Midwest average GHG credit was 15.2 gCO_2e per MJ of ethanol. In previous studies this value has ranged from 17 to 25 gCO2e MJ^{-1} (Liska et al., 2009; Farrell et al., 2006; Wang, 1999). The average value we report here is smaller than these previous estimates because we include co-product fed to dairy and swine, which are less efficient users of co-product. In addition, our analysis uses a different distribution of co-product types produced and livestock classes fed based on the most recent data available for actual usage. The GHG credit we estimate is further reduced by variability in upstream emission factors which, for some parameters, may be relatively conservative in BESS compared to the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (Liska and Cassman, 2009).

Marginal N_2O emissions due to co-product feeding from animal manure N loss, field application of manure, and N_2O evolution from indirect atmospheric N deposition were not evaluated in this study, and they may impact the co-product GHG credit (IPCC, 2006). The range in parameter values reported by the IPCC for these factors is quite large and environmentally dependent. Further research and evaluation are needed to accurately incorporate these parameters into the co-product credit model for each livestock class.

We show that current U.S. livestock numbers have the capacity to fully use DGS production from current corn-ethanol production capacity as well as the expected increase in capacity to 57 bly as mandated under the Energy Independence and Security Act of 2007. This would justify use of the full co-product credit for all U.S. corn-ethanol production under this mandate.

In conclusion, accurate estimates of net GHG emissions from biofuel systems are critical for estimating the anthropogenic impact of biofuel production on the atmosphere. The co-product GHG credit represents a large portion of total direct emissions in the corn-ethanol life cycle. Our analysis documents substantial variation in the magnitude of energy intensity and GHG credits associated with co-product use in corn-ethanol systems and contributes to improved understanding of the factors responsible for this variation. Given the need to assess GHG emissions of biofuel systems as mandated under the renewable fuel standard of the 2007 EISA, it is clear that the accuracy of these assessments can be improved with specification of DGS use in terms of processing and use by different livestock classes. The revised BESS model with the new co-product scenarios can be used to perform such an LCA. More complete data on the types of co-products produced and use of co-products by livestock animal class at state and national levels would further improve estimates of the co-product credit and life cycle GHG emissions from U.S. corn ethanol.

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Fig. 1. Emissions intensities of life cycle components (crop, biorefinery, and co-product credit) for average co-product production and livestock feeding practices in Iowa, Midwest, Nebraska, and Texas (selected scenarios from Table 4). The co-product credit is proportional to the cropping system emissions intensity.

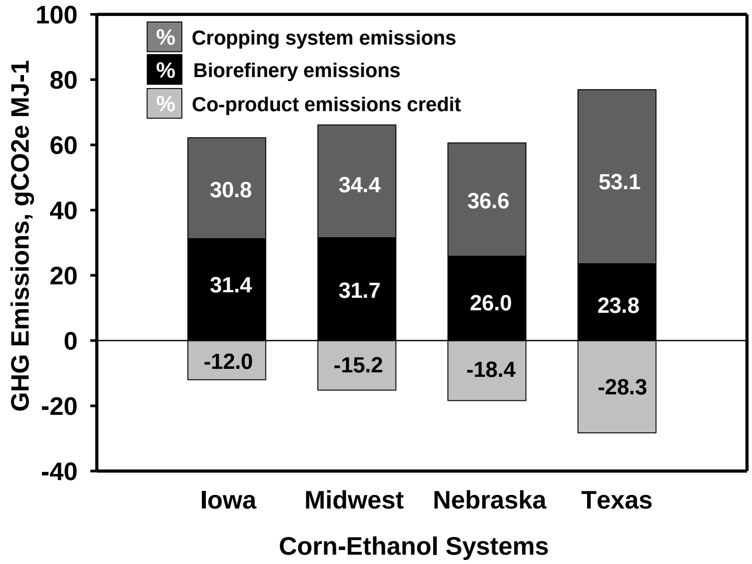
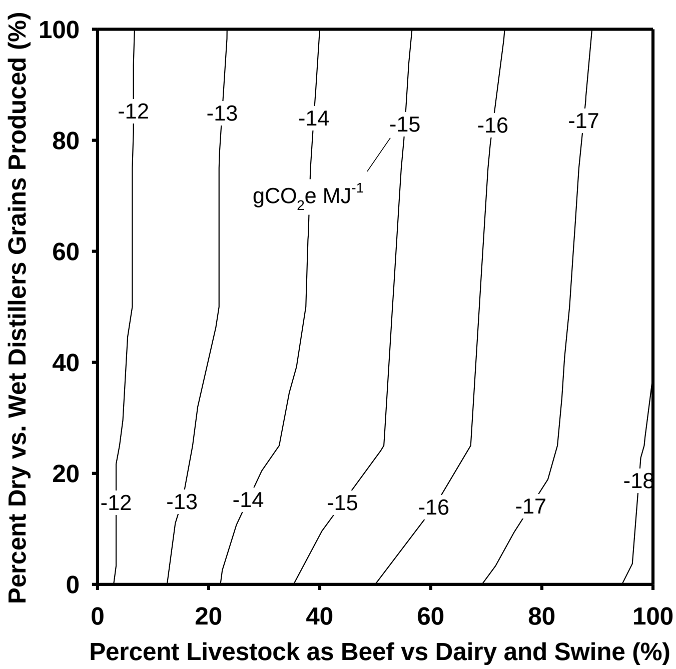


Fig. 2. Co-product greenhouse gas emissions credit isoquant lines (A) and corn-ethanol life cycle emissions intensity (B) relative to the percentage of co-product fed to beef livestock (as opposed to dairy and swine, divided equally) vs. the percentage of distillers grains produced dry (as opposed to modified wet and wet DGS, divided equally); 100% (x axis) is beef and 100% (y axis) is dry DGS. Simulations are based on average Midwest corn production scenario in BESS 2009.4.0 (www.bess.unl.edu). Corn-ethanol GHG reduction percentages compared to gasoline (97.7 gCO2e MJ–1) are shown in parentheses.

A)



B)

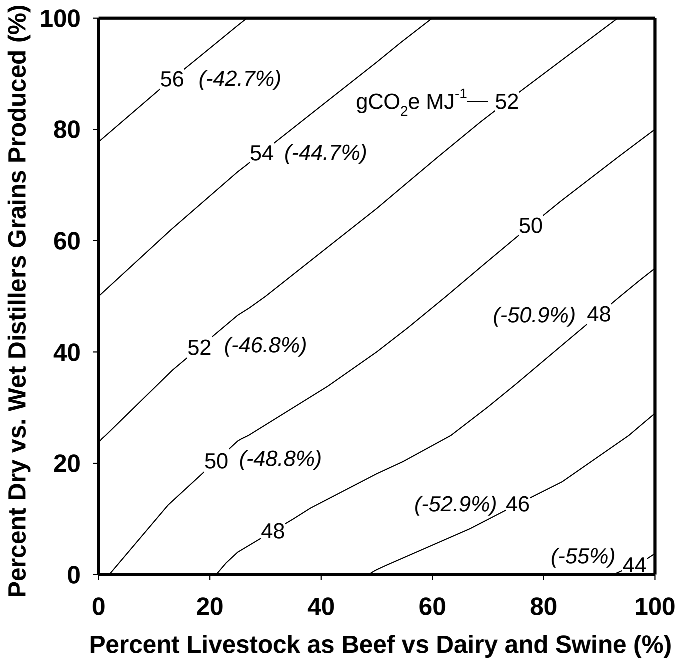

Percent Dry vs. Wet Distillers Grains Produced (%)
Percent Livestock as Beef vs Dairy and Swine (%)
0
20
40
60
80
100
56 (-42.7%)
54 (-44.7%)
gCO2e MJ-1 — 52
52 (-46.8%)
50
50 (-48.8%)
(-50.9%) 48
48
(-52.9%) 46
(-55%) 44

Table 1. Biomass and energy characteristics of corn grain.

	Grain composition	**Energy density†**	**Energy amount**	**Energy fraction**
	kg kg^{-1}	MJ kg^{-1}	MJ	%
Starch‡ (to ethanol)	0.726	16	11.6	66.6
Co-products				
Protein‡	0.088	25	2.3	12.6
Lipid‡	0.042	39	2	9.4
Cellulose§	0.090	16	1.3	8.3
Lignin§	0.022	25	0.3	3.2
Ash§	0.016	0	0	0
Co-Product total	0.258	22.6¶	5.8	33.4

† Loomis and Connor (1998).

‡ Nebraska Corn Board (2008).

§ NRC (2000).

¶ Proportion-weighted energy content of distillers grains. Based on the ethanol yield per unit grain (Table 3), at 418 L of ethanol per Mg grain, 13.9 MJ of energy per liter of ethanol would be contained in the co-products.

Table 2. Midwest livestock co-product use in 2006, potential feeding scenarios for differing distillers grains plus solubles (DGS) use in diets in the future, and corresponding corn-ethanol production capacity.

U.S. Midwest livestock industry characteristics†, 2006

Livestock Classes:	Beef	Dairy	Swine	Total
Corn Belt production, million head	11.3	3.2	64.1	78.6
Corn Belt production, % of United States	50	33	70	–
Operations feeding co-product, % of Corn Belt	36	38	12	–
Fraction of herd fed co-product, % of herd	63	49	40	–
Current and projected feeding scenarios				
Midwest industry use, 2006 (34 million head fed DGS)				
Dietary DGS inclusion level, % of dietary intact	20	10	9	–
Total DGS use, million Mg, (% inclusion × total fed cattle)	2.4	1.3	0.6	4.3
Distribution of DGS use, % of total	56	30	14	100
Ethanol industry to supply DGS, Billion L yr^{-1}	3.4	1.9	0.9	6.2
Theoretical biological maximum co-product inclusion levels (BMCIL) (34 million head)				
Dietary DGS inclusion level, % of dietary intact	45	30	27	–
DGS use, Million Mg of dry matter	5.5	3.9	1.9	11.3
Distribution of DGS use, % of total	48	35	17	100
Ethanol industry to supply DGS, Billion L yr^{-1}	7.7	5.6	2.7	16.0

Theoretical complete Midwest industry adoption at BMCIL (79 million head)				
Dietary DGS inclusion level, % of dry matter	45	30	27	–
DGS use, Million Mg of dry matter	8.6	8.1	4.7	21.4
Industry DGS use, % of total	40	38	22	100
Ethanol industry to supply DGS, Billion L yr^{-1}	12.2	11.4	6.6	30.2
Theoretical complete U.S. industry adoption at BMCIL (124 million head)				
Dietary DGS inclusion level, % of dry matter	45	30	27	–
DGS use, Million Mg of dry matter	17.3	24.4	6.7	48.4
Industry DGS use, % of total	36	50	14	100
Ethanol industry to supply DGS, Billion L yr^{-1}	24.5	34.5	9.5	68.5

† Historical Midwest feedlot cattle marketed from 1000+ head feedyards, lactating dairy cows, and grow-finish pig livestock numbers and the DGS use survey (NASS, 2008) are presented as the base scenario of Midwest industry use in 2006. The theoretical biological maximum co-product inclusion level (BMCIL) scenario assumes that all animals in the base scenario fed DGS have dietary DGS inclusion increased to biological maximum levels. The theoretical complete Midwest industry adoption at BMCIL assumes that all animals in the Midwest region are fed maximum inclusion of DGS. The theoretical complete U.S. industry adoption at BMCIL assumes that all U.S. beef feedlot cattle, finishing swine, and lactating dairy cows are fed maximum inclusions of DGS.

Table 3. Performance of new natural gas powered dry mill biorefineries (nine in survey).

Parameter (unit)	Average and Standard Deviation	Range
Ethanol capacity, million liter yr^{-1}	198 ± 20	175–243
Ethanol yield†, L ethanol Mg^{-1}	418 ± 10	404–432
Electricity, kWh L^{-1} ethanol	0.176 ± 0.043	0.145–0.268
DGS production rate, kg L^{-1} ethanol	0.632 ± 0.043	0.59–0.71
Natural gas (total use), MJ L^{-1} ethanol	7.72 ± 0.57	6.80–8.41
Natural gas used for drying DGS, %	36 ± 9.5	17–47
Natural gas (boiler), MJ L^{-1} ethanol	4.91 ± 0.62	3.61–5.75
Natural gas (drying), MJ L^{-1} ethanol	2.81 ± 0.81	1.18–3.82
DDGS, % of production	67 ± 35	0–98
MDGS, % of production	32 ± 36	0–100
WDGS, % of production	1 ± 2	0–5

† Anhydrous ethanol yield is relative to grain at 15.5% moisture.

Table 4. Co-product production and livestock feeding scenarios used to estimate rates of substitution of conventional feed and the range of corresponding co-product credits for energy (MJ L^{-1} ethanol) and greenhouse gas emissions (gCO_2e MJ^{-1}) for the corn-ethanol life cycle.

Scenario name:	MWavg	IAavg	NEavg	TXavg	MWdav	MWfav	NEdb	NEmb	NEwb	MWds	MWdd	MWdb
Corn crop production region:	Midwest	Iowa	Nebraska	Texas	Midwest	Midwest	Nebraska	Nebraska	Nebraska	Midwest	Midwest	Midwest
Emissions intensity†, gCO_2e kg^{-1}	306	274	308	473	306	306	308	308	308	306	306	306
Co-product type produced and fed												
DDGS (dm), %	35	72	14	0	100	67	100	0	0	100	100	100
MDGS (dm), %	32.5	14	19	0	0	16.5	0	100	0	0	0	0
WDGS (dm). %	32.5	14	67	100	0	16.5	0	0	100	0	0	0
Beef cattle, %	56	18	74	97	56	36	100	100	100	0	0	100
Dairy cattle, %	30	10	2	3	30	50	0	0	0	0	100	0
Swine, %	14	72	24	0	14	14	0	0	0	100	0	0

Dietary substitutions, kg kg^{-1}, dm												
Corn	0.910	0.682	1.20	1.35	0.893	0.746	1.21	1.12	1.38	0.573	0.450	1.21
Soybean meal	0.225	0.363	0.072	0.017	0.225	0.335	0.0	0.0	0.0	0.427	0.550	0.0
Urea	0.036	0.012	0.055	0.064	0.036	0.023	0.064	0.062	0.066	0.0	0.0	0.064
Diesel fuel, L kg^{-1} DGS	0.001	< 0.000	0.002	0.002	< 0.000	< 0.000	< 0.000	0.002	0.002	0.0	0.0	< 0.000
Energy savings, MJ L^{-1} ethanol												
Corn	1.21	0.739	2.12	4.03	1.19	0.995	2.14	1.97	2.44	0.764	0.60	1.62
Soybean meal	0.376	0.606	0.121	0.028	0.376	0.560	0.0	0.0	0.0	0.714	0.919	0.0
Urea	0.597	0.192	0.908	1.07	0.593	0.382	1.06	1.04	1.10	0.0	0.0	1.06
Diesel fuel	0.025	0.011	0.054	0.066	0.001	0.008	0.002	0.05	0.068	0.0	0.0	0.002
Total	2.16	1.53	3.09	5.06	2.16	1.93	3.20	2.96	3.47	1.48	1.52	2.68
GHG emissions credit, gCO_2e MJ^{-1}												
Corn	9.64	6.50	12.8	22.1	9.46	7.92	12.9	11.9	14.7	6.12	4.81	12.8
Soybean meal	2.82	4.56	0.91	0.21	2.82	4.21	0.0	0.0	0.0	5.37	6.91	0.0
Urea	1.60	0.52	2.43	2.85	1.59	1.02	2.84	2.78	2.94	0.0	0.0	2.84

Diesel fuel	0.10	0.04	0.21	0.26	0.01	0.03	0.01	0.19	0.26	0.0	0.0	0.01
Enteric fermentation	1.27	0.424	2.52	3.42	1.13	0.772	2.01	1.18	3.53	0.0	0.0	2.01
Total	15.2	12.0	18.4	28.3	15.0	13.9	17.7	15.7	20.9	11.5	11.7	17.7
Biorefinery Thermal Energy MJ L^{-1}	7.72	7.60	5.70	4.91	8.33	7.47	8.33	6.55	4.91	8.33	8.33	8.33
Ethanol Intensity, gCO_2e MJ^{-1}	52.3	51.6	43.7	50.0	54.2	52.9	51.7	48.8	38.9	57.7	57.5	51.6
GHG Reduction, %	46.5	47.2	55.3	48.8	44.5	45.8	47.1	50.1	60.1	40.9	41.2	47.2

† Emissions intensity for grain production is at 15.5% moisture.

Table 5. Greenhouse gas (GHG) emissions inventory of the corn-ethanol life cycle for a new natural gas dry mill biorefinery in U.S. Midwest (MWavg, Table 4).

Component	GHG emission category	$gCO_2e\ MJ^{-1}$	Percent of life cycle
Crop production			
	Nitrogen fertilizer, N	4.44	6.71
	Phosphorus fertilizer, P_2O_5	1.01	1.53
	Potassium fertilizer, K_2O	0.53	0.80
	Lime	6.59	10.0
	Herbicides	1.77	2.68
	Insecticides	0.075	0.114
	Seed	0.086	0.131
	Gasoline	0.520	0.787
	Diesel	2.32	3.51
	LPG	0.895	1.35
	Natural gas	0.423	0.640
	Electricity	0.923	1.40
	Depreciable capital	0.276	0.418
	N_2O emissions†	14.5	22.0
	TOTAL	**34.4**	**52.0**
Biorefinery‡			
	Natural gas input	13.8	20.8
	Natural gas input: drying DGS	7.88	11.9

	Electricity input	7.52	11.4
	Depreciable capital	0.454	0.7
	Grain transportation	2.09	3.2
	TOTAL	**31.7**	**48.0**
Co-Product Credit			
	Diesel	0.095	0.144
	Urea production	–1.60	–2.42
	Corn production	–9.64	–14.6
	Enteric fermentation-CH_4	–1.27	–1.92
	Soybean production	–2.82	–4.3
	TOTAL	**–15.2**	**–23.1**
Transportation of Ethanol from Biorefinery		1.40	
LIFE CYCLE NET GHG EMISSIONS		52.3	100%
GHG-intensity of gasoline§, g CO2e MJ^{-1}		97.7	
GHG reduction relative to gasoline, %		46.5	

† Includes emissions from N inputs (synthetic fertilizer, manure N) and N losses (volatilization, leaching/runoff, crop residue) (BESS User's Guide for details); roughly 1.8% of applied synthetic N is lost as N_2O (IPCC, 2006).

‡ Biorefinery performance is based on data in Table 3.

§ 100% pure petroleum-based gasoline, containing a tar sands fraction (Liska and Perrin, 2009).

Impact of distillers grains moisture and inclusion level on greenhouse gas emissions in the corn-ethanol-livestock life cycle

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ABSTRACT

New meta analysis equations of feedlot cattle performance fed 0 to 50% of diet DM as corn wet (WDGS, 32% DM), modified (MDGS, partially dried WDGS, 46% DM), or dry (DDGS, 90% DM) distillers grains plus solubles replacing dry rolled and high moisture corn were incorporated into the Biofuel Energy Systems Simulator (BESS; www.bess.unl.edu) to evaluate the impact of DGS moisture and inclusion level on greenhouse gas (GHG) emissions from the corn-ethanol-livestock life cycle. Equations were derived from pen-level performance for 20 trials evaluating WDGS, 4 trials evaluating MDGS, and 4 trials evaluating DDGS conducted at University of Nebraska research feedlots. Feeding value of WDGS was 145 to 131% of the corn replaced in diets from 20 to 40% of diet DM. Using the same approach, feeding value of MDGS was 124 to 117% and 110 to 112% for DDGS. Performance response was not detected when DGS was fed to swine and dairy cows. Midwest corn-ethanol-livestock life cycle GHG reduction relative to gasoline (97.7 gCO_2e/MJ ethanol) was greatest when WDGS was fed to feedlot cattle and decreased from 61 to 57% for 20 to 40% of diet DM as WDGS. Feeding MDGS and DDGS to feedlot cattle resulted in a reduction of GHG emissions by 53 to 50% and 46 to 41%, respectively. Life cycle GHG reduction for WDGS, MDGS, or DDGS for dairy cows was 53, 48, and 43%, respectively, and DDGS for swine was 42%. Reduction in GHG emissions when DDGS was fed was less than for WDGS and MDGS for beef or dairy. Reduction in GHG emissions was comparable for all three livestock classes when DDGS was fed. Partial drying (MDGS) or complete drying (DDGS) of WDGS reduced both feeding value and GHG reductions for corn-ethanol relative to

gasoline. Feeding WDGS to feedlot cattle was the optimum feed use of DGS based on feeding performance and GHG reduction. Accurate data for ethanol and gasoline GHG emissions are essential for providing a meaningful comparison of these fuels.

Keywords: Distillers Grains, Cattle Performance, Greenhouse Gases, Life Cycle Assessment

*Abbreviations:*ADG, average daily gain; BESS, Biofuel Energy Systems Simulator; DGS, distillers grains plus solubles; DDGS, dried distillers grains plus solubles; DM, dry matter; DMI, dry matter intake; gCO_2e, grams of carbon dioxide equivalents; G:F, feed efficiency; GHG, greenhouse gas; MDGS, modified distillers grains plus solubles; WDGS, wet distillers grains plus solubles;

1. Introduction

Corn (Zea mays) distillers grains plus solubles (DGS) is an important part of the corn-ethanol-livestock life cycle when comparing greenhouse gas (GHG) emissions of ethanol to gasoline. Distillers grains contains a significant quantity of energy and offsets corn, urea and soybean meal in livestock diets. The corn and protein replacement value of DGS is dependent on DGS moisture level, dietary inclusion level, and livestock class fed. Ethanol plant energy use and associated GHG emissions are impacted by moisture content of DGS produced. All ethanol plants produce wet DGS (WDGS; 68% moisture). Some plants choose to remove moisture from WDGS to form modified DGS (MDGS; 54% moisture) or dried DGS (DDGS; 10% moisture). Ethanol plant energy use (e.g. natural gas) to remove moisture has been identified as a parameter of importance in comparing GHG emissions from ethanol relative to gasoline (Liska et al., 2009; Bremer et al., 2010b).

The Biofuel Energy Systems Simulator (BESS; www.bess.unl.edu) was developed to compare life cycle GHG emissions from ethanol production relative to gasoline as a motor fuel, while accounting for the dynamic interactions of corn production, ethanol plant operation, and co-product feeding to livestock. Modeling GHG emissions requires accurate biological equations developed from animal performance over a broad range of DGS feeding conditions. Good summaries of DGS feeding to swine and dairy cattle are available. Limited data on DGS feeding summaries for feedlot cattle have been available. Initial BESS feedlot cattle DGS performance equations were developed from a meta-analysis of feeding WDGS and individual feeding trials of MDGS and DDGS (Liska et al., 2009; Bremer et al., 2010b). Multiple trials for all three DGS moistures have been completed in the recent past to augment the initial datasets. Revised meta-analyses of cattle performance equations developed from these more complete databases should improve the accuracy of modeling GHG emissions from ethanol production.

Therefore, the objectives of the current study were to update cattle performance equations of BESS with the most complete data available and to evaluate the impact of DGS moisture and inclusion level in livestock diets on ethanol GHG emissions from the corn-ethanol-livestock life cycle relative to gasoline.

2. Materials and methods

2.1 Cattle performance data

Wet DGS cattle performance predictions were developed from 20 feedlot cattle finishing trials with 350 pen means and represent 3,365 steers fed (Larson et al., 1993; Ham et al., 1994; Al-Suwaiegh et al., 2002; Vander Pol et al., 2005; Godsey et al., 2008a, 2008b; Meyer et al., 2008; Wilken et al., 2008; Corrigan et al., 2009; Rich et al., 2009; Vander Pol et al., 2009; Loza et al., 2010; Luebbe et al., 2010; Moore et al., 2010; Nuttelman et al., 2010; Rich et al., 2010; Sarturi et al., 2010). These data have previously been summarized by Bremer et al., 2010a. Modified DGS cattle performance predictions were developed from 4 UNL feedlot trials with 85 pens and represent 680 steers (*Adams et al., 2007; Huls et al., 2008; Luebbe et al., 2010; Nuttelman et al., 2010*). Dried DGS cattle performance predictions were developed from 4 UNL feedlot trials with 66 pens and represent 581 steers (*Ham et al., 1994; Buckner et al., 2010; Nuttelman et al., 2010; Sarturi et al., 2010*).

All trials included in the analyses evaluated feeding corn DGS replacing dry-rolled corn, high-moisture corn, or a blend of the two corn types. Individual animal carcass data were collected on all steers and feeding performance was calculated from a carcass adjusted final weight. Trials fed from 0 to 50% of diet DM as a single DGS moisture type co-product in the diet. All trials were conducted under similarly managed feedlot research settings across multiple years at University of Nebraska Beef Research Feedlots. Animal use procedures were reviewed and approved by the University of Nebraska Institutional Animal Care and Use Committee.

2.2 Data Analysis

Meta-analysis methodology for integrating quantitative findings from multiple studies was utilized for data analysis of the three individual DGS products (St-Pierre, 2001). This method accounts for the random effect of individual trials with a structured iterative analytical process using the PROC MIXED procedure of SAS (SAS Inst., Inc., Cary, NC, USA). Pen mean was the experimental unit of analysis. Trials were weighted by number of WDGS levels to prevent artificial linear responses from trials with 0 and one other level of DGS evaluated. Each DGS moisture type was analyzed with a separate dataset and biological performance equations were developed based on significant model variables. The intercepts (0% DGS diet) of the MDGS and DDGS predicted performance equations were scaled to the intercept of the WDGS dataset to compare differences in cattle performance relative to a common 0% DGS diet. The equation adjustment allowed the evaluation of how an individual steer would perform if given one of the three products relative to a common base point.

2.2. Model Parameters

The assumptions and calculations of BESS have been discussed extensively (Liska et al., 2009, Bremer et al., 2010b). Bremer et al. (2010b) further discussed the dynamic livestock and DGS components of the BESS model. Midwestern United States corn production efficiency of 362 gCO_2eq/kg of corn DM was used for all scenarios (Bremer et al., 2010b). Ethanol plant GHG emissions from ethanol production and dryer operation were developed from a survey of 9 ethanol plants (Bremer et al., 2010b). Average ethanol plant GHG emissions from natural gas and electricity use for plant operation and DGS drying were 21.0, 25.6, and 30.5 gCO_2e/MJ ethanol for WDGS, MDGS, and DDGS, respectively. Cattle performance equations were updated with the previously mentioned meta-analyses. Specifically, the prediction equations for diet daily dry matter intake (DMI) and feed efficiency (G:F) were used to calculate cattle growth to a common end weight (Bremer et al., 2010b). Distillers grains replaces corn and urea nitrogen in beef finishing diets (Klopfenstein et al., 2008a). Distillers grains replaces corn and soybean meal in swine finishing and dairy lactating diets (Bremer et al., 2010b). Summaries of dairy and swine DGS feeding data (Schingoethe, 2008; Stein, 2008) do not indicate a feeding value of DGS greater than a combination of soybean meal and corn. Therefore, a direct replacement of corn and soybean meal (kg for kg of DM) was utilized when DGS is fed to these animal classes.

An average emissions intensity for gasoline considering a tar sands fraction (7%) and California reformulated gasoline blendstock is estimated at 97.7 gCO_2e/MJ. This value was used as the gasoline reference point for all scenarios (Liska and Perrin, 2009)

2.3 Scenarios evaluated

Corn production efficiency and ethanol plant operation except for drying of DGS was held constant for all scenarios. Greenhouse gas emissions of ethanol produced from the corn-ethanol-livestock life cycle relative to gasoline were calculated for the following scenarios. The ethanol plant produces WDGS fed at 10, 20, 30, or 40% of diet DM to feedlot cattle or fed at 10, 20, or 30% of diet DM to lactating dairy cows. Similar scenarios for both feedlot and dairy were evaluated for MDGS and DDGS. Swine use of DGS is limited to DDGS and scenarios of 9,18, or 27% of finishing diet DM were evaluated.

3. Results

3.1 Cattle performance

Steer DMI increased quadratically as DGS inclusion level increased (Table 1). The greatest improvement in DMI occurred when DDGS replaced corn. The DMI response to MDGS inclusion was intermediate to DDGS and WDGS. Maximum DMI of steers fed DDGS occurred at a greater level of DGS inclusion than MDGS, and the maximum DMI intake of steers fed WDGS occurred at the lowest level of DGS inclusion of the three DGS moisture products. Quadratic increases in average daily gain (ADG) and G:F were observed when steers were fed WDGS or MDGS. Steer ADG and G:F improved linearly as DDGS replaced corn in the diet. Steer ADG was similar for the three DGS moisture products. The DGS products all contained greater feeding value than corn. The feeding values of WDGS, MDGS, and DDGS, when fed at 20 to 40% of diet DM, were 143 to 130, 124 to 117, and a constant 112% of corn (DM basis), respectively. The feeding value of DGS decreased as moisture level decreases. The feeding value of WDGS and MDGS decreased as inclusion level increases. The feeding value of DDGS was a constant 112% of corn DM.

3.2 GHG emissions of ethanol

All scenarios evaluated had ethanol life cycle emissions less than gasoline (Table 2). The life cycle that included feeding WDGS to feedlot cattle had the least ethanol GHG emissions of the scenarios evaluated. The next best option was feeding WDGS to dairy cows. Feeding MDGS to feedlot cattle was superior to feeding MDGS or DDGS to dairy cattle. Feeding DDGS to feedlot cattle was slightly superior to feeding DDGS to swine and dairy cows.

4. Discussion

Pre-gastric fermentation of low quality feedstuffs into protein provides the beef industry an opportunity compete with more efficient food protein producing industries such as poultry and fish. DGS is used not only as a protein source but also as an energy source (Klopfenstein et al., 2008a; NRC, 1996). Ruminants are able to utilize the fat, fiber, and protein components of DGS. Fractionation of DGS products for biodiesel production from the fat component and cellulosic ethanol production of the fiber fraction will result in a concentrated protein source. The GHG balance of ethanol and other co-products produced from fractionated corn processes may be significantly different from the current systems analyzed due to uses of co-products produced, change in corn processing, and environmental costs of implementing the technology. The feeding value of these products may also be reduced (Buckner et al., 2010). Furthermore, exploitation of fibrous biomass fermentation for ethanol production would directly compete for the resource niche that cattle currently utilize.

Although ethanol production has altered the availability of corn for livestock production, the use of DGS as livestock feed has helped to maintain the synergistic relationship between the livestock and corn production industries. Feeding DGS results in up to 0.43 kg of corn DM offset as DGS for each kg of corn DM fermented at the ethanol plant. The US livestock industry is of sufficient scope to fully utilize DGS production from a 69 billion liters per year corn ethanol industry (Bremer et al., 2010b). That is a corn ethanol industry 1.7 times larger than the 40 billion liters per year ethanol production capacity (RFA, 2009). These DGS use calculations are conservative since they do not account for exporting DGS and feeding DGS to non-lactating dairy cows, beef cattle on grass, feedlot cattle finished in yards less than 1,000 cattle capacity, and poultry (Klopfenstein et al., 2008b). Increasing the scope of corn ethanol production would not significantly alter ethanol GHG emissions (Bremer et al., 2010b).

4.1 DGS moisture

A decrease in steer feeding performance as moisture is removed from WDGS, as indicated by the results of the meta analyses, is in agreement with individual trials evaluating both WDGS and DDGS in the same trial (Ham et al., 1994; Sarturi et al., 2010; Nuttelman et al., 2010). The three trials evaluated feeding DGS in the WDGS or DDGS forms and found the feeding value of WDGS to be greater than DDGS. Nuttelman et al., 2010 conducted the first trial to evaluate feeding multiple dietary inclusion levels of WDGS, MDGS, and DDGS in the same trial. In addition the MDGS and DDGS were sourced from the same ethanol plant. The researchers also noted the feeding value of WDGS being greater than MDGS and both being greater than DDGS. This may indicate cattle fed dryer DGS products eat to a constant energy intake. This is evidenced by an increase in DMI as DGS moisture decreases with equal steer ADG.

The feeding value of DGS is set at the ethanol plant with management decisions on how to market WDGS. Target market livestock populations and DGS transportation costs are drivers of how WDGS is processed at the ethanol plant (Buckner et al., 2008; Bremer et al., 2010b). Drying WDGS improves shelf life and decreases shipping costs due to less moisture being hauled. Drying DGS allows access to markets unattainable with WDGS. Export markets, the swine industry, and livestock industries in other regions of the US are achievable with DDGS. This flexibility comes at a cost. In addition to the decrease in feeding value of DDGS relative to WDGS, the fixed and variable cost of owning and operating a dryer in an ethanol plant are significant (Baumel, 2008). Ethanol plant decisions on DGS moisture management also impact the GHG balance of ethanol produced. Ethanol plants producing DDGS requires 167% as much energy and produce 145% of the GHG emissions of ethanol plants producing WDGS. This emphasizes making ethanol production decisions that are economically and environmentally sound.

4.2 Gasoline reference point

The evaluation of ethanol relative to gasoline not only requires accurate evaluation of the ethanol production cycle, but also an accurate reference point for the GHG-intensity of gasoline. Gasoline emissions not only include combustion emissions, but also upstream emissions from crude oil recovery, refinery emission, and flaring losses (Brandt and Farrell, 2007). Emissions due to military security associated with acquisition of Middle Eastern petroleum, changes in the composition of petroleum supplies toward more GHG-intensive fuels, and other additional emissions from petroleum processing must also be considered (Liska and Perrin, 2009). Indirect GHG emissions from military security for maritime oil transit are estimated to raise the GHG intensity of gasoline from the Middle East by roughly 20% over the conventional baseline (Liska and Perrin 2010).

Ethanol production does not displace average gasoline, but displaces a marginal unit of gasoline that may have a much greater environmental cost than average gasoline (US EPA, 2010). As the proportion of gasoline derived from more energy intense processes increases, the GHG life cycle reference point of gasoline should be updated to compare a marginal liter of gasoline to an equal energy quantity from ethanol. The GHG-intensity of gasoline is increasing due to depletion of efficiently accessible deposits (Brandt and Farrell, 2007). Unconventional and less efficiently processed sources of petroleum such as tar sands, coal-to-liquids, and oil shale will likely be used to fill the difference between current petroleum supply and energy demand. In fact, Canadian tar sands could supply 20% of US gasoline by 2020 (Liska and Perrin, 2009).

4.3 Indirect GHG impacts of ethanol and gasoline

Evaluation of indirect GHG emissions from ethanol and gasoline was not evaluated in this study due to the immense complexity in calculating the totality of significant indirect GHG emissions (Liska and Perrin, 2009; US EPA, 2010). A methodology to incorporate both reasonably accurate scientific knowledge about direct life cycle emissions and relatively diffuse and uncertain scientific knowledge concerning potentially significant indirect emissions must be developed to fully evaluate the GHG mitigation potential of ethanol (Liska and Perrin, 2009; US EPA, 2010). This is especially true when the indirect effects may provide a large impact on the life cycle being analyzed.

One may be tempted to add the single indirect emission from land use change due to increased ethanol production (e.g. as done by the California Air Resources Board), yet land use change is only one significant indirect GHG emission among many. Other significant indirect emissions include military security emissions, changes in rice cultivation, and changes in livestock globally (Liska and Perrin, 2009; Liska and Perrin 2010; US EPA, 2010). Further research is needed before we can have reasonable confidence in the net effects of indirect GHG emissions of both biofuels and petroleum fuels (Liska and Perrin, 2009). A comprehensive assessment of the total GHG emissions implications of substituting ethanol for petroleum needs to be completed before the impact of indirect GHG emissions from land use change alone can be accurately determined.

4.4 Current ethanol production vs. future expansion GHG emissions

Indirect land use change is only associated with future expansion of the ethanol industry. Emissions from existing ethanol production facilities are limited to direct emissions, given whatever indirect emissions were associated with initiating ethanol production at these facilities has already occurred. Because of this, biofuels use now from existing facilities not only reduces GHG emissions from transportation fuel use compared to petroleum, but also supports national security goals and rural development objectives. Evaluation of these additional policy objectives are not considered in GHG emissions modeling frameworks, but are important considerations when comparing fuels.

5. Conclusion

Feeding DGS to livestock is a significant contribution to the environmental benefit of fuel ethanol relative to gasoline. The GHG emissions benefits of ethanol are determined by how DGS moisture is managed at the ethanol plant and what animal classes DGS are fed. Feeding WDGS to feedlot cattle provided the optimum feed use of DGS for livestock. Partial drying (MDGS) or complete drying (DDGS) of WDGS reduced the feeding value and increased ethanol GHG emissions relative to WDGS. In state and federal GHG regulations for fuels, regulators must continually update and use the most representative and accurate data for assessing ethanol and gasoline GHG emissions. Yet, achieving this accuracy requires much more complete research on the underlying systems involved, such as the research results presented here.

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Table 1. Finishing steer performance when fed different dietary inclusions of corn wet distillers grains plus solubles (WDGS), modified distillers grains plus soluble (MDGS) or dried distillers grains plus soluble (DDGS) replacing dry rolled and high moisture corn.

DGS Inclusion [1]:	0DGS	10DGS	20DGS	30DGS	40DGS	Lin [2]	Quad [2]
WDGS [3]							
DMI, kg/d	10.4	10.6	10.6	10.4	10.2	0.01	< 0.01
ADG, kg	1.60	1.71	1.77	1.78	1.75	< 0.01	< 0.01
G:F	0.155	0.162	0.168	0.171	0.173	< 0.01	< 0.01
Feeding value, % [4]		150	143	136	130		
MDGS[5]							
DMI, kg/d	10.4	10.8	10.9	10.9	10.6	0.95	< 0.01

ADG, kg	1.60	1.71	1.77	1.78	1.74	< 0.01	< 0.01
G:F	0.155	0.159	0.162	0.164	0.165	< 0.01	0.05
Feeding value, % [4]		128	124	120	117		
DDGS[5]							
DMI, kg/d	10.4	10.9	11.2	11.3	11.3	< 0.01	0.03
ADG, kg	1.60	1.66	1.72	1.77	1.83	< 0.01	0.50
G:F	0.155	0.156	0.158	0.160	0.162	< 0.01	0.45
Feeding value, % [4]		112	112	112	112		

[1] Dietary treatment levels (DM basis) of distillers grains plus solubles (DGS), 0DGS = 0% DGS, 10DGS = 10% DGS, 20DGS = 20% DGS, 30DGS = 30% DGS, 40DGS = 40% DGS.

[2] Estimation equation linear and quadratic term t-statistic for variable of interest response to DGS level.

[3] WDGS data presented are summarized from Bremer et al., 2010.

[4] Percent of corn feeding value, calculated from DGS inclusion level feed efficiency relative to 0WDGS feed efficiency, divided by DGS inclusion.

[5] MDGS and DDGS steer performance was scaled to the WDGS intercept for equal comparison across byproduct types. This process was validated by Nuttelman et al., 2010.

Table 2. Percent reduction in greenhouse gas (GHG) emissions for an equivalent quantity of energy from ethanol relative to gasoline when accounting for distillers grains (DGS) moisture content, dietary inclusion level, and livestock type fed.

Livestock Type	Beef				Dairy	Swine
DGS, % of diet DM[1]	10	20	30	40	10-30	9-27
WDGS, GHG % reduction to gasoline[2]	62.4	60.6	58.4	56.7	52.6	---
MDGS, GHG % reduction to gasoline[2]	53.9	52.6	50.9	49.7	47.9	---
DDGS, GHG % reduction to gasoline[2]	46.1	45.4	44.4	43.9	42.8	42.3

[1] DM = dry matter, WDGS = wet distillers grains with solubles, MDGS = modified wet distillers grains with solubles, and DDGS = dried distillers grains with solubles.

[2] Gasoline reference point is 97.7 gCO2e/MJ (Liska and Perrin, 2009).