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Effects of drying distillers grains plus solubles on feedlot cattle performance and nutrient digestibility

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EFFECTS OF DRYING DISTILLERS GRAINS PLUS SOLUBLES ON FEEDLOT

CATTLE PERFORMANCE AND NUTRIENT DIGESTIBILITY

by

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All dry milling ethanol plants produce wet distillers grains (WDG) and distillers solubles (DS). Depending on the plant, WDG and DS will be combined to produce wet distillers grains plus solubles (WDGS). Some plants will partially dry WDGS and market modified distillers grains plus solubles (MDGS), or other plants will completely dry WDGS to produce dried distillers grains plus solubles (DDGS). These products have been shown to contain greater feeding values than the corn it replaces in finishing diets. However, as drying intensity of distillers grains plus solubles (DGS) increases, the feeding value relative to corn decreases. Three finishing experiments and two metabolism experiments were conducted to evaluate the effect drying WDGS has on finishing cattle performance and carcass characteristics and the effects on nutrient digestibility. Diets containing DGS had greater ADG and were more efficient than the corn-based control. As a result, cattle fed DGS had heavier HCW and greater 12th rib fat thickness at harvest. Using the G:F values, all types of DGS regardless of moisture content had greater feeding values than the corn it replaced. Additionally, WDGS had

greater feeding values than MDGS and DDGS, and MDGS had a greater feeding value than DDGS. Although not significant, diets containing WDGS had numerically greater NDF digestibility than diets containing DDGS. Organic matter digestibility was improved for WDGS compared to DDGS. Completely and partially drying WDGS reduces the feeding value in finishing diets and reduces OM digestibility.

Key Words: Dried distillers grains plus solubles, Finishing diets, Wet distillers grains plus solubles

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DEDICATION

This dissertation is dedicated to all of the past, present, and future family, friends, and the friends who have become my family.

CHAPTER I

INTRODUCTION

Fuel grade ethanol can be produced by one of two milling processes referred to as dry milling and wet milling. The primary objective of the dry milling process is for the production of ethanol. This process is outlined in greater detail according to Stock et al. (2000). Briefly, the starch contents of cereal grain, primarily corn, is removed and fermented to produce ethanol. Starch accounts for roughly two-thirds of the corn kernel; once removed, the remaining nutrients are increased three-fold (Klopfenstein et al., 2008). In addition to ethanol, all dry milling plants produce wet distillers grains and distillers solubles. Depending on the design, location, and interests of the plant, these co-products can be marketed as numerous different products most commonly as: 1) wet distillers grains (WDG); 2) distillers solubles (DS); 3) WDG and DS can be combined and marketed as wet distillers grains plus solubles (WDGS); 4) WDG can be dried to produce dried distillers grains (DDG); 5)WDGS can be dried to produce dried distillers grains plus solubles (DDGS); 6) WDGS can be partially dried to produce modified distillers grains plus solubles (MDGS).

Numerous studies have evaluated the effects of replacing corn with WDGS in finishing diets on cattle performance (Vander Pol et al., 2005; Loza et al., 2010), MDGS (Huls et al., 2008; Luebbe et al., 2012a), and DDGS (Buckner et al., 2008a) and have reported greater performance for diets containing DGS compared with diets not containing DGS . Bremer et al. (2011) conducted three meta-analyses using studies conducted in the same feedlot under similar conditions when WDGS, MDGS, or DDGS

replaced corn. These meta-analyses indicated that cattle consuming diets containing WDGS, MDGS, or DDGS had greater ADG and were more efficient compared with those offered a corn-control based diet. When comparing the means for types of DGS, DMI was greatest for steers consuming diets containing DDGS, intermediate for MDGS, and lowest for WDGS. Daily gain was not different for cattle fed different types of DGS, but G:F was greatest for WDGS, intermediate for MDGS, and lowest for DDGS. Using the G:F values to calculate a feeding value relative to corn, WDGS contained 143, 136, and 130% the feeding value of corn when included in the diet at 20, 30, and 40% of diet DM. Calculated feeding values for MDGS were 124, 120, and 117% that of corn when included in the diet at 20, 30, and 40%. Although still greater than corn, the feeding value of DDGS was 112% across all concentrations evaluated.

Limited research has been conducted comparing different types of DGS in the same study, and to our knowledge there is no research comparing WDGS, MDGS, and DDGS in the same study. When comparing across different studies WDGS, MDGS, and DDGS result in different performance outcomes, even though the only nutrient removed during the drying process is water. Therefore, the objectives of these studies were to compare WDGS, MDGS, and DDGS in the same finishing studies, evaluate the effects drying DGS has on nutrient metabolism, and evaluate different drying methods at the ethanol plant and the effects on feeding value relative to corn in finishing diets.

CHAPTER II

A REVIEW OF THE LITERATURE

Introduction. There are two common milling practices that yield fuel ethanol referred to as the dry and wet milling industries. While both industries produce ethanol, the process from which the ethanol is obtained, as well as the primary intentions of the two industries contrast greatly. Bothast and Schlicher (2005) explain the primary focus of a dry milling plant is to maximize the capital return per liter of ethanol, while the wet milling process separates valuable components of the grain before fermenting to ethanol. Both the dry and wet milling industries produce byproducts that are viable and valuable feedstuffs for the beef industry. This current review of literature will focus primarily on feeding byproducts from the dry milling process; however both processes will be described below because feeding wet milling byproducts will be discussed to a certain degree.

Wet Milling Process. Only #2 or better yellow dent corn can be used in the wet milling process because most of the products produced are intended for human consumption (Stock et al., 2000). According to the Corn Refiners Association (2002) the wet milling process is accomplished in five basic steps as described below. Upon arrival to the plant, the corn is inspected and cleaned. The cleaning process is performed twice and removes crop residues, fines, and broken kernels before steeping.

The first processing step, referred to as steeping, soaks whole corn in 50^0C water for 30 to 40 hours. Sulfur dioxide is added to the water at 0.1% to prevent bacterial

growth and to break down the waxy coat covering the kernel. The moisture concentration of the kernels increases from 15 to 45% and increases the size of the kernel greater than two-fold. This coupled with the mild acidity of the steepwater loosens gluten bonds within the corn and releases the starch. Kernels are ground following the steeping process to break the germ free from other components. The steepwater contains nutrients released from the kernel during the steeping process is condensed and referred to as steep liquor (Stock et al., 2000).

According to the Corn Refiners Association (2002), the next step of the wet milling process is to transport the slurry of coarsely ground kernels to the cyclone separators to remove the germ. The germ is pumped onto screens and washed numerous times to remove remaining starch. The germ contains 85% of the oil in the kernel. The oil is extracted from the germ through a combination of mechanical and solvent processes, and is ultimately refined and filtered into corn oil. The remaining germ residue is recovered and utilized in animal feed.

The water slurry and remaining portion of the kernel are ground for a second time. This process releases the starch and gluten (i.e. protein) from the fiber of the kernel. The fiber is removed from the slurry by passing over fixed concave screens that trap the fiber and allow the starch and gluten to pass. The fiber is screened a second time to collect any residual starch and protein that did not separate from the fiber during the first screening. According to Stock et al. (2000), the fiber portion of the kernel is referred to as bran, and is pressed to remove much of the water (40% DM).

The suspension composed of starch and gluten is transported to the starch separators for further processing (Corn Refiners Association, 2002), and the starch-gluten

suspension is passed through a centrifuge. The density of gluten is less than starch, and therefore is readily separated from the starch during centrifugation. The gluten is processed into corn gluten meal and is high in CP and escape protein, and is predominately used in the pet food and poultry industries (Stock et al, 2000).

The starch is diluted, washed 8 to 14 times, rediluted, and washed again in hydroclones to remove the last trace of protein (Corn Refiners Association, 2002). This washing yields high quality starch that is typically 99.5% pure. A small fraction of the starch is marketed as-is or modified into specialty starches. However, the majority of the starch is converted into glucose by liquefying the starch in a water suspension and introducing acids and/or enzymes that convert the starch to glucose, yielding a low-glucose solution. There are multiple end products of starch that can be obtained by managing certain processes that are dependent upon each specific plant. Some of these products are corn syrups and high-fructose corn sweetener. According to Stock et al. (2000), some wet milling plants convert starch to dextrose. Dextrose can be fermented by yeast to produce fuel ethanol. The alcohol is removed through distillation, leaving distillers solubles. The distillers solubles contain yeast cells and unfermented sugars and can be evaporated separately or with steep liquor to approximately 40 to 50% DM (Stock et al., 2000).

Corn gluten feed (CGF) is composed primarily of bran and steep liquor (Stock et al., 2000). However, other components can include distillers solubles, germ meal, and cracked corn screenings. The nutrient composition of CGF can vary depending on the proportions of each ingredient listed above, as well as how the ingredients were combined. For example, all of the steep liquor produced cannot be applied to the wet

bran because of the inability of the wet bran to absorb all the steep. Some plants may dry the bran to 15% moisture to allow greater amounts of steep liquor to be added to the bran, or some plants will sell a portion of the steep liquor as an individual ingredient. Corn gluten feed can also be sold as wet corn gluten feed (WCGF; 40 to 60% DM) or dried corn gluten feed (DCGF), and the CP content can range from 14 to 24% (DM basis) depending on the amount of steep added at the plant.

Dry Milling Process. The second of the two most common milling practices that ferment cereal grains for the production of fuel ethanol is known as the dry milling process. According to Stock et al. (2000), the dry milling industry has an advantage compared to the wet milling industry because it has flexibility in the type and quality of grain that can be used in the fermentation process. A variety of grains can be used in the process such as corn, grain sorghum, wheat or barley as well as a mixture of these grains. The grain is first ground through a hammer mill to form a coarse flour (Bothast and Schlicher, 2005) referred to as meal. The meal is slurried with water to form a "mash" (Bothast and Schlicher, 2005; Renewable Fuels Association, 2005). Bothast and Schlicher (2005) report the next step in the process is cooking, and continues by breaking down the starch into simple sugars. This is accomplished by first adjusting the pH of the mash to a pH of 6.0, followed by the addition of alpha-amylase enzymes. The mash is heated above 100^0C and held constant at this elevated temperature for several minutes to cleave and rupture starch molecules.

The next step in the dry milling process is liquefaction. The mash is liquefied for at least 30 minutes to reduce the size of the starch polymer after the temperature decreases to 80 – 90^0C when additional alpha-amylase is added. The mash is cooled and

adjusted to a pH of 4.5. Glucoamylase enzyme is added to convert the liquefied starch to glucose and allows fermentation by yeast to occur.

Fermentation begins by cooling the mash to 32^{0}C and transferring the mash to the fermenters. Ammonium sulfate or urea is added simultaneously with the yeast in the fermenters to provide a nitrogen source for growth. Depending on the reference and most likely the specific dry milling plant, the fermentation step requires 40 – 50 h (Renewable Fuels Association, 2005) or 48 – 72 h (Bothast and Schlicher, 2005) to be complete. During the fermentation process, carbon dioxide is produced and the pH of the mash declines to 4 and is now referred to as beer. The carbon dioxide may be captured and sold to be utilized in carbonating soft drinks, manufacturing dry ice, and other industrial processes.

Following the fermentation process, the resulting beer is transferred to the distillation columns. During this step, ethanol is separated from the whole stillage which is composed of a slurry of solids and water. According to Stock et al. (2000), the coarse feed particles can be removed from the mash before entering the distillation column. However, the alcohol yield per bushel of grain fermented is higher if the entire mash is processed through the distillation column. The product from the distillation columns is 95% pure (190 proof) ethanol (Bothast and Schlicher, 2005; Renewable Fuels Association, 2005). A molecular sieve system is utilized to remove the remaining 5% water from the ethanol to produce 100%, 200 proof ethanol. At this point, anhydrous ethanol is blended with approximately 5% denaturant to render it undrinkable.

The remaining whole stillage following distillation is 5 to 10% DM. The coarse grain particles are removed by using centrifuges or by presses/extruders. Stock et al.

(2000) explains the coarse particles removed from the whole stillage are referred to as wet distillers grains (WDG) and can be marketed as-is, or the WDG can be dried and marketed as dried distillers grains (DDG). Additionally, the remaining liquid fraction of the whole stillage is approximately 5 to 10% DM and referred to as thin stillage. Thin stillage is evaporated to 24 – 35% DM and is called condensed distillers solubles (CDS). The CDS contains fine grain particles and yeast cells. Condensed distillers solubles can be marketed as a separate feedstuff, or it may be added to WDG to produce wet distillers grains plus solubles (WDGS; 32 - 35% DM) or may be added to DDG to produce dried distillers grains plus solubles (DDGS; 88 - 90% DM). Additionally, some plants will partially dry WDG before adding CDS, or will partially dry WDGS to produce partially dried modified distillers grains plus solubles (MDGS; 45 – 55% DM).

DISTILLERS GRAINS PLUS SOLUBLES IN FEEDLOT DIETS

Feeding Distillers Grain Plus Solubles. Corn is the primary energy source utilized in beef cattle finishing diets (Vasconcelos and Galyean, 2007). As ethanol production continues to increase, the demand and competition between feedlots and ethanol plants will increase. Cattle producers can alleviate some of the competition for corn by incorporating distillers grains plus solubles (DGS) into cattle growing and finishing diets. Once starch is removed from the kernel, the remaining nutrients are increased three-fold. Variation between and within plants produce variability in the nutrient composition of DGS. Buckner et al. (2008b) collected samples from six ethanol plants in Nebraska. The mean fat content of WDGS was 11.8%, and ranged from 10.7 to

12.1% between plants. Akayezu et al. (1998) and Spiehs et al. (2002) reported fat ranges for DDGS of 10.2 to 11.7% and 8.8 to 12.4%, respectively. Mean sulfur content was 0.79% and ranged from 0.65 to 0.90% among plants. Range for S content reported by Speihs et al. (2002) was lower than Buckner et al. (2008b) and ranged from 0.33 to 0.74%. The range for CP was 30.1 to 32.2%, and the mean was 31% among all plants. This range for CP is consistent with Akayezu et al. (1998) and Spiehs et al. (2002) reporting CP of 28.7 to 31.6% and 27.7 to 32.3%, respectively.

Due in part to the starch content of DGS being low, and protein and phosphorous concentrations being high, DGS fits well as supplements into forage based diets. Loy et al. (2007) compared the effects of supplementing dry-rolled corn (DRC) and DDGS to heifers consuming low quality forages (45.7% IVDMD). Supplements were offered daily or three times a week at low (0.21% of BW) or high (0.79% of BW) concentrations. Supplements consisted of DDGS, DRC, or a combination of DRC and corn gluten meal (COMBO). The combination treatment was formulated to provide similar MP estimates of DDGS. Heifers receiving the DDGS supplement at low concentrations had increased ADG with similar DM intake, and thus better G:F compared to DRC or COMBO supplements. Heifers on the high concentration of supplementation had greater ADG when receiving DDGS or COMBO, but there were no significant differences in DMI or G:F. Morris et al. (2006) studied the effects of supplementing DDGS to yearling steers grazing summer native Sandhills range. Treatments consisted of supplementing 0, 0.26, 0.51, 0.77, or 1.03% BW of DDGS. Average daily gain increased linearly (70 g per 1.0 kg of DDGS) with increased concentrations of DDGS. A meta-analysis conducted by Griffin et al. (2012) evaluated 13 studies supplementing DDGS to cattle consuming

forage-based diets. Ending BW and ADG increased quadratically as DDGS supplementation concentration increased. Additionally, forage intake decreased quadratically as concentration of DDGS supplementation increased. These authors concluded that DDGS is an excellent source of protein and energy for high forage diets.

Wet Distillers Grains Plus Solubles in Feedlot Diets. Ethanol production has increased dramatically over the past decade and ultimately led to an increase in the availability of DGS. As a result, this has led to a paradigm shift of feeding DGS solely as a protein source to feeding DGS as a protein and energy source. Erickson and Klopfenstein (2002) suggested that DGS are utilized as a source of protein when included in diets at 15% or less, but serve as protein and energy sources when included at concentrations greater than 15%. The remainder of this review will evaluate DGS in cattle finishing diets, primarily as an energy source.

One of the initial studies utilizing DGS as an energy source was conducted by Farlin (1981). Dry-rolled corn was replaced in finishing diets with 25, 50, or 75% (DM) WDG. Results showed WDG provided more energy than the corn it replaced. Due to the early work reported by Farlin (1981), a large number of additional studies have been conducted to determine the usefulness of DGS as an energy source in finishing diets.

Larson et al. (1993) reported two studies looking at the effects of 40% WDG and thin stillage replacing DRC and protein in yearling and calf-fed steers. Gain efficiency was improved 20% for steers fed WDG and thin stillage as a result of decreased DMI and increased ADG. Similar results for G:F were reported by Ham et al. (1994), Al-Suwaiegh et al. (2002), and Wilken et al. (2009) when DRC was replaced by 40, 30, or 43.8% WDGS, respectively (19, 11, and 15% improvement, respectively). Daily gain

was increased for diets containing WDGS, and there were no effects on DMI. In contrast to these results, Mateo et al. (2004) replaced cracked corn with 20 or 40% WDGS and reported no differences among treatments for DMI, ADG, or G:F. Godsey et al. (2009a) replaced DRC with WDG and reported a 17.5% increase for ADG and 16.7% improvement for G:F. Comparable improvements were noted for ADG and G:F when cracked-corn was replaced with 28.5% WDG (Trenkle, 1996, 1997ab). The percent improvement for diets that contained WDGS compared to cracked corn were 7.9, 4.0, and 12.8% for ADG, respectively, and 9.7, 10.7, and 12.8%, respectively, for G:F in these three experiments. Similarly, Corrigan et al. (2009) evaluated the effects of replacing DRC with WDGS. When compared to the DRC-based control containing no DGS, ADG and G:F were improved 11.0 and 6.7%, respectively, when 27.5% WDGS replaced DRC. Within the same study, ADG and G:F were improved 7.8 and 7.7%, respectively when HMC was replaced with 27.5% WDGS.

Studies using WDGS to replace 1:1 blends of HMC and DRC (BLEND) have been reported. Loza et al. (2010) reported a 9.7% increase for ADG, 5.6% increase for DMI, and 8.7% increase for G:F when 30% WDGS replaced BLEND in steer calves. Similarly, Vander Pol et al. (2005) observed that replacing 30% BLEND with WDGS increased ADG by 18.1%, DMI by 8.3%, and G:F by 13.1%. Meyer et al. (2009) did not observe a difference for DMI between cattle fed BLEND or 25% WDGS, but ADG improved 6.7% and G:F improved 8.5% for cattle fed diets containing WDGS, and similar DMI when WDGS replaced BLEND. Godsey et al. (2009b) replaced 20 and 40% BLEND with WDGS and observed no differences for DMI between cattle fed diets with and without WDGS. Similar to Meyer et al. (2009), Godsey et al. (2009b) observed 5.1

and 5.7% greater ADG for cattle fed 20 and 40% WDGS, respectively, and 5.4 and 8.2% greater G:F for cattle fed 20 and 40% WDGS. Luebbe et al. (2012a) replaced 30% BLEND with WDGS in calves and increased DMI and ADG 7.5%, and observed no effect on G:F. Contrasting to these reports, Vander Pol et al. (2009) reported no change in animal performance for cattle consuming diets with 0, 20, or 40% WDGS.

The response to WDGS may be dependent on the concentration of WDGS fed. Vander Pol et al. (2005) increased the concentration of WDGS from 0 to 50% in increments of 10 percentage units. There was a quadratic increase for DMI. Daily intake increased 8.3% as concentration of WDGS increased from 0 to 30%, and decreased 11.3% from 30 to 50% WDGS concentration. In a study conducted by Trenkle (1996), cracked corn was replaced by 14.6, 26.2, or 37.5% WDGS. Daily intake was maximized for cattle consuming diets with 14.6% WDGS and decreased 10.5% for cattle consuming diets containing 37.5% WDGS compared to cattle fed control diet containing no DGS. Vander Pol et al. (2009) reported no difference in DMI in diets containing 0, 20, or 40% WDGS. Similarly, Firkins et al. (1985) replaced cracked-corn with 25 or 50% WDGS and observed no difference for DMI. Trenkle (1997b) observed no difference for DMI among diets containing 0, 16, 28, or 40% WDGS. However, Trenkle (1997a) reported a linear decrease for DMI as WDGS concentration increased from 0 to 40%. A meta-analysis conducted by Bremer et al. (2011) included treatment means from 20 different experiments that were conducted under relatively similar conditions representing 3,365 steers comparing diets with WDGS replacing corn. Concentrations of WDGS ranged from 0 to 40%. There was a quadratic increase for DMI with maximum DMI at 20% WDGS inclusion.

The study conducted by Vander Pol et al. (2005) compared 0, 10, 20, 30, and 50% WDGS. The diet containing no WDGS gained the slowest and ADG was greatest for steers fed 30 and 40% WDGS inclusion. When comparing these 5 diets containing WDGS, the 50% concentration had the lowest ADG. Efficiency of BW gain increased from 0 to 40% and decreased at 50% WDGS. Firkins et al. (1985) observed a linear increase for ADG and G:F as concentration of WDGS increased, and observed similar DMI among diets. There were no differences for ADG or G:F as WDGS replaced 0, 20, or 40% corn (Vander Pol et al., 2009). Trenkle (1997a) reported greater ADG and G:F for cattle fed 20% WDGS compared to 40% WDGS. Both diets containing WDGS had greater ADG and G:F than diets without WDGS. In the meta-analysis mentioned previously (Bremer et al., 2011), ADG was maximized at 30% WDGS concentration, and G:F was maximized between 30 and 40% WDGS for diets containing DRC or BLEND.

The majority of research replacing DRC, HMC, or BLEND with WDGS has been conducted in the Northern Great Plains and Corn Belt (Cole et al., 2006). However, in the Southern Great Plains, feedlots predominately utilize steam-flaked corn (SFC) as the energy source in finishing diets. The response for animal performance when WDGS replaces SFC in finishing diets does not appear to be as great as when WDGS replaces DRC, HMC, or BLEND.

Depenbusch et al. (2009b) evaluated the effects of replacing 15% SFC with wet or dry DGS, and reported no differences for DMI, ADG, or G:F between diets. Quinn et al. (2011) and May et al. (2011) reported there were no differences for final BW, DMI, ADG, or G:F when SFC was replaced with 15 or 30% WDGS. Buttery et al. (2012) reported no differences for DMI, ADG, or G:F for cattle consuming diets containing 0 or

20% WDGS. These results are inconsistent with May et al. (2010) in which SFC was replaced by 15 or 30% WDGS. Cattle fed diets containing no WDGS, had heavier final BW and increased DMI, ADG, and G:F than cattle fed diets containing WDGS. Depenbush et al. (2008) reported decreased G:F for cattle fed diets containing 25% WDGS when compared to SFC-diets with no WDGS.

Luebbe et al. (2012b) replaced SFC with in increments of 15 percentage units with a maximum concentration of WDGS being 60%. These authors reported linear decreases for final BW, ADG, and G:F as concentrations of WDGS increased. There was a quadratic increase for DMI with increasing concentrations of WDGS. The maximum DMI was observed at 15 and 30% WDGS inclusion concentrations. These results are slightly different than the results of Corrigan et al. (2009). Final BW and ADG increased quadratically with the highest gain reported for the 15% concentration of WDGS. Steers fed diets containing 0 and 15% WDGS had the greatest DMI, and steers fed 60% WDGS diet had the least DMI. Results from May et al. (2010) and Quinn et al. (2011) reported heavier final BW for cattle fed 15% WDGS compared to 30% WDGS in SFC-diets. Daily gain was not different between 15 and 30% WDGS for May et al. (2010), but was greater for 15% WDGS than 30% for Quinn et al. (2011). Additionally, G:F was greater for diets containing 15% WDGS compared to 30% WDGS (Quinn et al., 2011). May et al. (2011) did not observe any differences for final BW, ADG, DMI, or G:F when comparing 15 and 30% WDGS in SFC-diets.

Some research has been conducted evaluating the effects of different corn processing methods that replace portions of the corn with WDGS. Vander Pol et al. (2008) compared DRC, HMC, BLEND, and SFC in finishing diets containing 30%

WDGS. Steers fed DRC, HMC, or BLEND diets had greater ADG and DMI than steers fed SFC diets. Daily gain was similar for steers when HMC and DRC were compared to BLEND. However, there was a tendency for ADG to be greater for steers fed DRC compared to steers consuming HMC. Steers fed diets containing HMC had greater G:F compared to steers fed SFC, but were similar to steers consuming DRC or BLEND. There were no differences for G:F among steers fed DRC, BLEND, and SFC treatments when 30% WDGS replaced a portion of the respective corn. Corrigan et al. (2009) replaced DRC, HMC, or SFC with 0, 15, 27.5, or 40% WDGS. The authors reported a corn processing method by WDGS concentration interaction for final BW, ADG and G:F. As concentration of WDGS increased in DRC diets, final BW and ADG increased linearly. Cattle fed diets containing HMC had heavier final BW and greater ADG for 15 and 27.5% WDGS, whereas steers fed SFC-diets were heavier for 15% WDGS concentration. There was a quadratic decrease for DMI as concentration of WDGS increased for DRC, HMC, and SFC diets. Efficiency of BW gain increased linearly for DRC and HMC diets as concentration of WDGS increased, but increased concentrations of WDGS had no effect in SFC-diets. Contrasting to the results of Corrigan et al. (2009), Buttrey et al. (2012) did not observe a corn processing by WDGS concentration interaction for ADG, DMI, or G:F. In the study of Buttrey et al. (2012), the authors compared DRC and SFC with 0 or 20% WDGS. Final BW and ADG were not different between DRC and SFC. Diets containing SFC consumed 7% less feed than DRC and were 9% more efficient. There were no differences for DMI and ADG when 20% WDGS replaced corn, and there was a tendency for G:F to be improved when WDGS replaced corn.

Modified Distillers Grains Plus Solubles in Feedlot Diets. As mentioned previously, some dry mill ethanol plants elect to partially dry their DGS and market this product as MDGS. Limited research has been conducted to evaluate the effects of replacing corn with MDGS in finishing diets. Luebbe et al. (2012a) compared 15 and 30% MDGS in finishing diets containing BLEND with yearling steers. The authors reported no differences for final BW or G:F. Cattle fed diets containing MDGS gained 6.9% more than cattle fed diets without MDGS. Intake tended to increase for cattle fed MDGS diets compared to cattle fed diets without MDGS. There were no animal performance differences among concentration of MDGS. Similar improvements in yearling steer performance as observed by Luebbe et al. (2012a) were reported by Huls et al. (2008) when BLEND was replaced with MDGS from 0 to 50% of the diet in increments of 10 percentage units. Final BW, DMI, and ADG increased quadratically with increasing concentration of MDGS. Using the quadratic prediction equation, DMI was maximized at 19% MDGS, and ADG was maximized at 26% MDGS inclusion. There was a linear response for G:F as MDGS concentration increased. Intake was maximized when 20% MDGS replaced DRC in yearling cattle (Trenkle, 2008). Within this same study, cattle fed 0, 20, or 40% MDGS were not different for ADG and G:F. Cattle fed 60% MDGS gained less and were less efficient than other treatments. Trenkle, (2007) reported no differences for performance among calves consuming 24.9% MDGS and DRC diets containing no MDGS. However, when 47% of DRC was replaced with MDGS, DMI was reduced with no effects on ADG. Consequently, this resulted in improved G:F for the higher concentration of MDGS. Bremer et al. (2011) conducted a meta-analysis comparing 4 finishing studies conducted under similar conditions in the

same research yard that replaced DRC or BLEND with MDGS. There was a quadratic response for DMI, ADG, and G:F as concentration of MDGS increased. The maximum DMI was observed for 20 and 30% MDGS concentrations, ADG was maximized for 30% concentration, and G:F was maximized for 40% concentration.

Dried Distillers Grains Plus Solubles in Feedlot Diets. Incorporating DDGS into feedlot diets allows producers that are greater distances from an ethanol plant to utilize these co-products without the increased cost of freight due in part to the high moisture content of WDGS. Feeding DDGS in finishing diets have given variable results in regards to the effects DDGS has on animal performance.

Ham et al. (1994) replaced 40% DRC in finishing steers with DDGS. Steers fed diets containing DDGS had greater ADG, DMI, and G:F than steers consuming diets with no DDGS. Benson et al. (2005) evaluated the effects of replacing 15, 25, or 35% cracked corn with DDGS. There was a quadratic increase for DMI and ADG. Steers fed diets containing 25% DDGS had greater DMI and ADG than steers fed diets containing no DDGS. Steers fed 15 and 35% DDGS concentrations were intermediate of 0 and 25% DDGS concentration for DMI and ADG. Buckner et al. (2011) replaced 30% BLEND with DDGS and reported greater DMI, ADG, and G:F for steers fed diets containing DDGS when compared to steers consuming diets containing no DDGS.

Contrasting to these results, Vander Pol et al. (2009) replaced 20 or 40% DRC with DDGS and observed no differences in animal performance among treatments. It is necessary to note however, all diets in this study contained 30% WCGF and this could have contributed to lack of differences. Additionally, Mateo et al. (2004) reported no

differences among steers fed diets containing 20 or 40% DDGS when compared to the cracked-corn control diet containing no DDGS.

Buckner et al. (2008a) evaluated the effects of feeding increasing dietary inclusions concentrations of DDGS from 0 - 50% in increments of 10 percentage units. Cattle on the 50% DDGS diet were removed due to challenges associated with polioencephalomalacia. Therefore, the results reported are for diets containing 0, 10, 20, 30, or 40% DDGS. There were no differences observed among concentrations of DDGS for DMI. Daily gain responded in a quadratic fashion and using the prediction equation was maximized at 23.5% DDGS concentration. Although not significant, G:F approached a significant quadratic increase, similar to ADG. Maximum G:F was calculated with the predication equation to be 24.7% DDGS concentration. Sarturi et al. (2013) replaced BLEND with 20, 30, or 40% DDGS and observed a linear increase for DMI as concentration of DDGS increased. Daily gain numerically increased with increasing concentration of DDGS, and similar to Buckner et al. (2008a), there were no significant differences for G:F among steers fed DDGS diets when compared to steers fed the control. In a meta-analysis conducted by Bremer et al. (2011), 4 studies comparing the effects of replacing corn with DDGS were evaluated. These results showed a linear response for ADG and G:F as concentration of DDGS increased to 40%.

Similar to WDGS, when DDGS are fed in finishing diets replacing SFC, the response is different when DRC and/or HMC are replaced. Depenbusch et al. (2009a) evaluated the effects of replacing SFC with 0 – 75% DDGS in increments of 15 percentage units. There was a quadratic increase for DMI and ADG. Maximum ADG and DMI were observed for 15% DDGS concentration and were least for 75% DDGS

concentration. The 0, 30, 45, and 60% concentrations were not different for both ADG and DMI. However, G:F decreased linearly as concentrations of DDGS increased. Uwituze et al. (2010) and May et al. (2010) replaced SFC with 25% DDGS. The authors observed no differences for DMI, ADG, or G:F. Interestingly, the study reported by May et al. (2010) also compared the effects of replacing 25% DRC with DDGS. There were no grain processing by DDGS inclusion interactions. The lack of interactions contradict Corrigan et al. (2009). May et al. (2010) suggest the lack of interaction could be due in part to the lower (25%) concentration of DDGS incorporated into the diet compared to the higher (40%) concentration in Corrigan et al. (2009).

Calculated Feeding Values of Distillers Grains Plus Solubles in Feedlot Diets.

Corn is the primary source of grain fed in finishing diets across the United States (Vasconcelos and Galyean, 2007). When DGS are included in finishing diets, corn is commonly replaced. Some reasons for replacing corn with DGS in these diets would be to feed a less expensive feedstuff if DGS can be purchased cheaper than corn, to improve animal performance, or both. The response to DGS is dependent on the type of corn replaced in the diet, and the concentration and type of DGS included (Ham et al., 1994; Vander Pol et al., 2005; Corrigan et al., 2009). When decisions are made to replace corn with DGS, the feeding value of DGS needs to be estimated. One method to compare feeding values of DGS across studies is to compare the G:F values of DGS diets relative to corn. Assuming the difference is solely due to the inclusion of DGS, the difference in G:F can be divided by the DGS concentration to determine the feeding value of DGS relative to the corn type in the study.

Ham et al. (1994) replaced 40% DRC with WDGS and calculated the feeding value of WDGS to be 147% that of DRC. Similarly, Wilken et al. (2009) replaced 43.8% DRC and reported the feeding value to be 137% that of DRC. Contrasting to these results, Mateo et al. (2004) reported no differences for feeding values for DRC and WDGS when 20 and 40% DRC was replaced with WDGS. Corrigan et al. (2009) replaced DRC with 15, 27.5, and 40% WDGS and reported the feeding value of WDGS to be 129, 140, and 134%, respectively. Within the same study, these authors also evaluated the effects of replacing HMC with the same source of WDGS at the same concentrations and determined the feeding value of WDGS compared to HMC to be 122, 128, and 115 for the 15, 27.5, and 40% concentration of WDGS, respectively.

When WDGS replaced a combination of BLEND, greater feeding values than BLEND have been reported for WDGS. Vander Pol et al. (2009) reported increased feeding values of 138 and 144% when WDGS inclusion concentration was 20 and 30%, respectively. When WDGS increased to 40 and 50%, the feeding value decreased to 137 and 121% that of BLEND, respectively. The calculated feeding value for 25% WDGS reported by Meyer et al. (2009) was 134%. Similarly, Godsey et al. (2009b) replaced 20 or 40% BLEND with WDGS and reported the feeding value of WDGS to be 127 and 121%, respectively, that of BLEND. Conversely, Luebbe et al. (2012a) replaced 15 and 30% BLEND with WDGS and did not observe a difference in feeding values between BLEND and WDGS. The response to WDGS in DRC diets seems to be greater than diets feeding BLEND. The meta-analysis conducted by Bremer et al. (2011) utilized studies that replaced DRC, HMC, or BLEND with WDGS. The authors concluded that

the feeding value of WDGS linearly decreased from 143 to 130% that of corn when included in diets from 20 to 40%.

The G:F data for replacing SFC with WDGS is variable, but suggests the feeding value of WDGS in SFC is dependent on the study. Corrigan et al. (2009) replaced 15, 27.5, and 40% SFC with WDGS and reported the feeding value to be 115, 100, and 101%, respectively. Similarly, May et al. (2010) reported the feeding value of 15% WDGS to be 113% of SFC. However, when WDGS concentration increased to 30% in the study reported by May et al. (2010), the feeding value for WDGS was 89% that of SFC. Godsey et al. (2009a) reported greater values when replacing 20 and 40% SFC with WDG. The authors reported that WDG contains 134 and 111% the feeding value of SFC for 20 and 40% WDGS, respectively. In a recent study conducted by Luebbe et al. (2012b), WDGS replaced SFC in increments of 15 percentage units. The maximum WDGS concentration was 60%. This study suggests the feeding value of WDGS decreased linearly from 0 to 60% WDGS concentrations.

The majority of the research evaluating MDGS has been conducted replacing DRC and/or HMC. Feeding values for MDGS were 125 and 108% that of BLEND for 15 and 30% MDGS concentrations, respectively (Luebbe et al., 2012a). Huls et al. (2008) reported the calculated feeding value for MDGS compared to BLEND ranged from 123 to 111%. The greatest feeding value was obtained with the 20% inclusion concentration. Contrasting to these results, Trenkle (2008) fed 0, 20, 40, and 60% MDGS in cracked-corn diets and reported decreased feeding values for MDGS as concentration of MDGS increased. The meta-analysis conducted by Bremer et al. (2011)

concluded the feeding value for MDGS was 128, 124, 120, and 117% that of the corn it replaced for 10, 20, 30, and 40% MDGS inclusion concentration, respectively.

The feeding values for DDGS follow a similar trend to WDGS with the exception that the maximum concentrations for DDGS are lower than that of WDGS. The feeding value for DDGS compared to DRC was 124% (Ham et al., 1994). Buckner et al. (2008a) observed similar feeding values for lower concentrations of DDGS as Ham et al. (1994), but the feeding values for the higher DDGS concentrations were not as great. In this study, DRC was replaced by 10 to 40% DDGS. Feeding values were 127, 128, 106, and 105% of DRC for 10, 20, 30, and 40% DDGS concentrations, respectively. Similarly, Buckner et al. (2011) fed 30% DDGS with BLEND and reported the feeding value for DDGS was 103%. Sarturi et al. (2012) replaced 20, 30, and 40% BLEND with DDGS and reported equal feeding values for DDGS and BLEND.

Bremer et al. (2011) conducted two separate meta-analyses comparing pen means from experiments comparing WDGS or DDGS to a corn-based control. The DGS evaluated replaced DRC, HMC, or BLEND. The WDGS meta-analysis included 20 separate experiments evaluated under similar conditions where concentrations of WDGS ranged from 0 to 40%. The feeding values were 150, 143, 136, and 130% that of corn for 10, 20, 30, and 40% WDGS concentration, respectively. The DDGS meta-analysis included 4 experiments evaluating DDGS concentrations up to 40% (DM). The feeding values for DDGS were 112% that of corn for all DDGS concentrations.

POTENTIAL REASONS FOR OBSERVED FEEDING VALUES OF DISTILLERS GRAINS PLUS SOLUBLES IN FEEDLOT DIETS

Effects of Distillers Grains Plus Solubles on Site of Starch Digestion. It could be assumed that by removing the primary source of energy in corn (i.e. starch), the feeding value of DGS would be less than corn. However, as discussed previously, this does not hold true in all cases. Once starch is removed from the kernel, the remaining nutrients that remain are increased three-fold compared to corn (Klopfenstein et al., 2008).

Steam-flaked corn, HMC, and DRC are the three most common grain processing methods practiced in feedlots (Vasconcelos and Galyean, 2007) to increase starch utilization, thus improving animal performance (Huntington, 1997). The different processing methods influence the site and extent of the starch digested. Ensiled HMC and SFC have 3% greater total-tract digestibility than DRC (Galyean et al., 1976; Cooper et al., 2002). Huntington (1997) reported 7% greater total-tract starch digestibility for SFC than DRC with HMC being intermediate. Ruminal starch digestion was greater for HMC compared to DRC (89.3 and 77.8%, respectively); while SFC (82.9%) was intermediate of HMC and DRC (Galyean et al., 1976). Ruminal starch digestibility for DRC, HMC, and SFC were 76, 90, and 85% (Huntington, 1997) and 76, 92, and 90%, (Cooper et al., 2002), respectively.

In a review conducted by Owens et al. (1986), the efficiency of feed use was equal to ruminal starch digestion multiplied by 0.159 and small intestinal starch digestion multiplied by 0.227. This suggests starch digested within the rumen is only 70% as efficient as starch digested within the small intestine. Richards et al. (2002) observed linear improvements for intestinal starch disappearance when casein was infused into the abomasum to mimic UIP. Zein is the primary protein in DGS, and has been shown to

contain high rumen escape values (McDonald, 1954; Little et al., 1968). Therefore, it could be hypothesized that the high concentrations of UIP associated with DGS may increase the amount of starch digested within the small intestine, thus increasing the amount of energy for growth. Total-tract starch digestibility was greater for SFC than DRC or HMC in diets containing WDGS (Corrigan et al., 2009). Similarly, May et al. (2009) reported greater total-tract starch digestibility for SFC compared to DRC in diets containing 25% DDGS. However, others reported that diets containing DGS were not different for total-tract starch digestibility compared to diets containing no DGS (Corrigan et al., 2009; May et al., 2009). Similarly, Vander Pol et al. (2009) reported similar total-tract starch digestibility for 0 and 40% WDGS diets. Therefore, it does not appear that DGS alters the site of starch digestion from the rumen to the small intestine.

Nutrient Digestibility and Metabolism of Wet and Dried Distillers Grains Plus Solubles. Vander Pol et al. (2009) compared WDGS or a set of composites formulated to contain similar nutrient compositions of WDGS to DRC. The composites consisted of corn bran and corn gluten meal (COMP); or corn bran, corn gluten meal and corn oil (COMP + OIL). The DRC control was fed with (DRC + OIL) and without (DRC) supplemental corn oil. Additionally, the COMP and COMP + OIL treatments were formulated to contain the same amounts of NDF and CP as WDGS. The COMP + OIL and DRC + OIL treatments were formulated to contain similar amounts of fat as WDGS. Ruminal OM and NDF digestibility were not different among treatments (Vander Pol et al., 2009). Total tract DM, OM and NDF digestibilies were not different for WDGS and DRC. Corrigan et al. (2009) reported no differences for total tract NDF digestibility when 40% WDGS was compared to DRC and HMC. However, total tract

DM and OM was 5.5 and 6% less, respectively for WDGS diets. Ham et al. (1994) reported no differences between WDGS and DRC for total tract OM digestibility. However, in this same study, NDF digestibility was increased 11% for WDGS compared to DRC. Luepp et al. (2009) reported no differences for OM digestibility when comparing DDGS and DRC. In a study conducted by May et al. (2009), DRC or SFC was replaced with 25% DDGS. The authors reported a tendency for total tract DM and OM digestibility to decrease for DDGS diets compared to corn diets. There were no differences for percent NDF digestion among diets with or without DDGS, or among DRC or SFC. Similar to the results comparing WDGS to corn-based control, there were no differences for NDF digestibility when DDGS were included in the diets and compared to corn-based control (Leupp et al., 2009; Uwituze et al., 2010).

Molar proportions of acetate were less and proportions of propionate were greater for WDGS compared to other diets (Vander Pol et al., 2009). Contrasting to these results, Ham et al. (1994) did not observe a change in molar proportions of acetate or propionate between DRC and WDGS treatments. Corrigan et al. (2009) reported increased molar proportions of propionate for diets containing 40% WDGS compared to DRC and HMC diets with 0% WDGS. However, there were no differences for SFC diets with 0% WDGS for molar proportions of propionate compared to DRC, HMC, and SFC diets containing 40% WDGS. There were no differences for molar proportions of acetate among 0 and 40% WDGS, and DRC, HMC, or SFC.

Rumen pH has previously been greater with increasing concentrations of dietary NDF (Allen, 1997; Benton et al., 2007). Therefore, it would seem intuitive that replacing corn (9% NDF; NRC, 1996) with DGS in finishing diets would increase rumen pH as a

result of increased dietary NDF and decreased dietary starch. However, Vander Pol et al. (2009) reported numerically lower rumen pH and greater time below pH 5.6 for diets containing 40% WDGS compared to DRC diets. There were no differences for maximum or minimum pH and pH change among treatments. Corrigan et al. (2009) reported a tendency for maximum pH and pH variance to be less for diets containing 40% WDGS. Similarly, Ham et al. (1994) reported a slight numeric decrease in rumen pH for WDGS compared to DRC. Although dietary NDF increases with increasing concentrations of WDGS, the fiber from WDGS does not influence rumen pH to the extent of forage NDF.

Hsu et al. (1987) reported corn bran is a highly digestible (> 70%) source of fiber. However, the feeding value of corn bran is less than BLEND (Macken et al., 2004). In this study, 40% corn bran replaced BLEND and resulted in decreased G:F. Bremer et al. (2010) reported similar total tract NDF digestibility for WDGS compared to BLEND. However, in other studies, total tract NDF digestibility for WDGS has been reported to be greater than corn diet NDF digestibility (Ham et al., 1994; Corrigan et al., 2009; Vander Pol et al., 2009).

Two studies were conducted by Lodge et al. (1997b) to evaluate individual components within DGS. The diets in the first study were 1) DRC control; 2) DDGS; 3) WCGF; 4) COMP1. The COMP1 diet consisted of 47.5% WCGF, 30.5% corn gluten meal, 11.9% DS, and 9.7% tallow. Daily intake was not different among diets. Efficiency of BW gain was 27% greater for COMP1 compared to WCGF. The second study utilized yearling steers and evaluated 5 different diets. Diets were 1) DRC control; 2) WCGF; 3) wet distillers grains composite (COMP2); 4) wet distillers grains composite

minus fat (-FAT); and 5) wet distillers grains composite minus corn gluten meal (-CGM). The wet distillers grain composite contained 65.7% WCGF, 26.3% corn gluten meal, and 8.0% tallow. Daily gains for steers were not different among treatments. Steers fed COMP2 had 10% greater G:F than WCGF or DRC. Although, not significant, steers fed -FAT and –CGM were 7% more efficient than steers fed WCGF or DRC. These results suggest that the increased fat and UIP of DGS have an additive effect on the feeding value of DGS in finishing diets.

Fat Supplementation in Finishing Diets. Reported values for ether extract of WDGS from six different ethanol plants ranged from 10.7 to 13.0% (Buckner et al., 2008b). The feeding value of fat has been reported to contain 2.5 (Plascenia et al., 1999; 3.95 Mcal/kg) to 3.0 (Zinn, 1988 and Zinn et al., 2000; 4.53 and 4.69 Mcal/kg, respectively) times the NEg of corn (1.55 Mcal/kg). Fat ingested in the rumen is resistant to microbial degradation and primarily absorbed as free fatty acids (FA) post-ruminally (Zinn et al., 2000). Zinn (1989) reported that for every percentage unit of supplemental fat above 4.0%, digestibility of supplemental fat decreases 3.4%. Similarly, Plascencia et al. (1999) reported post-ruminal fat digestibility decreases as concentration of fat supplementation increases. Formation of bile salt micelles is responsible for absorption of (FA). Interactions of bile salts and insoluble-swelling amophiles such as unsaturated FA increase micelle surface area and result in greater surface area for fat digestibility (Zinn et al. 2000). In a study reported by Zinn et al. (2000), the authors compared different types of fat that varied by degree of susceptibility to ruminal biohydrogenation. Within this study, intestinal digestibility of fat was increased as degree of ruminal biohydrogenation of supplemental fat decreased. For every one percent increase of 18:1

that entered the small intestine, the digestibility of 18:0 increased 1%. Therefore, it could be beneficial to feed sources of fat that are less susceptible to biohydrogenation in the rumen.

The aforementioned study of Vander Pol et al. (2009) reported greatest fat digestibility for WDGS and the least for COMP. Diets supplemented with corn oil had greater proportions of 18:0 reaching the duodenum, whereas WDGS had the least amount of 18:0 reaching the duodenum. However, proportions of unsaturated FA (18:1 and 18:2) reaching the duodenum were greater for WDGS than for other diets. This suggests that the FA in WDGS are protected in a way to avoid biohydrogenation to the same degree as corn oil. Bremer et al. (2010) observed similar results as Vander Pol et al. (2009) and supported the hypothesis that there is less biohydrogentation of fat found in WDGS. Bremer et al. (2010) fed diets that contained 8.2 to 8.6% dietary fat. Fat sources were added corn oil, tallow, DS, or WDGS. The omasal FA profile for WDGS contained proportionally greater 18:1 and 18:2 than other treatments. Additionally, supplemental fat from DS does not appear to be protected from ruminal biohydrogentation. Although a greater proportion of unsaturated FA reached the duodenum for WDGS, FA digestibility reaching the omasum was not different among treatments. This contradicts the report of Zinn et al. (2000) that suggests the degree of ruminal biohydrogenation and concentration of FA digested in the small intestine are inversely related.

Comparing Wet and Dried Distillers Grains Plus Solubles. It seems counter intuitive to expend energy on drying DGS to produce DDGS, when the primary purpose of dry-milling plants is to produce energy. However, there are benefits to dehydrating WDGS. The lower moisture content of DDGS allows the product to be shipped further

distances from the ethanol plant because the trucking cost per unit of DM is reduced. The higher moisture content of WDGS also decreases the shelf-life of the feedstuff due to issues with mold. Feeding DDGS decreases shrink associated with mold and moisture loss.

The production of WDGS and DDGS require the same steps, with an additional drying step when producing DDGS. Theoretically, the nutrient content of WDGS and DDGS should be the same. However, when compared within the same study, the responses have been different. Ham et al. (1994) compared WDGS and DDGS in DRC-based diets. The DGS was included in the diet at 40%. Daily gain was not different between steers fed WDGS or DDGS. Daily intake was 20% greater for steers fed DDGS, thus decreasing G:F 8.4% compared to steers fed WDGS. These data suggest the feeding value of WDGS is 121% of DDGS. Similarly, Mateo et al. (2004) compared 20 and 40% WDGS and DDGS in cracked-corn diets and reported similar gains for steers fed DDGS or WDGS. There was a DGS type x DGS concentration interaction for DMI. Steers fed 40% WDGS had reduced DMI compared to steers consuming 20% WDGS and 20 and 40% DDGS. However, numerically, DMI was reduced 3.5% for steers fed 20% WDGS compared to steers fed 20% DDGS. Steers fed diets containing WDGS were 9% more efficient than steers consuming DDGS. The feeding value of WDGS was 132% that of DDGS. More recently, Sarturi et al. (2013) compared 20, 30, and 40% WDGS and DDGS. There were no differences for ADG among treatments, but DMI was 10% greater for steers fed DDGS. This resulted in G:F for steers consuming WDGS to be 11% than G:F for steers fed DDGS. These data suggest the calculated feeding value of WDGS is 137% that of DDGS (Sarturi et al., 2013).

The three meta-analyses conducted by Bremer et al. (2011) evaluated studies that replaced corn with WDGS, MDGS, or DDGS. The feeding value of WDGS contained the greatest (143 to 130%) feeding value, MDGS was intermediate (124 to 117%), and DDGS contained the lowest (112%) feeding value. The feeding values of all three types of DGS were still greater than corn.

One potential reason explaining the difference between WDGS and DDGS could be the amount of DS added to the grains at the ethanol plant. Corrigan et al. (2007) suggested that ethanol plants have the ability to add 0 to 110% of the DS produced onto the grains when producing DDGS, but some plants have difficulties adding 100% of the DS to WDG. Ham et al. (1994) suggested that WDGS is comprised of 62.5:37.5 WDG:DS. Corrigan et al. (2007) suggested the ratio of DDG to DS in DDGS to be 80:20. Godsey et al. (2009b) evaluated three different proportions of WDG to DS in finishing diets containing BLEND. The concentrations of WDG:DS were 100:0, 85:15; and 70:30 and replaced 20 or 40% of BLEND. There were no differences for any animal performance variables measured among treatments. This suggests that the solubles ratio may not have an effect on the feeding value of DGS. However, contrary to these results, Bremer et al. (2010) compared WDG and WDGS (6.7 vs. 12.9% ether extract). Daily gain and carcass adjusted final BW were greater for steers fed WDGS diets compared to steers fed the control and WDG diets. Quinn et al. (2011) compared the effects of different WDG:DS ratios on IVDMD. There were three ratios of WDG:DS; 100:0, 75:25, and 50:50. Each combination was included in the diet at 15 or 30%, in addition to a control diet containing no WDG or DS. Concentration of WDGS and ratio of WDG:DS

had no effect on IVDMD. Cao et al. (2009) reported increased DM and CP disappearance as concentration of DS increased in proportion to DG.

During the wet-milling process, steep liquor and distillers solubles are added to the corn bran. Drying WCGF reduced the G:F for lambs compared to WCGF (Green et al., 1987). Dried corn gluten feed had lower DM, NDF, and ADF digestibilities compared to WCGF. Within this study, the authors also compared wet corn bran (WCB) to dry corn bran (DCB) and reported similar G:F. Digestibilities for DM and NDF tended to be higher for DCB compared to WCB. Cattle fed WCB, DCB, or re-hydrated corn bran had similar performance (Macken et al., 2004). This suggests that the negative effects of drying WCGF occurs during the drying process of the steep liquor which is approximately one-third of WCGF. Similarly, Ham et al. (1995) reported increased digestibility for WCGF compared to DCGF. If the reduced feeding value of DCGF is a result of drying the steep liquor, potentially drying DS onto WDG reduces the feeding value of DDGS compared to WDGS.

Firkins et al. (1984) compared the ruminal digestion characteristics of WDGS and DDGS. These authors reported that WDGS and DDGS ruminal DM digestion (57.7 and 57.3%, respectively) and NDF digestion (62.6 and 63.5%, respectively) were not different. As a follow up to this study, Firkins et al. (1985) compared WDG and DDG in sheep. There was a tendency for NDF digestibility to be greater for DDG compared to WDG (68.6 and 62.0, respectively). There were no differences for DM and CP digestibility. The extent of DM and NDF disappearance in vivo was greater for DDG after 9 and 18 h when compared to WDG. The authors suggest this is likely due to the rapid washout of DDG. There were no differences among WDG and DDG for extent of

DM and NDF disappearance after 27 h. More recently, Cao et al. (2009) evaluated WDGS and DDGS and the differences among ruminal degradation and intestinal digestibility. Across all incubation times, WDGS had greater DM and CP disappearance than DDGS. In a study conducted by Ham et al. (1994), the particulate passage rate was faster for DDGS when compared to DDGS plus water. Water was added to DDGS in an amount to equal the moisture content of WDGS. Wet DGS was intermediate of the two DDGS. Sarturi et al. (2013) reported no differences for DM digestibility among WDGS and DDGS. In this same study, there were no differences among WDGS and DDGS for VFA molar proportions. Ruminal pH was reported to be greater for DDGS compared to WDGS. Within this same study, DMI was greater for DDGS compared to WDGS. Rumen pH represents the amount of available fermentable substrate within the rumen. Therefore, greater DMI and pH for DDGS diets suggests a lower energy value for DDGS compared to WDGS.

In a review conducted by Kandylis (1984), the production of hydrogen sulfide in ruminants is responsible for health issues and depressed intake and growth when excess S is fed. A study conducted by Sarturi et al. (2013), evaluated the effects of three concentrations of WDGS (20, 30, or 40% DM) and two concentrations (0.82 and 1.16%) of sulfur content in WDGS. There was an interaction for S and dietary concentration of DGS. Daily gain decreased linearly and quadratically for WDGS and DDGS, respectively for the high (1.16%) S DGS. There was a tendency for a linear increase for ADG for low (0.82%) sulfur DDGS, while there was no effect on ADG as concentration of low (0.82%) WDGS increased. These data suggest there is a potential change that occurs during the drying process that alters the availability for conversion of S to

hydrogen sulfide. The S content of DGS needs to be considered when assigning a feeding value for DGS.

Comparing Corn and Sorghum Distillers Grains Plus Solubles. A majority of dry-milling ethanol plants have been constructed in the northern Great Plains and Corn Belt regions and utilize corn during the fermentation process to produce ethanol (Cole et al., 2011). However, dry-milling production has increased in the southern Great Plains where sorghum is frequently used as a grain source. The majority of the research feeding DGS in the northern Great Plains has replaced DRC, HMC, or BLEND with DGS and have seen greater feeding values for DGS than the corn it replaced. However, research conducted in the southern Great Plains has mostly evaluated the effects of replacing SFC. The response to DGS is not as great in SFC diets as it is in DRC and HMC diets. Corrigan et al. (2009) reported a corn processing by WDGS concentration interaction. The WDGS was produced from fermentation of corn only. In this study, there were no differences for G:F among concentrations of WDGS in SFC diets. Contrasting to these results, Luebbe et al. (2012b) reported decreased G:F values as concentration of DGS increased in SFC diets. This leaves the question whether DGS produced from sorghum is similar in feeding value to DGS produced from corn grain.

Vasconcelos et al. (2007) compared 10% sorghum WDGS and 10% corn WDGS. The sorghum WDGS contained 47.1% sorghum centrifuge cake, 18.4% solubles, and 34.5% corn dried distillers grains. There was a tendency for DMI to be greater for sorghum WDGS compared to corn WDGS. There were no differences for ADG or G:F among treatments. Similarly, Depenbush et al. (2009) replaced 15% SFC with corn or sorghum DGS. There were no differences among types of DGS for DMI, ADG, or G:F.

Al-Suwaiegh et al. (2002) replaced 30% DRC with corn WDGS or sorhum WDGS. These sources of WDGS were produced from the same ethanol plant from a sole source of grain for each DGS type. Daily intake was greater for sorghum WDGS diets compared to corn WDGS. There were no differences among types of WDGS for ADG or G:F.

Two studies were conducted by Lodge et al. (1997a) to compare corn and sorghum WDGS in finishing diets. The finishing study replaced 40% DRC with sorghum WDG, sorghum WDGS, or sorghum DDGS. There were no differences among treatments for ADG and DMI. However, sorghum DDGS were less efficient than other diets. The calculated feeding values for sorghum WDG, sorghum WDGS, and sorghum DDGS were 96, 102, and 80%, respectively. In the digestion study conducted by Lodge et al. (1997a), corn and sorghum WDGS were compared. Organic matter digestibility was greater for corn WDGS than sorghum WDGS. These results contradict May et al. (2010) and Cole et al. (2011) that reported no differences for DM or OM digestibility among corn and sorghum WDGS. However, there were no differences for NDF digestibility among treatments (Lodge et al., 1997a; May et al., 2010).

CONCLUSION

As ethanol production continues to increase and compete for the available corn supply, cattle feeders need to find alternative sources of energy to feed to cattle. Distillers grains plus solubles are an exceptional source of protein and energy in finishing diets. The DGS concentration and type (corn or sorghum DGS; WDGS or DDGS) of

DGS can influence the feeding value in finishing diets. Demand for DGS will continue to increase, and therefore require greater distances that the products need to be hauled. Drying DGS is an effective way for producers that are long distances from ethanol plants to incorporate DGS into their finishing diets without the increased cost due to trucking greater concentrations of water and spoilage. It appears when comparing different types of DGS from different studies that the feeding values decrease as drying intensity increases. Limited research has been conducted to compare WDGS, MDGS, and DDGS in the same study. Additionally, there is limited work suggesting why the feeding values for MDGS and DDGS are less than WDGS. Therefore, additional work needs to be conducted to directly compare WDGS, MDGS, and DDGS to evaluate the effects on animal performance and nutrient metabolism.

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CHAPTER III

COMPARING WET, MODIFIED, OR DRIED DISTILLERS GRAINS PLUS SOLUBLES ON YEARLING FEEDLOT CATTLE PERFORMANCE[1]

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ABSTRACT: Two experiments were conducted to compare dry, wet, and modified (partially dried) distillers grains plus solubles (DGS) in yearling finishing cattle diets. During Exp. 1, crossbred, yearling steers (n=440; initial BW = 353 ± 19 kg) were used in a randomized block design with steers stratified within block, and assigned randomly to one of 55 pens (8 steers/pen). Pens were assigned randomly to one of ten treatments as a 3x3+1 factorial. Treatments included 3 concentrations (20, 30, or 40%) and 3 different types of DGS. A corn control was also fed. Types of DGS were: wet distillers grains plus solubles (WDGS, 34.8% DM), modified distillers grains plus solubles (MDGS, 50.6% DM), or dried distillers grains plus solubles (DDGS, 91.4% DM). In Exp. 2, yearling, crossbred steers (n=171; 362 ± 30 kg) were used in a randomized block design, stratified within block, and assigned randomly to one of 21 pens (8 or 9 steers/pen). Pens were assigned randomly to one of three treatments that consisted of: 1) corn-based control (CON); 2) 35% wet distillers grains plus solubles (WDGS, 34.6% DM); and 35% dried distillers grains plus solubles (DDGS, 88.2% DM). There were no DGS type by DGS concentration interactions ($P \geq 0.16$) in Exp. 1. No difference was observed for ADG ($P = 0.49$) among WDGS, MDGS, or DDGS treatments. Steers fed WDGS had 0.73 and 1.04 kg/d less ($P < 0.01$) DMI than steers fed MDGS and DDGS, respectively. Steers fed WDGS (0.166) had the greatest ($P < 0.01$) G:F, MDGS (0.158) was intermediate, and DDGS (0.150) was the least. Type of DGS had no impact ($P > 0.12$) on carcass traits. A linear increase ($P = 0.01$) for DMI, quadratic response ($P = 0.04$) for ADG, and a linear increase (P < 0.01) for G:F were observed as DGS increased from 0 to 40%. Based on G:F, the feeding value of WDGS was 35.4 and 17.8% greater than DDGS and MDGS, respectively. Daily gain increased 0.23 and 0.20 kg/d for WDGS and DDGS,

respectively when compared to CON ($P < 0.01$) in Exp. 2. Intake was not different ($P = 0.33$) between CON, WDGS, and DDGS (12.9, 13.1, and 13.2 kg/d, respectively). Cattle fed WDGS had greater G:F than DDGS and CON steers (0.162, 0.157, and 0.146, respectively; $P < 0.01$), and DDGS steers were more efficient than CON ($P < 0.01$). Using G:F values, calculated feeding value for WDGS and DDGS were 31.3 and 21.5% greater than CON, respectively, and WDGS was 9.1% greater than DDGS. Drying WDGS partially or completely has a negative impact on the feeding value relative to corn. Including DSG up to 40% of the diet will increase animal performance compared to a corn-based diet.

KEY WORDS Dried distillers grains plus solubles, Finishing cattle, Wet distillers grains plus solubles (2600 keystrokes)

INTRODUCTION

Grain, primarily corn, is fermented for the dry milling process to produce ethanol and the process is described in detail by Stock et al. (2000). During the fermentation process, all plants produce wet distillers grains and solubles. The solubles are commonly added to the wet distillers grains to produce wet distillers grains plus solubles (WDGS; 30 - 35% DM). Some plants remove a portion of this moisture and produce modified distillers grains plus solubles (MDGS; 45 - 50% DM), or dry WDGS to produce dried distillers grains plus solubles (DDGS; > 88% DM). Regardless of moisture content, all three types of distillers grains plus solubles (DGS) have been shown to contain equal or greater feeding values than corn when incorporated into feedlot diets up to 50% inclusion concentration (Buckner et al., 2008; Huls et al., 2008; Vander Pol et al., 2009). Feeding value is the change in G:F of diets containing DGS compared with the diet with no DGS

divided by the concentration of DGS in the diet. Feeding value of DGS is expressed as percent relative to corn.

Ham et al. (1994) fed DDGS and WDGS at 40% concentration and determined WDGS and DDGS to contain 47 and 24% greater feeding value than dry-rolled corn (DRC), respectively. Bremer et al. (2011) conducted three separate meta-analyses that evaluated replacing up to 40% high-moisture corn (HMC), DRC, or a combination of DRC and HMC with WDGS, MDGS, or DDGS. The authors concluded that the feeding values were 143 – 130%, 124 – 117%, and 112% for WDGS, MDGS, and DDGS, respectively. The increased feeding values compared to corn were relatively consistent across trials. However, it appears that WDGS has a greater feeding value than MDGS or DDGS. There has been limited work comparing the three different types of DGS in the same trial. The objectives of these studies were to compare the effects drying ethanol co-products produced from the dry milling process has on DMI, ADG, feed efficiency and carcass characteristics of yearling feedlot cattle fed WDGS, MDGS, or DDGS.

MATERIALS AND METHODS

Animal care for these experiments complied with procedures approved by the University of Nebraska Institutional Animal Care and Use Committee.

Steers for both studies were received at the University of Nebraska's Agricultural Research and Development Center (ARDC; Ithaca, NE) in the fall of 2008 and the fall of 2010 for experiments 1 and 2, respectively. Upon arrival at the feedlot, steers were individually identified, weighed, vaccinated with modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health, Madison, NJ), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health) and administered an injectable dewormer (Dectomax

Injectable, Zoetis Animal Health). Steers for Exp.2 were also dosed orally for parasite control (Safeguard Suspension, Merck Animal Health, De Soto, KS). All steers were weaned on smooth bromegrass pastures. Steers were revaccinated with modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health), clostridial vaccination (Ultrabac® 7/Somubac, Zoetis Animal Health), and pinkeye vaccine (Piliguard Pinkeye – 1, Merck Animal Health) approximately 16 d following initial processing, and then grazed corn residue and supplemented with 2.27 kg/d (DM basis) Sweet Bran® (branded corn gluten feed, Cargill, Blair, NE) during the winter. In early spring, cattle grazed cool-season grasses. Six days before tiral initiation, steers were placed in a dry lot and provided 45.7 cm of bunk space while being limit-fed at 2.0% of BW a diet consisting of 47.5% Sweet Bran, 47.5% of a 1:1 ratio of alfalfa hay and grass hay, and 5.0% supplement (DM basis). Steers were weighed individually on d 0 and 1 of each experiment, and the average of the two weights was used to obtain an initial BW.

Exp. 1

Following the spring grazing season, steers (n = 440; 353 ± 19 kg) were utilized in a randomized block design with three blocks based off of initial BW and included a heavy, medium, and light BW block with 1, 2, and 2 replication of each treatment, respectively. Initial BW were collected as described above. Steers were stratified by BW based on d 0 BW and assigned randomly to one of 55 pens (8 steers/pen) in May 2009. Treatments were arranged in a 3 x 3 +1 factorial treatment design with factors including DGS type (WDGS, MDGS, or DDGS) and concentration of DGS (20, 30, or 40% DM); a diet containing 0% DGS served as the control diet. Pen was assigned randomly to one of

ten dietary treatments (Table 1) that consisted of 0% DGS (CON), or 20, 30, or 40% DDGS, MDGS, or WDGS. The CON was repeated within replication (10 replications) whereas all other treatments had 5 replications. Basal ingredients consisted of a 60:40 (DM basis) blend of HMC and DRC, 15% corn silage, and 5% dry supplement (DM basis). Distillers grains plus solubles replaced corn. All diets were formulated to provide a minimum of 13.0% CP, 0.6% Ca, 0.25% P, and 0.6% K. Supplements contained monensin (33.1 mg/kg of DM; Elanco Animal Health, Indianapolis, IN), tylosin (8.3 mg/kg of DM; Elanco Animal Health), and thiamine (13.8 mg/kg DM). Thiamine was included in all diets targeting 150 mg/steer daily.

The supplements for diets containing 20% DGS contained 0.47% urea to ensure there was not a deficiency in degradable intake protein as determined by NRC (1996). Steers were adapted to the finishing diet by feeding 37.5, 27.5, 17.5, and 7.5% alfalfa hay (DM basis), replacing corn for 3, 4, 7, and 7 days, respectively. The respective DGS was included at the treatment concentration from d 1. Bunk readings were conducted daily at 0600 h to determine if any adjustments were necessary based off of the quantity of feed estimated to be remaining in the bunk at time of feeding. Steers were fed once daily using a Roto-Mix (Roto-Mix®, Dodge City, KS) mixer/delivery box mounted to a truck. Feed refusals were collected at the discretion of the unit manager, sampled, frozen, and analyzed for DM to determine DMI.

Dried DGS and MDGS were produced at the same commercial ethanol plant (Adams Ethanol, Adams, NE), and WDGS was produced from a second ethanol plant (Abengoa Bioenergy, York, NE). Total needs for each DGS was calculated, delivered to the ARDC within a 2-d span, and stored in plastic silo-bags (Ag-Bag, Miller-St. Nazianz,

Inc. Company, St. Nazianz, Wisconsin) before initiation of the trial. The likelihood of changes occurring to the nutrient composition of DGS during storage is minimal. Limited amounts of oxygen reduce spoilage concerns, and the acidic nature of DGS due to low pH (4 – 4.5) suggests fermentation is minimal (Erickson et al., 2008). Samples were taken from each load and a subsample was dried in a 60°C forced-air oven for 48 h to determine DM. An additional subsample was lyophilized using a Virtis Freezemobile model 25 ES (Virtis, Gardiner, NY), ground through a 1-mm screen (Willey Mill; Thomas Scientific, Swedesboro, NJ), and analyzed for CP, NDF, sulfur, and fat (Table 2). Nitrogen was determined using a LECO nitrogen analyzer (AOAC, 1999; method 990.03) and N was multiplied by 6.25 to determine CP, fat was determined by performing a biphasic lipid extraction procedure described by Bremer (2010), S was determined using combustion (TruSpec S Determinator, Leco Corporation, St. Joseph, MI), and NDF was determined using the procedure described by Van Soest et al. (1991) with modifications described by Buckner et al. (2010). The DGS were analyzed for NDF in sequence after fat extraction. The S content for WDGS was 0.1 percentage units greater than MDGS and DDGS. The difference for S content between DGS types are most likely due in part to the sulfuric acid used during the industrial process that is ultimately recovered in the soluble fraction at the end of the process (Erickson et al., 2010). To compensate for this difference, calcium sulfate was included in the diets containing DDGS and MDGS to minimize differences in S concentration of the diet (Sarturi et al., 2013b).

Steers were implanted on d 1 with Component TE-IS (Elanco Animal Health), and re-implanted on d 69 with Component TE-S® (Elanco Animal Health). Dietary

ingredients were sampled once weekly and analyzed for DM. A composite was compiled of each ingredient at the conclusion of the experiment and analyzed for CP, NDF, and fat according to the procedures outlined previously.

Steers were slaughtered on d 154 at a commercial abattoir (Greater Omaha Pack, Omaha, NE). Before shipping, final live BW was measured via weighing steers by pen and applying a 4.0% pencil shrink. Hot carcass weight was collected on day of slaughter. Following a 48-h chill, USDA marbling score, 12^{th} rib fat depth, and LM area were captured by cameras located in the plant and recorded at time of grading. Calculated final BW was determined based on a hot carcass weight adjusted to a common dressing percentage of 63% to minimize error associated with gut fill. Daily gain and G:F were determined using the calculated final BW.

A feeding value for each DGS type compared to corn was determined. The difference in G:F for diets containing DGS compared to diets with no DGS were divided by the DGS inclusion concentration. Similar calculations were made to determine the differences in feeding value between DGS type.

Data were analyzed using the MIXED procedures of SAS (Version 9.2, SAS Inc., Cary, NC). Pen was the experimental unit and BW block was treated as a fixed effect. Initially, the 3 x 3 factorial was tested for an interaction. If no significant interaction was observed, then main effects of DGS type and concentration were evaluated. Orthogonal polynomial contrasts were constructed to evaluate a response curve (linear and quadratic) for DGS concentration. If an interaction occurred, then simple effects of each type of DGS concentration were evaluated. Orthogonal polynomial contrasts were also constructed to determine a response curve (linear, quadratic, and cubic) to compare the

concentration of DGS using CON. Proc IML was used to obtain appropriate coefficients for uneven spacing of DGS concentrations. Differences were considered significant when $P \leq 0.05$.

Exp. 2

Following the 2011 spring grazing season, steers were shipped to the University of Nebraska-Lincoln's Barta Brothers Ranch (Rose, NE) to graze sandhills meadows until August 2011. Upon returning to the ARDC, cattle were limit-fed and weighed according to the procedures outlined previously. Steers (n = 171; 367 ± 30 kg) were utilized in a randomized block design which included a heavy, medium, and light BW block with 1, 4, and 2 replication of each treatment, respectively. Steers were stratified by BW within block based off of d 0 BW, and assigned randomly to one of 21 pens (8 or 9 steers/pen). Pens were assigned randomly to one of three treatments that consisted of: 1) corn-based diet containing no DGS (CON), 2) 35% WDGS (WDGS), or 3) 35% DDGS (DDGS). Basal ingredients consisted of dry-rolled corn (DRC) and (HMC) fed at a 50:50 ratio (DM basis), 7.5% grass hay, and 5% dry supplement (DM basis; Table 3). Distillers grains plus solubles were purchased from the same ethanol plant (Abengoa Bioenergy, York, NE) and replaced corn. The nutrient compositions (CP, S, fat, and NDF; Table 4) for WDGS and DDGS were determined according to the procedures outlined previously. All diets were formulated to provide a minimum of 13.0% CP, 0.6% Ca, 0.15% P, and 0.6% K. Supplements contained monensin (33.1 mg/kg of DM; Elanco Animal Health) and tylosin (8.3 mg/kg of DM; Elanco Animal Health).

Steers were adapted to the finishing diet by replacing grass hay and alfalfa hay with the corn-blend for steps 1, 2, and 3 (3, 4, and 7 days, respectively). Grass and alfalfa

hay were included at 21.25, 16.25, and 11.25% each for steps 1, 2, and 3, respectively. Step 4 included 7.5% grass hay and 5.0% alfalfa hay for 7 d. On d 22, alfalfa hay was removed and steers were fed their respective finishing diet until harvest. Bunk readings, feed delivery, and feed refusals were collected according to the procedures outlined previously.

Steers were implanted on d 36 of the trial with Revalor-S (Merck Animal Health). On d 148, steers were harvested at a commercial abattoir (Greater Omaha Pack, Omaha, NE). Live final BW, carcass measurements, and calculated final BW were collected according to the procedures outline previously. Daily gain and feed efficiency were determined using the calculated final BW.

Data were analyzed using the MIXED procedure of SAS (Version 9.2, SAS Inc.) as a randomized block design using a protected F-test as an unstructured treatment design. Block was treated as a fixed effect, and pen was the experimental unit. Differences were considered significant when $P \leq 0.05$.

RESULTS AND DISCUSSION

Exp. 1

There were no DGS type x DGS concentration interactions ($P > 0.16$) for the 3 x 3 factorial. Therefore, the main effects of DGS type and DGS concentration are presented.

Type of Distillers Grains

No significant differences ($P \geq 0.12$) were observed for initial BW, live final BW, calculated final BW, ADG, or any carcass traits (Table 5) between different types of DGS. Steers fed WDGS had the lowest ($P < 0.01$) DMI. Intake for cattle fed MDGS

were 0.8 kg/d greater (*P* < 0.01) than WDGS, and tended (*P* = 0.06) to be less than DDGS. Efficiency of BW gain was greatest (*P* < 0.01) for cattle fed WDGS, intermediate for MDGS, and least for DDGS.

Concentration of Distillers Grains

There were no differences ($P \geq 0.14$) observed for initial BW, calculated final BW, ADG, or DMI when comparing 20, 30, and 40% DGS (Table 6). There was a tendency for a quadratic (*P* = 0.06) increase for live final BW. Feed efficiency improved linearly (*P* = 0.05) as concentration of DGS increased. There were no differences (*P* > 0.13) among concentrations of DGS fed for HCW, dressing percent, marbling score, or LM area. Fat thickness tended (*P* = 0.09) to linearly increase as concentration of DGS increased.

Exp. 2

There were no differences (*P* = 0.44) for initial BW (Table 7). Live final BW, calculated final BW, ADG, dressing percent, HCW were greater ($P \leq 0.03$) for steers fed diets containing DGS compared to steers fed CON. However, the same variables were not different (*P* > 0.47) between WDGS and DDGS. There was no difference (*P* = 0.33) for DMI among treatments. Steers fed DGS were more efficient than CON (*P* < 0.01). Steers fed WDGS were 9.1% more efficient than steers consuming DDGS (*P* = 0.05). Steers fed DGS also had 19 kg greater (*P* < 0.01) HCW than CON. There were no differences among treatments for marbling score, 12^{th} rib fat thickness, or LM area ($P \geq 0.09$).

As previously mentioned, there were no DGS type x DGS concentration interactions in Exp. 1 when comparing DGS type and DGS concentration when CON was

not included in the analysis. For the remainder of this discussion, we will compare the simple effects of concentration for each type of DGS with CON included in the analysis (Table 8). There were no differences ($P = 0.44$) for DMI when WDGS concentration increased from 0 to 40% in Exp. 1. Similarly, there were no differences in Exp. 2 for DMI when WDGS replaced 35% corn and was compared to CON. Contrasting to these results, Vander Pol et al. (2005) reported a quadratic increase for DMI when evaluating concentrations of WDGS from 0 to 50% in diets replacing corn. Daily intake increased 8.3% from 0 to 30% WDGS concentration and decreased 11.3% from 30 to 50% WDGS concentration. Steers consuming 0% WDGS diet had the lowest DMI (Vander Pol et al., 2005). However, Sarturi et al. (2013a) reported no differences for DMI among cattle fed 0, 20, 30, or 40% WDGS. The meta-analysis reported by Bremer et al. (2011) observed a quadratic increase for DMI as it was maximized for 10 and 20% WDGS inclusion. There was a linear ($P < 0.01$) increase for ADG and G:F for steers fed diets containing WDGS in Exp. 1. The greatest increase for ADG in Exp. 1 was 13.0% and occurred when WDGS increased from 0 to 20% inclusion, and the increase from 20 to 40% concentration was 4.4%. Steers fed diets containing WDGS in Exp. 2 gained 12.2% more than corn-based control. Vander Pol et al. (2005) observed a quadratic increase for ADG as concentration of WDGS increased from 0 to 50%. Steers consuming the 0% concentration of WDGS had the lowest ADG, and steers fed 30 and 40% WDGS concentrations had the greatest ADG (Vander Pol et al., 2005). These data from Vander Pol et al. (2005) agree with the results from Exp. 1 and Exp. 2 in which steers fed diets containing WDGS gained faster than steers consuming diets without WDGS. However, in contrast to Vander Pol et al. (2005), in Exp. 1 there were no differences for ADG

among WDGS concentrations. Similar to the results from Exp. 1, Sarturi et al. (2013a) did not observe a difference for ADG when comparing 20, 30, and 40% WDGS. However, in the study reported by Saturi et al. (2013a), the authors did not observe a difference for ADG among steers consuming diets containing WDGS compared to steers fed the corn-based control. Steers fed diets containing WDGS in Exp. 1 and Exp. 2 were more efficient than steers consuming diets without WDGS. Efficiency of BW gain increased linearly as concentration of WDGS increased, and was greatest for the 40% inclusion for Exp. 1. Vander Pol et al. (2005) observed an increase from 0 to 40% WDGS for G:F, and then a 4.1% decrease from 40 to 50% inclusion. Sarturi et al. (2013a) observed a quadratic increase for G:F when replacing corn with 0, 20, 30, or 40% WDGS. However, the concentration for greatest G:F observed by Sarturi et al. (2013a) was at 20 and 30% WDGS and decreased 4.3% when WDGS concentration increased from 30 to 40%. The meta-analysis from Bremer et al. (2011) also reported a quadratic increase for G:F as concentration of WDGS increased. Similar to the results from Exp. 1, the concentration of WDGS that achieved the greatest G:F was 40% inclusion.

Replacing corn with MDGS increased ($P \leq 0.05$) DMI quadratically in Exp. 1, and was greatest for 30% MDGS concentration. Huls et al. (2008) replaced corn with 0 to 50% MDGS, and there was a quadratic increase for DMI and ADG as concentrations of MDGS increased. However, calculated maximum DMI was obtained with 19% inclusion for Huls et al. (2008), but was greatest for 30% inclusion for Exp. 1. Bremer et al. (2011) observed a quadratic increase for DMI, and reported the greatest DMI was for 20 and 30% inclusion. Daily gain for concentration of MDGS in Exp. 1 increased quadratically ($P = 0.04$). Steers fed diets containing MDGS had greater ADG than steers

fed CON, but were not different (*P* ≥ 0.56) among 20, 30, or 40% MDGS concentrations. Bremer et al. (2011) observed maximum ADG for 30% inclusion, and similarly, Huls et al. (2008) reported maximum ADG for 26% MDGS inclusion. There tended (*P* = 0.10) to be a quadratic increase for G:F in Exp. 1 as concentration of MDGS increased. Numerically, G:F was greatest at 20% MDGS. All concentrations of MDGS evaluated in Exp. 1 had greater G:F than CON. Huls et al. (2008) observed a linear increase for G:F as MDGS concentration increased. There was a quadratic increase for G:F reported by Bremer et al. (2011) and the greatest G:F was observed for 40% MDGS.

There tended (*P* = 0.09) to be a quadratic response for DMI as DDGS replaced corn in Exp. 1. However, in Exp. 2, there were no differences for DMI among steers consuming diets with and without DDGS. Sarturi et al. (2013a) observed greater DMI for steers consuming diets containing DDGS when compared to the corn-based control. Sarturi et al. (2013a) reported greater DMI for steers consuming diets containing 40% DDGS compared to 20 and 30% inclusion. Bremer et al. (2011) observed a quadratic increase as concentration of DDGS increased and reported greatest DMI for 30 and 40% inclusion. Buckner et al. (2008) observed no differences for DMI among steers fed 0 to 40% inclusion of DDGS. Daily gain was greater (*P* < 0.01) for steers fed diets containing DDGS in Exp. 1 and Exp. 2 when compared to CON. These data from Exp. 1 and Exp. 2 agree with Bremer et al. (2011) in that steers consuming DDGS gained faster than steers consuming diets without DDGS. Greater DMI coupled with greater ADG for steers consuming DDGS in Exp. 1 resulted in a linear increase (*P* = 0.05) for G:F as concentration of DDGS increased. For Exp. 2, G:F was greater for steers consuming diets containing DDGS compared to steers fed CON. Bremer et al. (2011) observed a

linear increase for G:F as concentration of DDGS increased. Contrasting to these results from Exp. 1 and Bremer et al. (2011), Buckner et al. (2008) and Sarturi et al. (2013a) did not observe a difference for ADG or G:F among steers consuming diets containing 0 to 40% DDGS.

Bremer et al. (2011) reported the feeding value of WDGS decreased from 143% to 130% that of corn as concentration of WDGS increased from 20 to 40% inclusion. The calculated feeding value for WDGS from Exp. 1 suggests WDGS contains 145, 146, and 143% the feeding value of corn for 20, 30, and 40% WDGS, respectively. Results from Exp. 2 suggest 35% WDGS contains 131% the feeding value of corn. Results from Exp. 1 suggest the feeding values of WDGS are greater than those reported by Bremer et al. (2011) and in Exp. 2. The calculated feeding values relative to corn for MDGS in Exp. 1 are similar to the results of Bremer et al. (2011), and are 148, 121, and 121 for 20, 30, and 40% MDGS inclusion, respectively. The results from Exp. 1 suggest that DDGS contains 107 to 110% the feeding value of corn. These data agree with Bremer et al. (2011) as they reported the feeding value for DDGS to be 112% for all concentrations of DDGS tested. The feeding value for DDGS is 122% that of corn in Exp. 2. The greater feeding value for DDGS in Exp. 2 when compared to the feeding value for DDGS in Exp. 1 is not understood.

Theoretically, growth performance and carcass characteristics of cattle fed WDGS or DDGS should be similar since water is the primary nutrient removed at the ethanol plant. However, there seems to be differences in the feeding value of WDGS, MDGS, and DDGS. Ham et al. (1994) compared 40% WDGS and DDGS in DRC-based diets and observed similar DMI among types of DGS. Although DMI was similar, ADG was

20% greater for steers fed WDGS compared to steers fed DDGS. This resulted in an 8.4% improvement in G:F for steers fed WDGS compared to those fed DDGS (Ham et al., 1994). Intake for cattle from Exp. 1 was greatest for DDGS, intermediate for MDGS, and least for WDGS. Contrasting to these results from Exp. 1, there was no difference for DMI among steers fed diets containing WDGS or DDGS in Exp. 2. Our results for ADG in Exp. 1 and Exp. 2 disagree with Ham et al. (1994), as there were no differences for ADG among steers fed WDGS or MDGS in Exp. 1 and Exp. 2. Similar ADG and different DMI among steers fed diets containing WDGS, MDGS, and DDGS in Exp. 1, and slight numeric differences for ADG and DMI among steers fed diets containing WDGS and DDGS in Exp. 2 resulted in greater G:F for steers fed WDGS diets compared to steers fed DDGS diets in both experiments. The response differences between WDGS and DDGS for DMI and ADG observed in Exp. 1 and Exp. 2 are unclear.

Regardless of the differences for DMI and ADG between studies, improved G:F for steers fed diets containing WDGS compared to steers fed diets containing DDGS are consistent across experiments. Steers consuming diets containing WDGS in Exp. 1 were 10.6% more efficient than steers fed diets containing DDGS, and were 9.5% more efficient than steers consuming diets containing MDGS. Steers fed WDGS were 3.2% more efficient than steers fed DDGS diets in Exp. 2. Sarturi et al. (2013a) replaced 20, 30, and 40% corn with WDGS and observed no differences for ADG. However, DMI was 10% greater for DDGS compared to WDGS, and resulted in an 11% greater G:F for WDGS compared to DDGS. The meta-analysis conducted by Bremer et al. (2011) suggests that steers consuming diets containing DDGS had the greatest DMI, MDGS diets were intermediate of DDGS and WDGS, and steers consuming WDGS diets

consume the least amount of feed. However, ADG was not different for steers fed different types of DGS, and therefore steers fed diets replacing corn with WDGS were more efficient, steers fed diets containing MDGS were intermediate of WDGS and DDGS, and steers fed diets containing DDGS were the least efficient.

Feeding values for WDGS compared to DDGS were calculated similarly to the methods used to determine the feeding values of DGS compared to corn. The feeding values for WDGS in Exp. 1 were 35.6 and 16.9% greater than DDGS and MDGS, respectively; the feeding value for MDGS was 17.8% greater than DDGS. Although the difference among WDGS and DDGS was not as great in Exp. 2 as it was in Exp. 1, WDGS had a 9.0% greater feeding value than DDGS. Ham et al. (1994) reported WDGS to contain 121% the feeding value of DDGS. Sarturi et al. (2013a) observed WDGS to contain 136% the feeding value of DDGS.

There were no differences among type of DGS for marbling score, LM area, and fat thickness in Exp. 1 and Exp. 2. Ham et al. (1994) observed no differences for quality grade or back fat thickness among steers fed WDGS or DDGS. Similarly, Sarturi et al. (2013a) reported no differences for carcass measurements between steers fed WDGS or DDGS. When comparing CON with concentration of DGS, there was a quadratic increase for HCW and linear increase for dressing percent and fat thickness as concentration of DGS increased in Exp. 1. Vander Pol et al. (2005) observed a quadratic increase for HCW, LM area, and fat thickness as concentration of WDGS increased. Buckner et al. (2008) did not observe a difference for fat thickness, marbling score, or LM area among cattle fed diets containing 0 to 40% DDGS. Steers that were fed DDGS diets had heavier HCW (Buckner et al., 2008).

The difference in moisture content between WDGS and DDGS could potentially affect passage rate out of the rumen, and thus affect the digestibility and result in reduced feeding values for DDGS. Firkins et al. (1984) reported a tendency for WDG and wet corn gluten feed (WCGF) to have lower solid passage rates than steers fed DDG or dry corn gluten feed (DCGF). However, the rate of in situ disappearance was not different for WDG and DDG (Firkins et al. 1985). This agrees with Cao et al. (2009) in which rate of passage was not different for WDG and DDG. Additionally, Ham et al. (1994) reported rates of passage for WDGS were not different when compared to DDGS. Therefore, it does not appear that the difference in reduced feeding value DDGS when compared to WDGS is a result of a more rapid passage out of the rumen.

A possible explanation for decreased feeding values for DDGS when compared to WDGS could be related to the findings of Green et al. (1987) and Ham et al. (1995). These authors concluded that the feeding value of DCGF is less than WCGF in feedlot diets. Macken et al. (2004) determined that drying corn bran has no negative impacts on the feeding value in feedlot diets, and that reconstituting dried corn bran had no effect on animal performance. Macken et al. (2004) concluded that the differences for feeding value among WCGF and DCGF determined by Green et al. (1987) and Ham et al. (1995) was not due to drying of the corn bran, but rather drying of the steep liquor. Perhaps drying the distillers solubles with WDG decreases the feeding value of DDGS and MDGS compared to WDGS.

The extent of drying has a negative impact on the feeding value of DGS in feedlot diets. Wet distillers grains plus solubles contains the greatest improvement in feeding value relative to corn, MDGS is intermediate, and DDGS contains the least improvement

in feeding value compared to corn. The cause of this decrease in feeding value when WDGS is dried or partially dried remains unknown. However, replacing DRC or HMC with up to 40% (DM) DGS in the diet up, regardless of type will improve steer ADG and G:F compared to diets without DGS.

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Table 1. Dietary treatments and chemical composition of final finishing diets comparing different concentrations of wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), and dried distillers grains plus solubles (DDGS) in Exp. 1.

		WDGS[1]			MDGS[1]			DDGS[1]		
Ingredients, % DM	CON[1]	20	30	40	20	30	40	20	30	40
HMC[2]	48.0	36.0	30.0	24.0	36.0	30.0	24.0	36.0	30.0	24.0
DRC[2]	32.0	24.0	20.0	16.0	24.0	20.0	16.0	24.0	20.0	16.0
WDGS	-	20.0	30.0	40.0	-	-	-	-	-	-
MDGS	-	-	-	-	20.0	30.0	40.0	-	-	-
DDGS	-	-	-	-	-	-	-	20.0	30.0	40.0
Corn Silage	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Dry Supplement[3]										
Finely ground corn	0.72	2.20	2.67	2.67	2.16	2.60	2.60	2.16	2.60	2.60
Limestone	1.68	1.68	1.68	1.68	1.62	1.55	1.55	1.62	1.55	1.55
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Tallow	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Urea	1.72	0.47	-	-	0.47	-	-	0.47	-	-
Calcium Sulfate	-	-	-	-	0.10	0.20	0.20	0.10	0.20	0.20
Potassium chloride	0.23	-	-	-	-	-	-	-	-	-
Trace mineral premix[4]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin A-D-E premix[5]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Rumensin-80 premix[6]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Tylan-40 premix[7]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Thiamine[8]	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Calculated Nutrient Analysis[9]										
Crude protein, %	12.96	14.06	15.06	17.32	14.04	15.03	17.27	14.02	15.00	17.23
Fat, %	3.96	5.47	6.29	7.07	5.57	6.44	7.27	5.47	6.29	7.07
NDF, %	14.91	20.26	22.08	24.40	20.31	22.16	24.52	19.89	21.53	23.68
Sulfur, %	0.13	0.26	0.33	0.40	0.26	0.33	0.40	0.26	0.33	0.40

[1]WDGS = wet distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DDGS = dried distillers grains plus solubles fed at 20, 30, or 40 % (DM basis); CON = corn control.
[2] HMC = high moisture corn; DRC = dry rolled corn.
[3] Supplement formulated to be fed at 5.0% of diet DM.
[4] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.
[5] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin E per gram.
[6] Premix contained 176 g/kg monensin.
[7] Premix contained 88 g/kg tylosin.
[8]Premix contained 88 g/kg of thiamine.
[9]Calculated nutrient analysis utilizing analyzed values for each ingredient.

Table 2. Nutritional composition of wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), and dried distillers grains plus solubles (DDGS) used in Exp. 1.

Variables[1]	WDGS[2]	MDGS[2]	DDGS[2]
CP, %	31.1	31.0	30.9
Sulfur, %	0.81	0.70	0.71
Fat, %	11.9	12.4	11.9
NDF, %	34.1	34.4	32.3

[1] Analyzed nutritional composition, DM basis.
[2] WDGS = wet distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DDGS = dried distillers grains plus solubles.

Table 3. Dietary treatments and chemical composition of final finishing diets comparing different concentrations of wet distillers grains plus solubles (WDGS) and dried distillers grains plus solubles (DDGS) to a corn control in Exp. 2.

Ingredients, % DM	CON[1]	WDGS[1]	DDGS[1]
HMC[2]	43.75	26.25	26.25
DRC[2]	43.75	26.25	26.25
WDGS	-	35.0	-
DDGS	-	-	35.0
Grass Hay	7.5	7.5	7.5
Dry Supplement[3]			
Finely ground corn	0.73	2.60	2.60
Limestone	1.90	1.87	1.87
Salt	0.30	0.30	0.30
Tallow	0.13	0.13	0.13
Urea	1.50	-	-
Potassium chloride	0.34	-	-
Trace mineral premix[4]	0.05	0.05	0.05
Vitamin A-D-E premix[5]	0.02	0.02	0.02
Rumensin-90 premix[6]	0.02	0.02	0.02
Tylan-40 premix[7]	0.01	0.01	0.01
Calculated Nutrient Analysis[8]			
Crude protein, %	12.8	17.3	16.2
Fat, %	3.9	7.0	6.0
NDF, %	15.1	21.8	25.1
Sulfur, %	0.12	0.36	0.32

[1] WDGS = wet distillers grains plus solubles fed at 35% (DM basis); DDGS = dried distillers grains plus solubles fed at 35% (DM basis); CON = corn control.
[2] HMC = high moisture corn; DRC = dry rolled corn.
[3] Supplement formulated to be fed at 5.0% of diet DM.
[4] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.
[5] Premix contained 29,974 IU vitamin A, 5,995 IU vitamin D, 7.5 IU vitamin E per gram.
[6] Premix contained 200 g/kg monensin.
[7] Premix contained 88 g/kg tylosin.
[8] Calculated nutrient analysis utilizing analyzed values for each ingredient.

Table 4. Nutritional composition of wet distillers grains plus solubles (WDGS) and dried distillers grains plus solubles (DDGS) used in Exp. 2.

Variables[1]	WDGS[2]	DDGS[2]
CP, %	34.1	31.0
Sulfur, %	0.81	0.71
Fat, %	10.5	10.2
NDF, %	30.0	39.5

[1] Analyzed nutritional composition, % DM.
[2] WDGS = wet distillers grains plus solubles; DDGS = dried distillers grains plus solubles.

Table 5. Main effect of type of distillers grains plus solubles on growth performance and carcass characteristics from steers fed 20, 30, or 40% (DM) wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), or dried distillers grains plus solubles (DDGS) in Exp. 1.

	Type of Distillers Grains[1]				*P* – value[2]	
	WDGS	MDGS	DDGS	SEM	Type	Type*Con
Performance						
Initial BW, kg	348	348	349	1	0.83	0.87
Live Final BW[3], kg	637	641	654	7	0.24	0.78
Final BW[4], kg	636	640	632	5	0.51	0.85
DMI, kg/d	11.2[a]	12.0[b]	12.3[b]	0.1	< 0.01	0.48
ADG[5], kg	1.86	1.89	1.84	0.03	0.49	0.84
G:F	0.166[a]	0.158[b]	0.150[c]	0.002	< 0.01	0.16
Carcass Characteristics						
HCW, kg	400	402	398	3	0.57	0.87
Dress, %	63.03	62.69	61.05	0.01	0.12	0.82
Marbling Score[6]	610	599	602	9	0.69	0.57
LM area, cm^2	85.6	85.2	86.2	0.6	0.55	0.80
12th rib fat, cm	1.61	1.63	1.53	0.04	0.14	0.68

[1] WDGS = wet distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DDGS = dried distillers grains plus solubles fed at 20, 30, or 40 % (DM basis).
[2] Type = *P* – value for main effect of distillers grains plus solubles type; Type*Con = interaction *P* – value for type and concentration of distillers grains plus solubles.
Live Final BW measured by weighing pen on pen scale d of shipping and applying a 4 percent pencil shrink.
[4] Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%.
[5] Calculated using carcass adjusted final BW.
[6] Marbling score: 550 = Small[50]; 600 = Modest[0], 650 = Modest[50] , etc.
[a,b,c] Means with different superscripts differ for main effect of DGS type ($P < 0.05$).

Table 6. Main effect of distillers grains plus solubles concentration on growth performance and carcass characteristics from steers fed 20, 30, or 40% (DM) wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), or dried distillers grains plus solubles (DDGS) in Exp. 1.

	Distillers Grains Concentration[1]				*P* – value[2]	
	20	30	40	SEM	Lin	Quad
Performance						
Initial BW, kg	348	348	349	1	0.14	0.22
Live Final BW[3], kg	649	634	655	9	0.55	0.06
Final BW[4], kg	634	631	642	5	0.24	0.26
DMI, kg/d	11.9	11.8	11.9	0.2	0.74	0.35
ADG[5], kg	1.86	1.84	1.90	0.03	0.30	0.30
G:F	0.156	0.157	0.160	0.003	0.05	0.48
Carcass Characteristics						
HCW, kg	399	398	404	3	0.21	0.25
Dress, %	61.65	63.06	61.59	0.01	0.92	0.13
Marbling Score[6]	609	599	603	11	0.70	0.52
LM area, cm^2	85.1	85.4	86.3	0.8	0.19	0.66
12^{th} rib fat, cm	1.56	1.57	1.65	0.05	0.09	0.44

[1] Percent concentration of distillers grains plus solubles included in diet.
[2] Contrast for the linear and quadratic effect of treatment *P* – value with main effects of 20, 30, and 40% distillers grains plus solubles concentration.
[3] Live Final BW measured by weighing pen on pen scale d of shipping and applying a 4 percent pencil shrink.
[4] Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%.
[5] Calculated using carcass adjusted final BW.
[6] Marbling score: 550 = $Small^{50}$; 600 = $Modest^{0}$, 650 = $Modest^{50}$, etc.

Table 7. Growth performance and carcass characteristis comparing corn-based control (CON), dried distillers grains plus solubles (DDGS), and wet distillers grain plus solubles (WDGS) in Exp. 2.

	Treatments[1]				
	CON	DDGS	WDGS	SEM	*P* - Value
Performance					
Initial BW, kg	367	367	367	1	0.44
Live Final BW[2], kg	655[a]	681[b]	684[b]	5	< 0.01
Final BW[3], kg	646[a]	675[b]	679[b]	5	< 0.01
ADG[4], kg	1.88[a]	2.08[b]	2.11[b]	0.03	< 0.01
DMI, kg/d	12.9	13.2	13.1	0.2	0.33
G:F	0.146[a]	0.157[b]	0.162[c]	0.002	< 0.01
Feeding value[5], %		122	131		
Carcass Characteristics					
HCW, kg	407[a]	425[b]	428[b]	3	< 0.01
Dressing Percent	61.7[a]	62.4[b]	62.5[b]	0.2	0.03
Marbling Score[6]	608	611	618	12	0.81
LM, area $cm.^2$	83.9	84.5	85.1	0.6	0.09
12th rib fat, cm.	1.40	1.47	1.52	0.05	0.24

[1] CON- Corn control diet with no distillers grains plus solubles. WDGS- Wet distillers grains plus solubles included at 35% of Diet DM. DDGS- Dry distillers grains with solubles included at 35% of diet.
[2] Live final BW measured by weighing pen on pen scale d of shipping and applying a 4 percent pencil shrink.
[3] Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%.
[4] Calculated using carcass adjusted final BW.
[5] Percent of corn feeding value, calculated from DGS G:F relative to corn-based control G:F, divided by DGS inclusion (35%).
[6] Marbling score: 550 = Small^{50}; 600 = Modest^{0}, 650 = Modest^{50} , etc.
[a,b,c] Within a row means without common superscript differ ($P \leq 0.05$).

Table 8. Growth performance of finishing-steer performance when fed increasing dietary inclusions (0, 20, 30, or 40% DM basis) of wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), or dried distillers grains plus solubles (DDGS) in Exp. 1.

	Concentration[1]					*P*-value	
	0	20	30	40	SEM	Lin[2]	Quad[2]
		WDGS					
DMI, kg/d	11.1	11.5	11.2	11.1	1	0.80	0.17
ADG[3], kg	1.62	1.83	1.85	1.91	0.04	< 0.01	0.25
G:F	0.146	0.159	0.166	0.171	0.002	< 0.01	0.68
Feeding value[4], %		145	146	143			
		MDGS					
DMI, kg/d	11.1	11.9	12.0	11.9	0.2	< 0.01	0.05
ADG[3], kg	1.62	1.90	1.86	1.89	0.05	< 0.01	0.04
G:F	0.146	0.160	0.155	0.158	0.003	< 0.01	0.10
Feeding value[4], %		148	121	121			
		DDGS					
DMI, kg/d	11.1	12.3	12.0	12.5	0.2	< 0.01	0.09
ADG[3], kg	1.62	1.82	1.80	1.90	0.05	< 0.01	0.53
G:F	0.146	0.149	0.149	0.152	0.002	0.05	0.62
Feeding value[4], %		110	107	110			

[1] Percent concentration of distillers grains (DM).

[2] Contrast for the linear and quadratic effect of treatment *P* – value with main effects of 0, 20, 30, and 40% distillers grains plus solubles concentration.
[3] Average daily gain calculated using carcass adjusted final BW.
[4] Percent of corn feeding value, calculated from the difference for the G:F value for respective DGS concentration divided by the G:F value for CON, divided by DGS concentration.

CHAPTER IV

COMPARING THE EFFECTS OF DRYING WET DISTILLERS GRAINS PLUS SOLUBLES ON FEEDLOT CALF PERFORMANCE AND NUTRIENT METABOLISM[1]

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ABSTRACT: Three experiments compared the effects of drying distillers grains plus solubles (DGS) on finishing performance and nutrient metabolism. In Exp. 1, 5 different types of distillers grains (DG) were produced by changing the time distillers solubles (DS) were added to the DG. Crossbred, steer calves (n=420; 305 ± 21 kg) were utilized in a randomized block design. Pens (n=42) were assigned randomly to one of 7 treatments that consisted of: 35% 1) wet distillers grains with solubles added to wet grains (38.5% DM; WDGS); 2) dried distillers grains plus solubles produced by drying WDGS (90.0% DM; DRY); 3) dried distillers grains produced by drying wet distillers grains with no solubles (89.0% DM) and adding DS at time of feeding (DDG+Soluble); 4) modified distillers grains plus solubles produced by partially drying WDGS (47.5% DM; MDGSPre); 5) modified distillers grains plus solubles produced by partially drying wet distillers grains and adding DS after the dryer, (55.0% DM; MDGSPost); 6) DRY with added water to equalize moisture content of MDGSPost (55.0% DM; DRY+H_2O); and a corn-based control (CON). In Exp. 2, six ruminally cannulated steers (BW = 482 kg, ± 35) were utilized in an unbalanced 4 x 6 Latin square experiment to determine the effects on nutrient metabolism when DGS are dried. Dietary treatments consisted of 40% WDGS, modified distillers grains plus solubles (MDGS), or dried distillers grains plus solubles (DDGS) and a corn-based control (CON). In Exp. 3, 12 crossbred yearling steers (525 ± 34 kg) were utilized in a three-period crossover design to determine digestibility of WDGS or DDGS in finishing diets compared to a corn control. Steers fed diets containing DGS in Exp. 1 had greater (P < 0.01) ADG, DMI, and G:F than CON. Steers fed diets containing WDGS, MDGSPre, and MDGSPost had greater (P < 0.01) G:F than other treatments. For Exp. 2, there were no differences ($P \geq 0.35$) for DM and

OM intake and digestibility among treatments. Although not significant (*P* = 0.17), NDF digestibility was numerically greatest for WDGS, intermediate for MDGS, and similar for CON and DDGS. Dry matter and OM digestibility for Exp. 3 was greater (*P* < 0.01) for CON compared to WET and DRY, but DM digestibility was not different (*P* = 0.15) among types of DGS. Organic matter digestibility tended (*P* = 0.11) to be greater for WET compared to DRY. Digestibility of NDF was greater (*P* = 0.09) for CON, but was not different (*P* = 0.51) among WET and DRY. Drying DS onto DG had limited effect on ADG, DMI, or G:F.

KEY WORDS Dried distillers grains plus solubles, Finishing cattle, Wet distillers grains plus solubles (2571 keystrokes)

INTRODUCTION

Distillers grains plus solubles (DGS) produced during the dry milling process have been shown to contain equal or greater feeding values than dry-rolled corn (DRC), high-moisture corn (HMC), or a blend of the two grain processing products that it replaces when included in feedlot diets up to 50% DM concentration (Buckner et al., 2008; Huls et al., 2008; Vander Pol et al., 2005). Feeding value is the change in G:F of diets containing DGS compared with the diet with no DGS divided by the concentration of DGS in the diet. Feeding value of DGS is expressed as percent relative to corn. However, drying wet distillers grains plus solubles (WDGS) partially to produce modified distillers grains plus solubles (MDGS; 47-55% DM) or more completely to produce dried distillers grains plus solubles (DDGS; 88-90% DM) reduces the feeding relative to corn (Ham et al., 1994; Nuttelman et al., 2011; Sarturi et al., 2013a).

Wet corn gluten feed (WCGF) is produced during the wet milling process, and is mostly a combination of corn bran and steep liquor (Stock et al., 2000). Drying WCGF reduces the feeding value in finishing diets (Green et al., 1987 and Ham et al., 1995). Macken et al. (2004) reported that drying corn bran does not have an effect on the feeding value compared to wet corn bran, or reconstituted corn bran. The reduced feeding values observed by Green et al. (1987) and Ham et al. (1995) may be a result of drying the steep liquor. We developed the hypothesis that drying distillers solubles (DS) produced during the dry milling process could have a negative impact on the feeding value of MDGS and DDGS in finishing diets. Therefore, three studies were conducted to determine if drying DS onto distillers grains (DG) has an impact on the feeding value and nutrient metabolism of MDGS and DDGS compared to WDGS in finishing diets.

MATERIALS AND METHODS

Animal care for these experiments complied with procedures approved by the University of Nebraska Institutional Animal Care and Use Committee.

Exp. 1

Five different types of distillers grains were produced from one ethanol plant (Green Plains Renewable Energy, Inc., Central City, NE) by changing the timing of drying the distillers grains in order to determine if drying distillers solubles affects the feeding value of DGS in feedlot diets. The five different types of distillers grains produced were: 1) wet distillers grains with solubles added to wet grains (38.4% DM; WDGS); 2) dried distillers grains plus solubles produced by drying WDGS to

approximately 90.0% DM (DDGS); 3) dried distillers grains produced by drying wet distillers grains with no solubles to approximately 89.0% DM (DDG); 4) modified distillers grains plus solubles produced by partially drying WDGS to approximately 47.5% DM (PREMOD); 5) modified distillers grains plus solubles produced by partially drying wet distillers grains and adding DS to the partially dried distillers grains, resulting in a product that was approximately 55.0% DM (POSTMOD). All DG fed during the study were produced during the same week, delivered to the research feedlot, and stored in silo bags (Ag-Bag, Miller-St. Nazianz, Inc. Company, St. Nazianz, Wisconsin) to reduce variation in nutrient composition by load. The likelihood of changes occurring to the nutrient composition of DGS during storage is minimal. Limited amounts of oxygen reduce spoilage concerns, and the acidic nature of DGS due to low pH (4 – 4.5) suggests fermentation is minimal (Erickson et al., 2008). Each load of DG and DS were sampled upon arrival and composited by type. Samples were taken from each load of DGS, DDG, and DS and a subsample was dried in a 60°C forced-air oven for 48 h to determine DM. An additional subsample was freeze-dried, ground through a 1-mm screen (Willey Mill; Thomas Scientific, Swedesboro, NJ), and analyzed for CP, NDF, sulfur, and fat (Table 1). Nitrogen was determined using a LECO nitrogen analyzer (AOAC, 1999; method 990.03), fat was determined by performing a biphasic lipid extraction procedure described by Bremer (2010), S was determined using combustion (TruSpec S Determinator, Leco Corporation, St. Joseph, MI), and NDF was determined using the procedure described by Van Soest et al. (1991) with modifications described by Buckner et al. (2010). The DGS were analyzed for NDF in sequence after fat extraction.

Crossbred steer calves were procured from auction barns, and were received at the University of Nebraska's Agricultural Research and Development Center (ARDC; Ithaca, NE) during the fall of 2009 over a 3-week period as they were purchased from the barns.

Upon arrival at the feedlot, steers were individually identified, weighed, vaccinated with modified live viral vaccine (Bovi-Shield Gold 5, Zoetis Animal Health, Madison, NJ), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health) and administered an injectable dewormer (Dectomax Injectable, Zoetis Animal Health). Steers were weaned and backgrounded in dry-lot pens located on the ARDC for a minimum of 3-weeks. Approximately 16-d following initial processing, steers were revaccinated with modified live viral vaccine (Bovi-Shield Gold 5), *Haemophilus somnus* bacterin (Somubac, Zoetis Animal Health), clostridial vaccination (Ultrabac® 7/Somubac, Zoetis Animal Health), and pinkeye vaccine (Piliguard Pinkeye – 1, Merck Animal Health). Six days before initiation of the trial, steers were limit-fed a common diet (% DM basis) consisting of 47.5% Sweet Bran®, 47.5% alfalfa hay, and 5.0% supplement to eliminate variation due to differences in gut-fill. Feed was offered at 2.0% of estimated BW, and steers were provided 45.7 cm of bunk space while being limit-fed. Steers were weighed individually on d 0 and 1 of the experiment, and the average of the two weights was used to obtain an initial BW.

From November 18, 2009 to May 25, 2010 calf-fed steers (n=420; 305 ± 21 kg) were used in a randomized block design with an unstructured treatment design. Steers were blocked by BW, stratified within block based on d 0 BW, and assigned randomly to one of 42 feedlot pens (10 steers/pen). There were two weight blocks with three replications of each treatment represented in each block. Pen was assigned randomly to

one of seven treatments. Treatments are presented in Table 2 and consisted of: 1) corn-based control (CON); 2) wet distillers grains plus solubles (WET); 3) modified distillers grains plus solubles with the DS added at the ethanol plant before the drier (MDGSPre); 4) modified distillers grains plus solubles with the DS added at the ethanol plant post dryer (MDGSPost); 5) dried distillers grains plus solubles with the DS dried onto the distillers grains (DRY); 6) dried distillers grains with DS dried onto the distillers grains and water added at the time of feeding (DRY+H_2O); 7) dried distillers grains fed mixed and fed with DS at time of feeding (DDG+Solubles). As a result there were three treatments that included 35% DGS where solubles were dried, and there were three treatments that included 35% DGS where solubles were not dried. Distillers solubles that were added to the dried distillers grains (DDG) at time of feeding were purchased from Nebraska Energy LLC. (Aurora, NE) on an as-needed basis. Distillers solubles were sampled and analyzed by load upon arrival at the feedlot. Concentration of DS added to DDG at time of feeding was adjusted according to differences in concentration of fat between loads so the fat portion from DDG+Solubles was similar to DDGS. During production of the WDGS and PreMod, 100% of the DS could not be added. Therefore, solubles were added to WDGS and PreMod at the time of feeding to equalize the concentration of fat to PostMod. Water was added to DDGS for DDGS+H_2O treatment at the time of feeding to bring the ingredient DM (55.0%) equal to PostMod. Basal ingredients in the finishing diet consisted of a 1:1 ratio of HMC:DRC, 4.1% grass hay, 4.1% sorghum silage, and 5.0% dry supplement (DM basis). Distillers grains and DS were included in the diet to total 35% (DM) and replaced the corn-blend.

Finishing diets were formulated to provide a minimum of 13.0% CP, 0.6% Ca, 0.25% P, and 0.6% K. Supplements contained monensin (33.1 mg/kg of DM; Elanco Animal Health, Greenfield, IN) and tylosin (8.3 mg/kg of DM; Elanco Animal Health).

Steers were adapted to the finishing diet by feeding 37.5, 27.5, 17.5, and 7.5% alfalfa hay (DM basis), replaced with corn for 3, 4, 7, and 7 days, respectively. On d 22, alfalfa hay was removed and steers were fed their respective finishing diet until harvest. Bunk readings were conducted daily at 0600 h to determine if adjustments were necessary based off of the quantity of feed estimated to be remaining in the bunk at time of feeding. Steers were fed once daily using a Roto-Mix (Roto-Mix®, Dodge City, KS) mixer/delivery box mounted to a truck. Feed refusals were collected at the discretion of the unit manager, weighed, subsampled, and frozen. A portion of this subsample was dried in a 60°C forced-air oven for 48 h to determine DM.

Steers were implanted on d 1 with Revalor-XS (Merck Animal Health, DeSoto, KS). Dietary ingredients were sampled once weekly and analyzed for DM. Steers were slaughtered on d 187 at a commercial abattoir (Greater Omaha Pack, Omaha, NE). Hot carcass weight was collected on day of slaughter. Following a 48-h chill, USDA marbling score, 12th rib fat depth, and LM area were captured by cameras located in the plant and recorded at time of grading. Calculated final BW was determined based on a hot carcass weight adjusted to a common dressing percentage of 63% to minimize error associated with gut fill.

A feeding value for each DGS type compared to corn was determined. The increase in G:F of diets containing DGS compared to diets with no DGS were divided by

the DGS inclusion concentration. Similar calculations were made to determine the differences in feeding value between DGS type.

Performance and carcass data were analyzed using the MIXED procedures of SAS (Version 9.2, SAS Inc., Cary, NC). The model included block and dietary treatment as fixed effects, and pen was the experimental unit (6 pens/treatment). Differences were considered significant when $P \leq 0.05$.

Exp. 2

Six ruminally fistulated steers (BW = 482 kg, ± 35) were utilized in an unbalanced 4 x 6 Latin square experiment to determine the effects of partially or completely drying DGS on nutrient metabolism from August 21, 2009 to November 13, 2009 (85 d). Dietary treatments are presented in Table 3 and consisted of 1) 40% DM wet distillers grains plus solubles (WET); 2) 40% DM modified distillers grains plus solubles (MOD); 3) 40% dried distillers grains plus solubles (DRY); or 4) a corn-based control (CON). All finishing diets contained 15.0% corn silage, 5.0% supplement, and a 60:40 blend of HMC and DRC. Distillers grains plus solubles replaced 40% corn. Dried DGS and MDGS were produced at the same commercial ethanol plant (Adams Ethanol, Adams, NE), and WDGS was produced from a different ethanol plant (Abengoa Bioenergy, York, NE). The sources of each DGS were delivered to the ARDC before initiation of the study, were stored in plastic silo bags (Ag-Bag, Miller-St. Nazianz, Inc. Company) at the ARDC, and were hauled to the University of Nebraska-Lincoln Animal Science complex located in Lincoln, NE in 210 liter barrels with plastic liners. The sources of DGS were used in a finishing experiment being conducted simultaneously at the ARDC. Nutrient compositions of DGS are presented Table 4. Supplements were

mixed at the feed mill located at the ARDC and each supplement was transported to the Animal Science complex and stored in temperature controlled room. All supplements contained monensin at 33.1 mg/kg of DM (Rumensin; Elanco Animal Health), tylosin at 8.3 mg/kg of DM (Tylan; Elanco Animal Health), and thiamine (13.8 mg/kg DM). Samples of DGS were collected and analyzed for CP, NDF, S, and fat according to the procedures outlined previously. The S content for WDGS was 0.1 percentage units greater than MDGS and DDGS. The difference for S content between DGS types are most likely due in part to the sulfuric acid used during the industrial process that is ultimately recovered in the soluble fraction at the end of the process (Erickson et al., 2010). To compensate for this difference, calcium sulfate was included in the diets containing DDGS and MDGS to minimize differences in S concentration of the diet (Sarturi et al., 2013b).

Steers were housed in 2.4 x 1.5 m^2 individual pens with slotted floors and rubber mats, in a temperature controlled room (25°C) with ad libitum access to water. Period duration was 21-d, including a 14-d adaptation period followed by a 7-d (d 15 through 21) pH data and a 5-d (d 17 through 21) fecal sample collection period. Cattle were fed once daily at 0800 h and allowed ad libitum intake of experimental diets. Steers and pens were washed twice daily. Feed ingredients were sampled during the collection period at the time of mixing, composited by period and frozen at -20°C. Feed refusals were collected daily at time of feeding during the collection period (d 15 through 21). A subsample of each d feed refusals was collected and composited by steer within period, and dried for 48 h in a 60°C forced-air oven to determine DM.

Chromic oxide was dosed intraruminally twice daily at 0800 and 1600 h to provide a total of 30 g/d on d 13, and then 15 g/d on d 14 through 20 to estimate fecal output. Fecal output (g/d) was calculated as chromium dose (g/d) divided by the fecal Cr concentration (g/g; Owens and Hanson, 1992). Fecal samples were collected at 0700, 1200, and 1600 h on d 17 through 21. Fecal samples were composited within steer by volume across day and frozen at -20°C.

Ruminal fluid samples were collected in 3 h intervals on d 21 between 0700 and 2200 h. Ruminal fluid samples (approximately 50 mL) were collected through the rumen cannula using a suction strainer technique (Raun and Burroughs, 1962), and immediately frozen at -20°C. Ruminal pH was measured continuously on d 15 through 21 using wireless pH probes (Dascor, Inc., Escondido, CA) submersed in the rumen. Measurements for pH were taken every minute (1,440 measurements/d) and then downloaded at the end of each collection period. Ruminal pH measurements included average ruminal pH and maximum and minimum ruminal pH by d. Ruminal pH variance and ruminal pH area below 5.6 were calculated as described by Cooper et al. (1999).

Fecal and feed samples were lyophilized at the conclusion of the study using a Virtis Freezemobile model 25 ES (Virtis, Gardiner, NY), and ground to pass through a 1-mm screen of a Wiley mill (Thomas Scientific). Samples were composited on dry weight basis for each steer within period. Fecal samples were ashed, digested (Williams et al., 1962), and analyzed for chromium using atomic absorption spectrophotometry (Varian Spectra AA-30) to determine total fecal output. Samples of feed and feces were analyzed for NDF and ether extract according to procedures outlined above, and OM (AOCC, 1999; method 4.1.03). Ruminal fluid preparation for determination of VFA

concentration was done according to Erwin et al. (1961) and analyzed using gas chromatography (Hewlett Packard 5890 Series II).

Data were analyzed as an unbalanced Latin square design using the MIXED procedure of SAS (SAS Inst. INC.). Period and treatment were included in the model as fixed effects and steer was considered random. An unstructured covariance structure was used for VFA analysis with hour as a repeated measure. Ruminal pH data were analyzed as a crossover design using the GLIMMIX procedure of SAS (SAS Inst. Inc.). A Cholesky covariance structure was utilized with day as a repeated measure as determined by the procedures outlined by Littell et al. (1998). A Kenward-Rogers denominator degrees of freedom adjustment was utilized and steer was treated as a random effect for all analyses. Fixed effects were considered significant when $P \leq 0.10$.

Exp. 3

Twelve crossbred, non-cannulated yearling steers (525 ± 34 kg) were utilized in a three-period crossover design to compare the digestibility of wet and dry DGS in finishing diets from July 2, 2011, to September 2, 2011 (63 d). Treatments consisted of 1) wet distillers grains plus solubles (WET); 2) dried distillers grains plus solubles (DRY); 3) and a corn control (CON) containing no DGS (Table 5). Basal ingredients in the finishing diet consisted of DRC, 7.5% alfalfa hay, and 5% of diet dry supplement (DM basis). Distillers grains plus solubles were included in the diet at 40% DM and replaced DRC. Molasses was included in the CON and DDGS diets at 5.0% to aid in prevention of sorting feed ingredients. Before initiation of the trial, one semi-truck load of WDGS was purchased from Abengoa Bioenergy (York, NE), and stored in a silo bag (Ag-Bag, Miller-St. Nazianz, Inc. Company). One day later, total needs for DDGS were

purchased from Abengoa Bioenergy (York, NE) and stored in bulk bins. Nutrient composition for DRC, WDGS, DDGS, and alfalfa hay are presented in Table 6.

Period duration was 21-d and included a 16-d adaptation period followed by a 5-d (d 17 through 21) total fecal collection period. During the adaptation period, steers were housed in 2.4 x 1.5 m^2 individual pens with slotted floors, in a temperature controlled room (25ºC) with ad libitum access to water. On the evening of d 16, steers were removed from their pen and tethered in individual stanchions with rubber mats on the floor and walls of the stall. The rubber mats prevented fecal matter losses or contamination with neighboring steers. The floors were sloped away from the feed bunks to allow urine to drain. On the morning of d 17 before 0800 h, all feces excreted from the previous night were scraped away and discarded. Beginning at 0800 h on d 17, feces were collected from the rubber mats and weighed the following d at 0800 h. A subsample of daily fecal matter excreted was collected and dried for 48 h in a 60º C forced-air oven to determine fecal DM output. A wet composite was made (based off of equal amounts of DM from each d) by steer within collection period, lyophilized, and analyzed for OM, N, and ether extract content according to the procedures outlined previously. Cattle were fed once daily at 0800 h and allowed ad libitum intake of experimental diets. Feed ingredients were sampled daily during the collection period at the time of mixing, composited by period and frozen. Feed refusals were collected daily at time of feeding during the collection period, a subsample from each d was taken and composited by period, and analyzed for DM to accurately determine DMI.

Data were analyzed in a crossover design using the MIXED procedure of SAS (SAS Institute, Cary, N.C.). Period and treatment were included in the model as a fixed

effect, and the random effect was steer. Differences were considered significant when $P \leq 0.10$.

RESULTS AND DISCUSSION

Exp. 1

Cattle fed DGS had heavier ($P < 0.01$) final BW and greater ADG ($P < 0.01$) than CON (Table 7). Final BW and ADG tended ($P = 0.08$) to be less for DRY when compared to DRY+Solubles, but was not different ($P \geq 0.13$) among DDG+Solubles, MDGSPost, MDGSPre, DRY+H_2O, and WDGS. Daily intake was least ($P < 0.01$) for CON compared to diets containing DGS. Steers fed DDG+Solubles tended ($P = 0.07$) to have greater DMI compared to DRY, but had greater ($P \leq 0.04$) DMI than other treatments containing DGS. Intake for steers consuming diets containing WET, DRY, MDGSPre, MDGSPost, and DRY+H_2O were not different ($P \geq 0.21$).

There were minimal differences among diets containing DGS for ADG and DMI; however, slight numeric differences resulted in a general trend for G:F to decrease as the extent of drying increased. Cattle fed WET had greater ($P < 0.01$) G:F than CON, DRY, DRY+H_2O, or DDG+Solubles. However, G:F was not different ($P \geq 0.23$) among steers fed diets containing WET, MDGSPre, and MDGSPost. Steers fed MDGSPre or MDGSPost had greater ($P \leq 0.03$) G:F than CON, DRY, and DDG+Solubles, but were not different ($P \geq 0.19$) than DRY+H_2O. Adding water to DRY at time of feeding did not improve ($P = 0.15$) G:F compared to DRY or DDG+Solubles. Efficiency of BW gain

was not different (*P* = 0.99) for steers fed diets containing DRY and DDG+Solubles, but tended (*P* = 0.07) to be greater than CON.

Replacing corn with any type of DGS increased DMI, ADG, and G:F compared to the corn-based control. Vander Pol et al. (2005) and Loza et al. (2010) observed an 18.1 and 9.7% increase for ADG, respectively, when 30% WDGS replaced corn. Daily intake was increased 8.3 and 5.6% compared to corn-based control when 30% WDGS were fed by Vander Pol et al. (2005) and Loza et al. (2010), respectively, and increased G:F by 13.1 and 8.7%, respectively, compared to corn-based control.

Buckner et al. (2008) replaced corn with 30% DDGS and observed greater ADG and DMI. Increased ADG observed by Buckner et al. (2008) resulted in a 3.7% increase for G:F for steers fed diets containing 30% DDGS compared to the corn-based control. Contrasting to these results from Buckner et al. (2008), Sarturi et al. (2013a) did not observe a difference for DMI or ADG when replacing corn with 30% DDGS. However, numeric differences reported by Sarturi et al. (2013a) for DMI and ADG resulted in steers consuming diets with DDGS to be 12% more efficient than steers consuming diets without DDGS.

Previous studies comparing WDGS and DDGS observed decreased performance for steers fed diets containing DDGS compared to steers fed diets containing WDGS (Ham et al., 1994; Nuttelman et al., 2011; Sarturi et al., 2013a). Sarturi et al. (2013a) replaced corn with 30% WDGS or DDGS and observed no differences for ADG. The authors observed a 9.4% increase for DMI for steers consuming DDGS diets, resulting in 11.8% greater G:F for steers fed WDGS diets compared to steers fed DDGS diets. Nuttelman et al. (2011) reported greatest DMI for cattle consuming DDGS, intermediate

for MDGS, and the least for WDGS. Daily gain was not different among cattle fed different types of DGS (Nuttelman et al., 2011) which resulted in 10.7 and 5.1% improvement in G:F for WDGS when compared to DDGS and MDGS, respectively, and 5.3% greater G:F for MDGS compared to DDGS. Bremer et al. (2011) conducted three separate meta-analyses from studies replacing corn with WDGS, MDGS, or DDGS. These meta-analyses suggest DMI was greatest for cattle fed DDGS, intermediate for MDGS, and the least for WDGS. Daily gain was not different across different types of DGS, and therefore steers fed diets replacing corn with WDGS were the most efficient, MDGS diets were intermediate of WDGS and DDGS, and steers fed diets containing DDGS were the least efficient.

In Exp. 1, steers fed diets containing DGS gained more rapidly than CON, and therefore had heavier ($P < 0.01$) HCW compared to CON. There was a tendency ($P \leq 0.11$) for steers fed diets containing DDG+Solubles and MDGSPost to have heavier HCW than DRY. Cattle fed DGS had greater ($P = 0.02$) 12^{th} rib fat than CON at harvest. These results are similar to the literature (Vander Pol et al., 2005; Nuttelman et al., 2011; Sarturi et al., 2013a) in which cattle fed diets containing DGS are fatter than corn-based controls and have heavier HCW at harvest when fed similar number of days. Marbling score and LM area were not different among treatments ($P \geq 0.32$) in the current study.

Using the G:F values observed in this study the calculated feeding value for WDGS compared to CON was 130%. The average G:F value for MDGSPre and MDGSPost (0.164) and for DRY, DRY+Solubles, and DRY+H_2O (0.158) was calculated and compared to CON. Using these G:F values for MDGS and DDGS resulted in the feeding value for MDGS and DDGS to be 125, and 111% that of corn, respectively. The

meta-analysis evaluating different concentrations of WDGS conducted by Bremer et al. (2011) reported the feeding values for WDGS were 143, 136, and 130% when replacing 20, 30, and 40% corn, respectively. When replacing corn with MDGS, the meta-analysis suggested the feeding values were 124, 120, and 117% that of corn when fed at 20, 30, and 40% inclusion. The DDGS meta-analysis suggested the feeding values for DDGS were 112% that of corn for all concentrations. Using the same calculations to determine the feeding value for WDGS compared to DDGS, WDGS was 118% that of DDGS. Sarturi et al. (2013a) reported that WDGS contained 139% the feeding value of DDGS, and Nuttelman et al. (2011) reported WDGS contained 135% the feeding value of DDGS.

Contrary to our hypothesis, partially or completely drying DS onto distillers grains did not explain the reduced feeding value for DDGS compared to WDGS. This study compared two types of DGS that had the DS at least partially dried, and three types of DGS in which the DS were never dried. Adding solubles to DDG at the time of feeding resulted in the same G:F as DDGS which had the DS dried onto the distillers grains at the ethanol plant. Similarly, adding solubles to the partially dried distillers grains at the ethanol plant after the dryers did not improve the feeding value compared to partially dried distillers grains that had the DS added to the grains before the dryer. Therefore, there must be some compositional change within the grains portion that occurs during the drying process.

Exp. 2

Average ruminal pH tended to be influenced (*P* = 0.14) by dietary treatment (Table 8). The average pH for steers fed DRY (5.92) was numerically greater than steers fed CON, MOD, and WET (5.73, 5.70, and 5.69, respectively). Minimum pH was

greatest ($P < 0.01$) for steers fed DRY when compared to other treatments. Minimum pH was greater ($P = 0.06$) for steers fed diets containing WET when compared to steers fed CON, but was not different ($P = 0.62$) between WET and MOD. Maximum pH was not different ($P = 0.29$) among diets. Time below pH 5.6 and pH magnitude were not different ($P \geq 0.23$) among treatments. There was a tendency ($P = 0.11$) for pH variance to be greater for CON when compared to WET, MOD, or DRY. Diets containing WET had the greatest ($P = 0.02$) area of pH below 5.6 compared to CON, MOD, and DRY. Greater area below pH 5.6 for WDGS treatment suggests that there was greater ruminal fermentation for WDGS diets. Vander Pol et al. (2009) reported numerically lower rumen pH and greater time below pH 5.6 for diets containing 40% WDGS compared to DRC diets. There were no differences for maximum or minimum pH and pH change among treatments Vander Pol et al. (2009). Corrigan et al. (2009) reported a tendency for maximum pH and pH variance to be less for diets containing 40% WDGS. Similarly, Ham et al. (1994) reported a slight numeric decrease in rumen pH for WDGS compared to DRC.

Molar proportions of acetate for CON were not different ($P = 0.27$) compared with WET, but greater ($P = 0.08$) than MOD and DRY (Table 8). Molar proportions of propionate were less ($P < 0.01$) for CON when compared to WET, DRY, and MOD. There was a tendency ($P \leq 0.12$) for molar proportions of propionate to increase for DRY compared to WET and MOD, but there was no difference ($P = 0.89$) between MOD and WET. Butyrate was not affected by treatment ($P = 0.41$). Increased propionate and decreased acetate molar proportions for diets containing DGS resulted in decreased acetate:propionate ratios ($P < 0.01$) compared to CON. Greater NDF in diets containing

DGS would suggest A:P would increase when DGS replace corn. However, Ham et al. (1994) did not observe a change in molar proportions of acetate or propionate among DRC and WDGS treatments. Contrasting to these results, Vander Pol et al. (2009) reported molar proportions of acetate were less and propionate were greater for WDGS compared to corn-based control. Similarly, Corrigan et al. (2009) reported increased molar proportions of propionate for diets containing 40% WDGS compared to DRC and HMC diets with 0% WDGS. However, SFC diets with 0% WDGS contained similar molar proportions of propionate as DRC, HMC, and SFC diets containing 40% WDGS. There were no differences for molar proportions of acetate among 0 and 40% WDGS, and DRC, HMC, or SFC (Corrigan et al., 2009). Leupp et al. (2009) reported decreased total VFA concentrations and acetate proportions, whereas propionate proportions increased with increasing concentrations of DDGS. Russel (1998) evaluated diets without DGS and suggested that the A:P decreased as pH decreased until pH 5.3, but when pH was below 5.3 A:P increased. Therefore, Russel (1998) suggested that some, but not all starch-fermenting bacteria can adapt to low pH. Minimum pH for CON (5.05) in Exp. 2 was lower than diets containing DGS suggesting conditions were favorable for acetate production at pH below 5.3 and thus explaining why A:P was greater for CON than diets containing DGS . However, average pH was similar among CON and DGS treatments, and area below pH 5.6 was not different for CON compared to MOD and DRY. There is not an apparent explanation why replacing corn with DGS decreased A:P.

Treatment did not affect ($P > 0.35$) DMI, or DM or OM digestibility (Table 9). Steers fed diets containing DGS had greater ($P < 0.01$) NDF intake compared to CON. There was no difference ($P = 0.17$) among treatments for NDF digestibility. Digestibility

of NDF was numerically lowest for CON. Fiber digestibility was numerically the least for DRY, intermediate for MOD, and the greatest for WET. Steers fed diets containing DGS had greater (*P* < 0.01) fat intake than CON, but digestibility of fat was not different (*P* = 0.53) among treatments. Vander Pol et al. (2009) observed an 11.7% increase for fat digestibility for diets containing 40% WDGS compared to a corn based control. Although not as great of an increase, Corrigan et al. (2009) observed a 3.4% increase for fat digestibility for diets containing 40% WDGS.

Exp. 3

There were no differences (*P* ≥ 0.15) for DM or OM intake among treatments (Table 10). Dry matter and OM digestibility were greater (*P* < 0.01) for CON compared to WET and DRY. There was no difference (*P* = 0.15) between WET and DRY for DM digestibility, but there was a tendency (*P* = 0.11) for OM digestibility to be greater for WET when compared to DRY. Digestibility for NDF was greater (*P* = 0.09) for CON when compared to WET and DRY. This is contradicting to the results from Exp. 2 when NDF digestibility was numerically 20% less for CON compared to WDGS. Results from Exp. 2 suggested there was a 15.6% reduction for NDF digestibility when WDGS are completely dried. However, results from Exp. 3 suggest there is only a 3.5% reduction for NDF digestibility when comparing DRY to WET. Firkins et al. (1985) compared DDG and WDG, and reported no difference for NDF digestibility. Vander Pol et al. (2009) reported NDF digestibility for WDGS and corn-based control were not different (78.2 and 78.9, respectively). Corrigan et al. (2009) reported similar values for total-tract NDF digestibility when diets replacing DRC or HMC with 40% WDGS were compared to diets without WDGS. Digestibility of NDF for CON diets compared to diets

containing DGS was less in Exp. 2, greater in Exp. 3, and not different as reported by Corrigan et al. (2009) and Vander Pol et al. (2009). The explanations for these differences among studies is not apparent.

The differences for OM digestibility values compared to the CON from Exp. 2 are numerically lower than Exp. 3, but the OM digestibility shifted equally 2.8 and 2.6 percentage units lower for WDGS and DDGS, respectively. Interestingly though, the percentage unit difference between diets containing WDGS and DDGS are nearly identical (0.1 percentage unit difference) between these two studies. The OM partial digestion coefficient for WDGS is 10.5% less than corn, and is 20.0% less for DDGS compared to corn. The partial digestion coefficient for WDGS was 9.5% greater than DDGS in Exp. 3. Vander Pol et al. (2009), reported similar total tract OM digestibility for WDGS and DRC. Similarly, Ham et al. (1994) reported no differences among WDGS and DRC diets for OM digestibility. However, Corrigan et al. (2009) reported total tract OM digestibility was 6% less for WDGS compared to DRC.

Replacing corn with DGS regardless of moisture content increased ADG, DMI, and G:F for calf-fed steers. Drying WDG reduced the feeding value compared to WDGS. The OM digestibility partial digestion coefficient for WDGS was 9.5% greater than DDGS. However, contrary to our hypothesis, drying DS did not appear to explain the reduced feeding value. The feeding values of DGS are greater than the corn it replaced, however it is a paradox as WDGS is 10.5% and DDGS is 20.0% less digestible than corn.

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Table 1. Nutrient composition of wet distillers grains plus solubles (WDGS), dried distillers grains with solubles dried onto grains (DDGS), dried distillers grains with no solubles (DDG), modified distillers grains with solubles added to wet grains prior to the drier (PREMOD), partially dried wet distillers grains with solubles added to the grains after the drier (POSTMOD), and distillers solubles (SOLUBLE) used in Exp. 1.

Variables[1]	WDGS[2]	DDGS[2]	DDG[2]	PREMOD[2]	POSTMOD[2]	SOLUBLE[2]
CP, %	33.5	31.8	34.6	31.3	32.3	25.9
Fat, %	12.2	11.5	7.5	12.2	12.8	21.7
NDF, %	37.8	36.9	47.1	35.9	36.6	-
S, %	0.76	0.77	0.63	0.70	0.84	1.26

[1] Analyzed nutritional composition, DM basis.
[2] WDGS - wet distillers grains plus solubles; DDGS - dry distillers grains with solubles dried onto the grains; DDG – dried distillers grains without solubles; PREMOD - modified distillers grains with solubles added to grains prior to the dryer; POSTMOD - modified distillers grains with solubles added to partially dried wet distillers grains post dryer; SOLUBLE – distillers solubles

Table 2. Dietary treatments and chemical composition of final finishing diets comparing different drying methods for distillers grains and solubles used in Exp. 1.

	Treatments[1]						
Ingredients, % DM	CON	WET	DRY	DRY+H_2O	MDGSPRE	MDGSPOST	DDG+SOLUBLE
HMC[2]	43.4	25.9	25.9	25.9	25.9	25.9	25.9
DRC[2]	43.4	25.9	25.9	25.9	25.9	25.9	25.9
Distillers Grains	-	33.0	35.0	35.0	33.0	35.0	28.0
Solubles	-	2.1	-	-	2.1	-	7.0
Sorghum Silage	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Grass Hay	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Dry Supplement[3]							
Finely ground corn	1.39	………… 3.03 …………					
Limestone	1.45	………… 1.44 …………					
Urea	1.38	………………………					
Salt	0.30	………… 0.30 …………					
Tallow	0.13	………… 0.13 …………					
Potassium chloride	0.25	………………………					
Trace mineral premix[4]	0.05	………… 0.05 …………					
Vitamin A-D-E premix[5]	0.02	………… 0.02 …………					
Rumensin-80 premix[6]	0.02	………… 0.02 …………					
Tylan-40 premix[7]	0.01	………… 0.01 …………					
Calculated Nutrient Analysis[8]							
Crude Protein, %	12.56	17.17	16.74	16.74	16.45	16.91	17.11
Fat, %	3.94	6.95	6.51	6.51	6.95	6.96	6.10
NDF, %	15.52	24.17	24.65	24.65	23.54	24.54	24.92
Sulfur, %	0.11	0.34	0.33	0.33	0.32	0.36	0.33

[1] CON - Control diet with no distillers grains. WET - Wet distillers grains plus solubles included at 35% of diet DM; DRY - Dried distillers grains with solubles added to grains prior to dryer included at 35% of diet DM; DRY+H_2O - Dried distillers

grains with solubles added to dry grains before the dryer and H_2O added at time of feeding to reconstitute DRY to same % moisture as POSTMOD; MDGSPRE - Modified distillers grains with solubles added to grains before the dryer; MDGSPOST - Modified distillers grains with solubles added to grains post dryer; DDG+Solubles- Dried distillers grains with solubles added to grains at time of feeding (~ 80% grains and 20% soluble DM).

[2] HMC = high moisture corn; DRC = dry rolled corn.

[3] Supplement formulated to be fed at 5.0% of diet DM.

[4] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.

[5] Premix contained 30,000 IU vitamin A, 6,000 IU vitamin D, 7.5 IU vitamin E per gram.

[6] Premix contained 176 g/kg monensin.

[7] Premix contained 88 g/kg tylosin.

[8] Calculated nutrient analysis utilizing analyzed values for each ingredient.

Table 3. Dietary treatments and nutrient composition of diets comparing the nutrient metabolism of wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), and dried distillers grains plus solubles (DDGS) to a corn based control (CON) in Exp. 2.

	Treatment[1]			
Ingredients, % DM	CON	WET	MOD	DRY
HMC[2]	48.0	24.0	24.0	24.0
DRC[2]	32.0	16.0	16.0	16.0
WDGS[2]	-	40.0	-	-
MDGS[2]	-	-	40.0	-
DDGS[2]	-	-	-	40.0
Corn Silage	15.0	15.0	15.0	15.0
Dry Supplement[3]				
Finely ground corn	0.72	2.67	2.60	2.60
Limestone	1.68	1.68	1.55	1.55
Tallow	0.13	0.13	0.13	0.13
Urea	1.72	-	-	-
Calcium Sulfate	-	-	0.20	0.20
Potassium chloride	0.23	-	-	-
Trace mineral premix[4]	0.05	0.05	0.05	0.05
Vitamin A-D-E premix[5]	0.02	0.02	0.02	0.02
Rumensin-80 premix[6]	0.02	0.02	0.02	0.02
Tylan-40 premix[7]	0.01	0.01	0.01	0.01
Thiamine[8]	0.12	0.12	0.12	0.12
Calculated Nutrient Analysis[9]				
Crude protein, %	12.96	17.81	17.75	17.71
Fat, %	3.96	7.32	7.52	7.32
NDF, %	14.91	24.96	25.06	24.22
Sulfur, %	0.13	0.40	0.40	0.40

[1]WET = wet distillers grains plus solubles; MOD = modified distillers grains plus solubles; DRY = dried distillers grains plus solubles fed at 40 % (DM basis); CON = corn control.
[2] HMC = high moisture corn; DRC = dry rolled corn; WDGS = wet distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DDGS = dried distillers grains plus solubles.
[3]Supplement formulated to be fed at 5.0% of diet DM.
[4]Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.
[5] Premix contained 29,974 IU vitamin A, 5,995 IU vitamin D, 7.5 IU vitamin E per gram.
[6] Premix contained 176 g/kg monensin.
[7] Premix contained 88 g/kg tylosin.
[8]Premix contained 88 g/kg of thiamine.
[9]Calculated nutrient analysis utilizing analyzed values for each ingredient.

Table 4. Nutritional composition of wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), and dried distillers grains plus solubles (DDGS) used in Exp. 2.

Variables[1]	WDGS[2]	MDGS[2]	DDGS[2]
CP, %	31.1	31.0	30.9
Sulfur, %	0.81	0.70	0.71
Fat, %	11.9	12.4	11.9
NDF, %	34.1	34.4	32.3

[1] Analyzed nutritional composition, DM basis.
[2] WDGS = wet distillers grains plus solubles; MDGS = modified distillers grains plus solubles; DDGS = dried distillers grains plus solubles.

Table 5. Dietary treatments and nutrient composition of diets comparing the nutrient metabolism of wet distillers grains plus solubles (WDGS) and dried distillers grains plus solubles (DDGS) to a corn based control (CON) in Exp. 3.

	Treatment[1]		
	CON	WET	DRY
DRC[2]	82.5	47.5	42.5
WDGS[2]	-	40.0	-
DDGS[2]	-	-	40.0
Alfalfa hay	7.5	7.5	7.5
Molasses	5.0	-	5.0
Dry Supplement[3]			
Finely ground corn	2.00	3.22	3.22
Limestone	1.23	1.23	1.23
Tallow	0.13	0.13	0.13
Salt	0.30	0.30	0.30
Urea	0.99	-	-
Potassium chloride	0.23	-	-
Trace mineral premix[4]	0.05	0.05	0.05
Vitamin A-D-E premix[5]	0.02	0.02	0.02
Rumensin-90 premix[6]	0.02	0.02	0.02
Tylan-40 premix[7]	0.01	0.01	0.01
Thiamine[8]	0.02	0.02	0.02
Calculated Nutrient Analysis[9]			
Crude protein, %	12.81	20.27	19.57
Fat, %	3.46	6.85	5.87
NDF, %	16.32	23.10	24.25
Sulfur, %	0.15	0.39	0.40

[1]WET = wet distillers grains plus solubles; DRY = dried distillers grains plus solubles fed at 40 % (DM basis); CON = DRC-based corn control.
[2]DRC = dry rolled corn; WDGS = wet distillers grains plus solubles; DDGS = dried distillers grains plus solubles.
[3]Supplement formulated to be fed at 5.0% of diet DM.
[4] Premix contained 6.0% Zn, 5.0% Fe, 4.0% Mn, 2.0% Cu, 0.28% Mg, 0.2% I, 0.05% Co.
[5] Premix contained 29,974 IU vitamin A, 5,995 IU vitamin D, 7.5 IU vitamin E per gram.
[6] Premix contained 200 g/kg monensin.
[7] Premix contained 88 g/kg tylosin.
[8]Premix contained 88 g/kg of thiamine.
[9]Calculated nutrient analysis utilizing analyzed values for each ingredient.

Table 6. Nutrient composition of feed ingredients comparing the nutrient metabolism of wet distillers grains plus solubles (WDGS), and dried distillers grains plus solubles (DDGS) to a corn based control (CON) in Exp. 3.

Variables[1]	DRC[2]	WDGS[2]	DDGS[2]	Alfalfa[2]
CP, %	9.7	34.9	33.3	18.9
Sulfur, %	0.12	0.79	0.74	0.27
Fat, %	3.9	11.2	10.4	1.3
NDF, %	13.6	28.5	33.1	65.6

[1] Analyzed nutritional composition, DM basis.
[2] DRC = dry rolled corn; WDGS = wet distillers grains plus solubles; DDGS = dried distillers grains plus solubles; Alfalfa = alfalfa hay.

Table 7. Growth performance and carcass characteristics of steers fed diets evaluating different drying methods for distillers grains and solubles in Exp. 1.

	Treatments[1]								
	CON	WET	DRY	DRY+H_2O	MDGSPre	MDGSPost	DDG+Solubles	SEM	*P* - Value
Performance									
Initial BW, kg	314	314	313	313	313	314	313	0.5	0.34
Final BW[2], kg	576[a]	622[b]	611[b]	616[b]	622[b]	623[b]	624[b]	5	< 0.01
ADG, kg	1.40[a]	1.65[b]	1.59[b]	1.63[b]	1.65[b]	1.65[b]	1.66[b]	0.01	< 0.01
DMI, kg/d	9.1[a]	9.8[b]	10.1[bc]	10.0[b]	9.9[b]	10.0[b]	10.5[c]	0.2	< 0.01
G:F	0.151[a]	0.167[d]	0.157[ab]	0.161[bc]	0.165[cd]	0.163[cd]	0.157[ab]	0.01	< 0.01
Carcass Characteristics									
HCW, kg	363[a]	392[b]	385[b]	389[b]	392[b]	392[b]	393[b]	3	< 0.01
Marbling Score[3]	509	539	545	539	529	523	551	13	0.32
LM, area cm.[2]	81.9	83.9	83.2	82.6	83.9	83.2	85.8	0.5	0.38
12[th] rib fat, cm.	1.09[a]	1.47[b]	1.42[b]	1.40[b]	1.42[b]	1.40[b]	1.40[b]	0.02	0.02

[1] CON- Control diet with no distillers grains. WET- Wet distillers grains included at 35% of Diet DM. DRY- Dry distillers grains with soluble added to grains before dryer. DRY+H_2O-Dried distillers grains with soluble added to grains before the dryer and H_2O added at time of feeding to reconstitute DDGS to same DM as MDGSPost. MDGSPre- Modified distillers grains with soluble added to grains before the dryer. MDGSPost- Modified distillers grains with soluble added to grains post dryer. DDG+Solubles- Dried distillers grains with soluble added to grains at time of feeding (~ 80% grains and 20% soluble DM).

[2] Calculated from hot carcass weight, adjusted to a common dressing percentage of 63.0%.

[3] Marbling score: 400 = Slight^{0}; 450 = Slight^{50}; 500 = Slight^{0}, etc..

[a,b,c,d] Means with different superscripts differ ($P < 0.05$).

Table 8. Ruminal pH variables and VFA profiles of steers fed wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), dried distillers grains plus solubles (DDGS), or corn based control (CON) in Exp 2.

	Treatment[1]					
	CON	WET	MOD	DRY	SEM	*P*-Value
Ruminal pH variable						
Average pH	5.73	5.70	5.69	5.92	0.08	0.14
Maximum pH	6.53	6.42	6.36	6.87	0.07	0.29
Minimum pH	5.05[a]	5.16[b]	5.13[ab]	5.36[c]	0.07	< 0.01
pH Magnitude	1.46	1.29	1.20	1.16	0.13	0.27
pH Variance[2]	0.139	0.087	0.096	0.097	0.019	0.11
Time < 5.6, min/d[3]	496	695	560	309	127	0.23
Area < 5.6[4]	106[a]	224[b]	128[a]	106[a]	38	0.02
VFA						
Total, mM	111.7	116.2	104.5	113.3	6.1	0.56
Acetate	62.6[a]	58.7[a,b]	55.0[b]	53.9[b]	3.0	0.08
Propionate	19.7[a]	24.2[b]	24.4[b]	27.0[b]	2.3	< 0.01
Butyrate	12.3	13.3	16.2	14.1	1.7	0.41
A:P[5]	3.34[a]	2.13[b]	2.28[b]	1.88[b]	0.4	< 0.01

[1] WET = wet distillers grains plus solubles; MOD = modified distillers grains plus solubles; DRY = dried distillers grains plus solubles; CON = corn control.
[2] Variance of daily ruminal pH.
[3] Time < 5.6 = minutes that ruminal pH was below 5.6.
[4] Area < 5.6 = ruminal pH units below 5.6 by minute.
[5] Acetate:propionate (A:P) ratio calculated using milimolar concentrations.
[a,b,c] Means with different superscripts differ ($P < 0.10$)

Table 9. Nutrient intake and apparent total tract digestibility in steers fed wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), dried distillers grains plus solubles (DDGS), or corn control (CON) in Exp. 2.

	Treatment[1]					
	CON	WET	MOD	DRY	SEM	*P* –Value
DM						
Intake, kg/d	9.9	9.3	9.3	10.0	0.7	0.70
Digestibility, %	78.6	76.6	74.6	73.4	2.2	0.39
OM						
Intake, kg/d	9.2	8.4	8.5	9.2	6.2	0.58
Digestibility, %	80.2	78.8	76.5	74.9	2.1	0.35
NDF						
Intake, kg/d	1.6[a]	2.2[b,c]	2.1[b]	2.5[c]	1.6	< 0.01
Digestibility, %	51.8	64.8	57.4	54.7	4.0	0.17
Fat						
Intake, kg/d	0.4[a]	0.7[b]	0.6[b]	0.7[b]	1.9	< 0.01
Digestibility, %	87.2	88.2	89.7	86.0	2.0	0.53

[1] WET = wet distillers grains plus solubles; MOD = modified distillers grains plus solubles; DRY = dried distillers grains plus solubles; CON = corn control.
[a,b,c] Means with different superscripts differ ($P < 0.10$)

Table 10. Nutrient intake and apparent total tract digestibility of steers fed wet distillers grains plus solubles (WDGS), dried distillers grains plus solubles (DDGS), or dry-rolled corn-based control (CON) in Exp. 3.

	Treatment[1]				
	CON	WET	DRY	SEM	*P* –Value
DM					
Intake, kg/d	11.4	11.3	12.0	0.4	0.15
Digestibility, %	76.8[a]	72.1[b]	68.4[b]	1.7	< 0.01
OM					
Intake, kg/d	11.2	10.9	11.5	0.4	0.25
Digestibility, %	78.6[a]	74.4[b]	70.6[b]	1.6	< 0.01
NDF					
Intake, kg/d	1.9[a]	2.6[b]	2.6[b]	0.1	< 0.01
Digestibility, %	68.2[a]	62.8[b]	60.6[b]	2.4	0.09

[1] WET = wet distillers grains plus solubles; DRY = dried distillers grains plus soluble; CON = Corn control diet containing no DGS.

[a,b] Means with different superscripts differ ($P < 0.10$).