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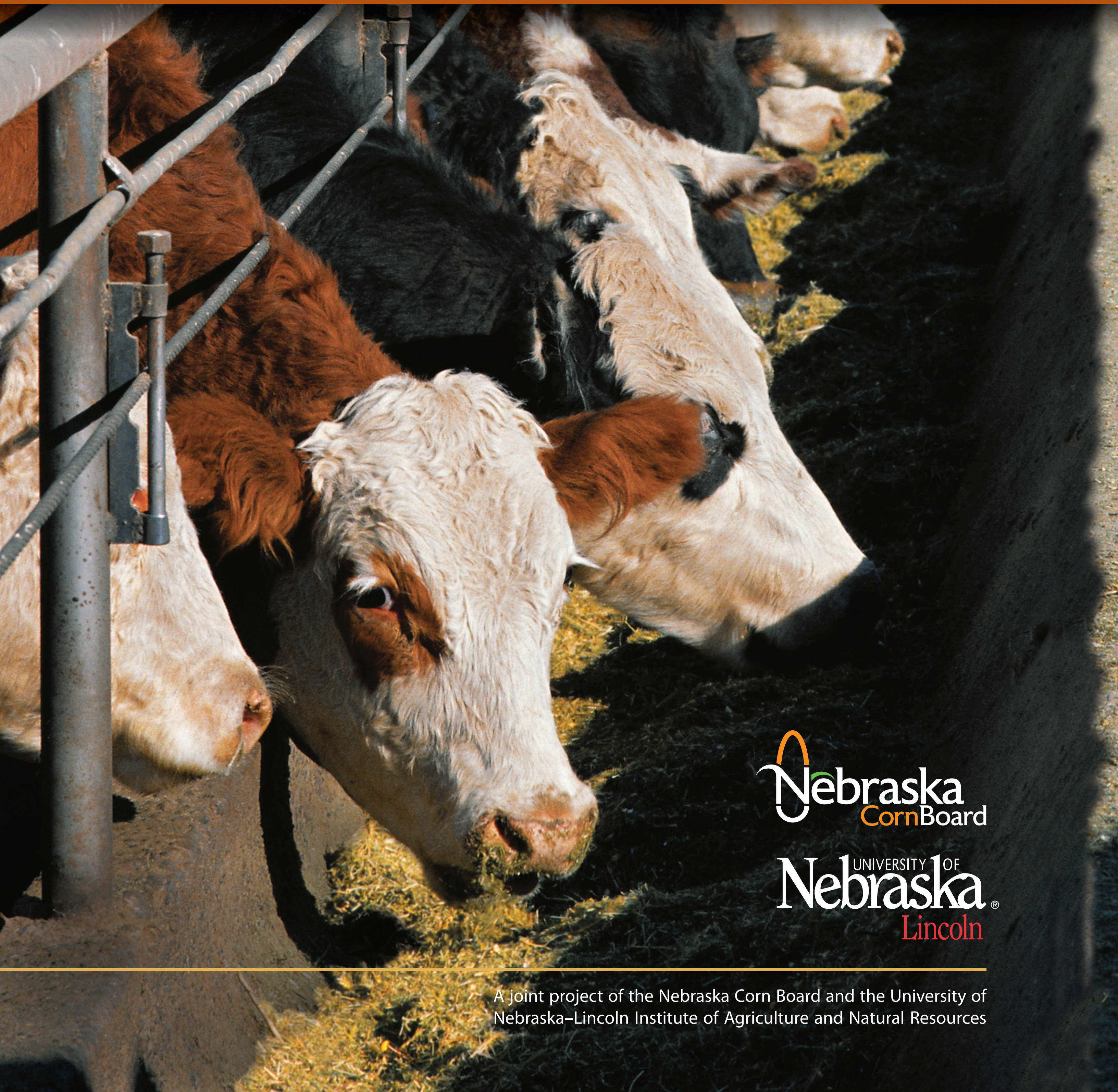
Feeding Corn Milling Co-Products to Feedlot Cattle



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Feeding Corn Milling Co-Products to Feedlot Cattle

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INTRODUCTION

Two primary types of milling processes currently exist, resulting in quite different feed products. These processing plants produce and market a variety of feed products, but in general, the dry milling process produces distillers grains plus solubles (DGS), and the wet milling process produces corn gluten feed (CGF). These feeds can be marketed as wet feeds, or they can be dried and marketed as either dry corn gluten feed (DCGF) or dry distillers grains (DDG) with or without solubles.

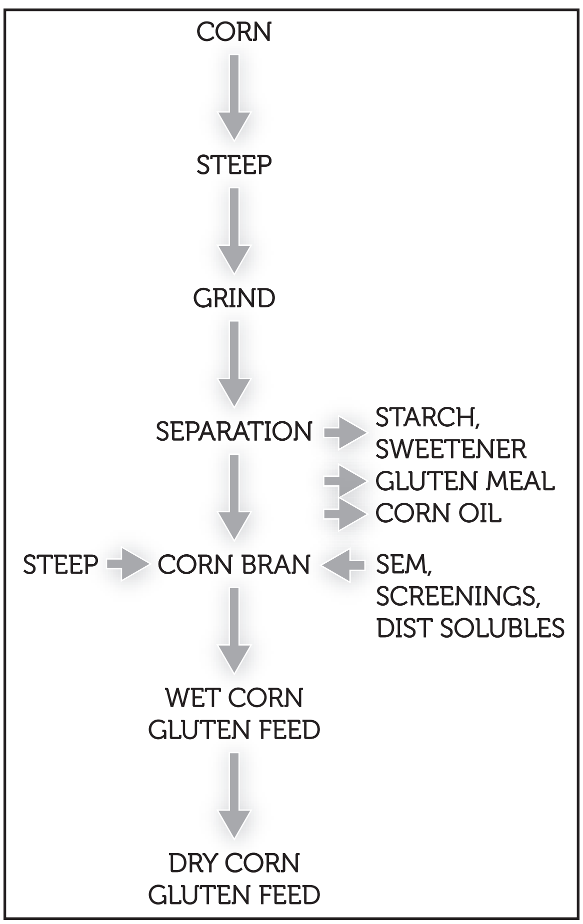
For the purposes of this report, wet corn gluten feed (WCGF), wet distillers grains plus solubles (WDGS), DCGF and dried distillers grains plus solubles (DDGS) will be discussed. The term DGS will be used for undifferentiated discussion about WDGS and DDGS. The majority of ethanol plant expansions are dry milling plants that produce DGS; however, an increase in supply of WCGF is also expected. Therefore, these feeds may be very attractive for beef producers to use as feed sources. This report will focus on the production, composition, feeding values and economics of using these co-products in feedlot situations. Management strategies will be discussed as well, including grain processing and roughage levels when these co-products are used in feedlot diets, and the use of co-products in combinations, at high dietary inclusions, in replacement of forages in adaptation diets, and the effects of fat, fiber and sulfur with these products. Storage methods for wet products and nutrient composition and variability from co-products will also be discussed.

MILLING PROCESSES

Wet Milling

Wet milling is a process that requires the use of high quality (U.S. No. 2 or better) corn that fractionates the corn kernel to produce numerous products intended for human use. Fresh water enters the milling system in the final stage of starch washing. Subsequently, it runs countercurrent with respect to the flow of corn, passing through numerous screens and separating implements, acquiring soluble nutrients at each step. Ultimately, this solution will serve as the resource to steep the corn in that is initially brought into the process.

Figure 1. Schematic of the wet milling industry resulting in wet or dry corn gluten feed



Lactic acid-producing bacteria in the steeping process ferment the soluble carbohydrates collected by the water to further kernel softening. Following the steeping process **(Figure 1)**, corn kernels are separated into kernel components of corn bran, starch, corn gluten meal (high in protein), germ and soluble components. If the wet milling plant is fermenting starch into ethanol, a portion of the steep water (now called steep liquor) is added to the fermentation vats to supply nutrients for the ethanol-producing yeast cells to grow. The ethanol is distilled off after the fermentation process. The solution exiting the still is called distillers solubles, not to be confused with dry milling distillers solubles. This product contains very little corn residue, almost no fat, and is high in protein from the remnants of yeast cells from the fermentation process. The distillers solubles and a portion of the steep liquor are added to the bran fraction of the corn resulting in WCGF. The WCGF can have a portion of the germ meal added if the plant has those capabilities. For a more complete review of the wet milling process, please refer to Blanchard (1992).

The actual composition of WCGF can vary depending on the plant capabilities. Steep, a combination of steep liquor and distillers solubles, contains more energy (136% the feeding value of corn) and protein than corn bran or germ meal (Scott et al., 1997). Therefore, plants that apply more steep to corn bran or germ meal will produce WCGF that is higher in crude protein (CP) and energy. For instance, Sweet Bran is a trademarked WCGF product that Cargill produces. This product contains more steep and some germ meal than WCGF made with less steep, making it greater in energy (112% the feeding value of corn).

WCGF contains 16-23% CP, which is approximately 70% ruminally degradable protein (degradable intake protein, DIP) used by rumen microbes. During wet milling, corn gluten meal is removed and marketed in higher value markets. Corn gluten meal should not be confused with WCGF, as corn gluten meal contains approximately 60% CP that is 40% DIP and 60% bypass protein (undegradable intake protein, UIP).

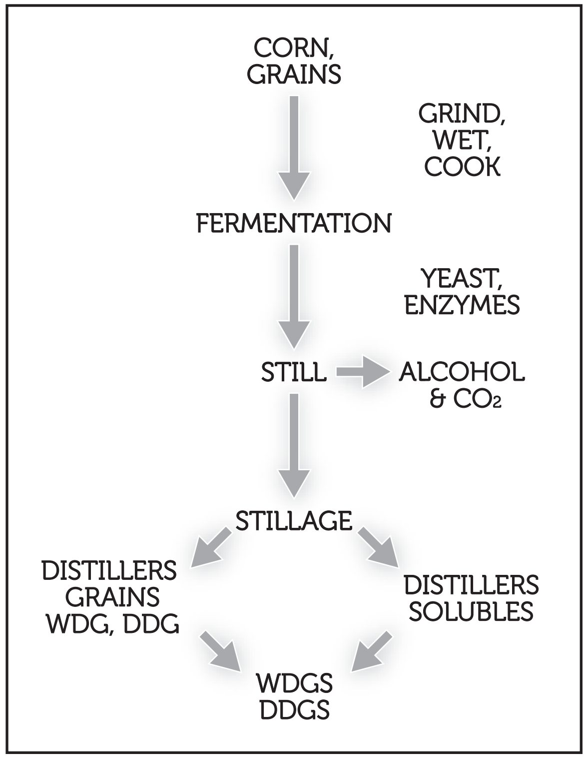
Dry Milling

The dry milling ethanol process **(Figure 2)** is relatively simple. Corn (or another starch source) is ground, fermented and the starch is converted to ethanol and CO_2. Approximately one-third of the dry matter (DM) remains as a feed product following starch fermentation, assuming the starch source is approximately two-thirds starch. As a result, all the nutrients are concentrated three-fold because most grains contain approximately two-thirds starch. For example, if corn is 4% fat, the WDGS or DDGS will contain approximately 12% fat.

After the ethanol distillation step, the resulting product, referred to as stillage, is centrifuged. The purpose of the centrifuging step is to separate the distillers grains from the distillers solubles. These distillers solubles are evaporated and are partially dried. Typically, the distillers solubles are added back to the distillers grains. However, nutrient composition may vary some depending on the relative ratios of distillers grains to distillers solubles and if the distillers grains are dried partially before the solubles are added. If all of the solubles are added back to the grains, DGS are approximately 80% distillers grains and 20% distillers solubles (DM basis; Corrigan et al., 2007a). Most distillers grains contain some solubles, but this can vary from plant to plant.

Solubles are a good source of protein, high in fat, phosphorus (P) and sulfur (S) and low in fiber (Corrigan et al., 2007a). Solubles contain 25% CP (60% DIP), 20% fat, 1.57% P, 0.92% S, and 2.3% neutral detergent fiber (NDF). Distillers solubles have

Figure 2. Schematic of the dry milling industry with the feed products produced



become a popular base for liquid feed supplements. As molasses prices have increased, liquid supplement companies are using steep from the wet milling industry and distillers solubles from the dry milling industry to replace a portion of molasses in liquid supplements. In addition, solubles may replace corn and protein in finishing diets (Trenkle, 1997b). Steers fed 4 or 8% of diet DM as corn distillers solubles had improved feed conversion compared to steers fed a conventional cracked corn diet.

The wet milling industry is more complex than dry milling in that the corn kernel is divided into more components for higher value marketing. For example, the oil is extracted and sold in the wet milling industry, as is the corn gluten meal, a protein fraction that contains a large amount of bypass

Table 1. Nutrient composition of selected corn milling co-products.

Feedstuff:[1]	DRC[2]	WCGF-A	WCGF-B	DDGS[3]	WDGS[3]	CCDS[3]	MDGS	Steep[4]
DM	90	44.7	60.0	90.4	34.9	35.5	46.2	49.4
CP, % of DM	9.8	19.5	24.0	33.9	31.0	23.8	30.6	35.1
UIP, % of CP	60	25	25	65	65	20	65	10
P, % of DM	0.32	0.66	0.99	0.51	0.84	1.72	0.84	1.92
NEg, Mcal/lb.[5]	0.70	0.70	0.78	0.78	0.91	0.87	0.85	0.95

[1]DRC = dry rolled corn with NRC (1996) values, WCGF-A = wet corn gluten feed,
WCGF-B = Cargill Sweet Bran wet corn gluten feed, DDGS = dried distillers grains + solubles, WDGS = wet distillers grains + solubles, CCDS=condensed corn distillers solubles (corn syrup), MDGS=modified wet distillers grains + solubles, steep is steep liquor from wet milling plants.
[2]DRC values based on NRC (1996) values with approximately 3500 samples
[3]Values are from spring, 2003 from only one plant in Nebraska that produces DDGS, WDGS, and CCDS with standard deviation based on weekly composites.
[4]DM values represent variation from daily composites for a 60-d period. Other nutrients are based on monthly composites for 2002 and half of 2003.
[5]NEg values are based on animal performance relative to DRC for all co-products. DDGS, WDGS, CCDS, and MDGS energy (NEg) values are dependent on dietary inclusion and should be used only as a guide.

protein, or UIP, commonly marketed to the poultry or pet industries. The importance of understanding the process is that the resulting feed products from these two industries are quite different.

Composition

Due to production process differences, corn milling co-products can vary in nutrient composition. To provide an overview of this composition and by production plants, refer to **Table 1**. Variation exists from plant to plant and even within a given plant. These table values should not replace sampling and analysis of feed from individual plants. The DDGS, WDGS and condensed corn distillers solubles (CCDS) are all from one plant in Nebraska and represent average values for 2003.

Examples of plants with an excellent database on variability are the Cargill facilities in Blair (NE), Eddyville (IA) and Dalhart (TX). The standard deviations are low on DM change from load to load. This relates to two things: process development to minimize variation and the quality control culture of personnel operating the plants to minimize variation in feed products. The energy values used in Table 1 are based on performance data summarized in this paper and other reviews.

The DDGS composition data in **Table 2** are based on the relative ratios of dried distillers grains to solubles ratio in DDGS (Corrigan et al., 2007a). The ethanol plant's normal DDGS averaged 19% solubles. However, in this study distillers grain products were produced with 0-22% solubles added back to the grains portion. Increasing the amount of solubles decreased the DM, CP and NDF content of the DDGS. However, the fat level increased in the DDGS as more solubles were added. As more solubles were added to the grains from 0-22%, the resulting DDGS changed from a golden yellow color to a brown color. However, the change in color was not related to total digestive tract protein digestibility as the protein was 97-98% digestible in all samples.

Samples of WDGS and modified WDGS (MDGS, partially dried, 42-50% DM) were collected for five consecutive days, across four different months, and within six dry milling plants and analyzed for DM, CP, fat, P and S (Buckner et al., 2008). Variation in DM content within each plant was minimal (coefficient of variation or CV was less than 3%), but DM was different across plants. Therefore, producers should be aware of the DM for each DGS product that is produced, particularly when buying DGS from more than one plant.

Table 2.[1] Nutrient composition and protein digestibility of DDGS based on solubles level.

	Solubles Level, % (DM)[2]				
	0	5.4	14.5	19.1	22.1
DM	96	92	91	89	90
CP, %	32	32	32	31	31
NDF, %	37	35	32	30	29
Fat, %	7	9	10	13	13
CP Digestibility, %[3]	97	97	98	98	98

[1]Adapted from Corrigan et al. (2009a).
[2] Solubles level calculated using % NDF of solubles (2.3%) and 0% solubles DDG.
[3] In situ total-tract protein digestibility.

On average, DGS contained 31.0% CP, 11.9% fat, 0.84% P and 0.77% S. Variation within days, across days, and within the same plants remained small for CP and P (CV less than 4%), but P varied some across plants. Variation in CP and P is likely of less nutritional concern. Fat content variation was slightly more but remained relatively small (CV less than 5%) within plants and within days, but greater variation was observed among ethanol plants. Fat content varied from 10.9 to 13.0% by plant, likely due to varying amounts of distillers solubles that the plants add to distillers grains. Therefore, producers should know the fat content from each plant and not be concerned with fat variation within a plant. Variation in S content was the largest for all nutrients tested as CV within days and across days (within the same ethanol plants) ranged from 3 to 13%. These data suggest S values should be routinely monitored as this can lead to nutritional challenges.

Benton et al. (2010) reviewed several published literature articles to summarize nutrient composition for DGS. Average nutrient composition for DGS was 31.5% CP, 10.5% fat, 6% starch, 43.2% NDF, 0.51% P and 0.57% S. Relatively low variation was observed for CP, NDF, P and S with CV of 10.7, 10.5, 8.4 and 6.3%, respectively. Greater variation was observed for fat and starch with CV of 31.4 and 36.3%, respectively. This large variation in fat and starch makes some logical sense as this is a summary of many samples over many ethanol plants. Not every ethanol plant is going to combine the same proportion of distillers solubles to distillers grains, nor use the same procedure for analyzing fat content. Ethanol plants are not likely going to ferment the same amount of starch from corn for ethanol production.

Although DM variation is probably of greatest importance with wet co-products, both fat and sulfur levels can vary in DGS. This can lead to changes in feeding value and potential for toxicity (especially polioencephalomalacia), respectively. Therefore, it is critical to have accurate analyses on feed ingredients and a sulfur analysis of the water that cattle drink. Previously, the NRC (1996) suggested that diets should not exceed 0.4% S (NRC, 1996), or even 0.3% S in high-grain feedlot diets (NRC, 2003). However, research has been conducted and will be discussed later that evaluates performance for cattle fed DGS diets with greater than 0.4% S. Thiamine is commonly added at 150-200 mg/steer daily as well to offset challenges related to sulfur-induced polio (PEM). This is an important issue to be aware of and to treat cattle as quickly as possible if any symptoms from PEM are observed.

Storage

Buying WDGS in the summer months can provide an opportunity for producers because these products historically are at their yearly economic low due to decreased demand. Producers can purchase large amounts of WDGS and store these until subsequent feeding in the winter. This is particularly helpful for small producers that cannot utilize semi-load quantities in a sufficient period of time to avoid spoilage. However, the main problem with storing these feeds is that they are very wet and do not compact well in silos or bags under pressure, which creates problems with the feed molding and difficulty in storing. WDGS has been successfully bagged if no pressure is applied to the bagger. Bags tend to settle because of the weight of the WDGS, resulting in low height and expanded width. MDGS and WCGF bag well, even with pressure.

Adams et al. (2008) conducted two experiments to determine methods to store WDGS (34% DM), because WDGS will not store in silo bags under pressure or pack into a bunker. The first study evaluated three forage sources, as well as DDGS or WCGF mixed with WDGS. The products were mixed in feed trucks and placed into 9 ft. diameter silo bags. The bagger was set at a constant pressure of 300 psi. The height of the silo bag was a determining factor of storability. Inclusion levels of the feedstuffs were adjusted to improve the bag shape. The recommended levels of feedstuffs for bagging with WDGS (DM basis) are 15% grass hay, 22.5% alfalfa hay, 12.5% wheat straw, 50% DDGS or 60% WCGF. The corresponding as-is percentages for the feedstuffs are 6.3, 10.5, 5.1, 27.5 and 53.7% of the mix, respectively.

The second experiment was conducted by mixing grass hay with WDGS and storing in a concrete bunker. Both 30 and 40% mixtures of grass hay with WDGS (DM basis) were packed into the bunker. These values correspond to 14.0 and 20.1% of the as-is grass hay mix. In both experiments, the product was stored more than 45 days and the apparent quality did not change. Wet DGS can be stored in a silo bag or bunker silo when mixed with drier or bulkier feedstuffs. More information is available at

Table 3.[1] DM loss and spoilage for 70% WDGS mixed with 30% straw or corn stalks.

	WDGS: Corn Stalks			WDGS: Straw	
	No cover	Plastic	Salt[2]	No cover	Solubles[3]
Barrel					
DM in, lb.	115.4	115.1	114.8	94.9	90.9
DM spoilage, lb.	20.2[a]	3.1[b]	19.8[a]	22.1[a]	8.6[b]
DM loss, lb.	17.6[a]	0.0[c]	4.2[b]	13.3[a]	0.35[c]
10 ft. Bunker[4]					
% DM loss[5]	3.4[a]	0.0[c]	0.82[b]	2.9[a]	0.1[c]
% Spoilage[6]	3.9[a]	0.6[c]	3.8[a]	4.9[a]	2.0[b]

[1]Adapted from Christensen et al. (2010).
[2]Salt was added to soluble at rate of 1.0 lb/ft^2.
[3]Solubles were added to simulate a 3-in cover equivalent, 45 lb (as-is); 16 lb of DM required in the barrel to provide 3 in.
[4]Losses and spoilage extrapolated to a bunker storage facility with 10 ft height, assuming all losses are from the surface and therefore the same whether a 27-in barrel or 10-ft bunker.
[5]% DM loss calculated based on the amount of loss as a percent of the total stored in a bunker that is 10 ft tall. The weight in a 10-ft bunker with 3 ft^2 surface area is calculated from DM density added to barrels.
[6]% Spoilage calculated similar to method for calculating % DM loss but without amount of spoilage DM.

Table 4.[1] **Nutrient composition**[2] **for non-spoiled and spoiled fractions of 70% WDGS stored with 30% straw or corn stalks with different covers.**

	Fat		pH		NDF		CP		Ash	
	Non-spoil	Spoiled	Non-spoil	Spoiled	Non-spoil	Spoiled	Non-spoil	Spoiled	Non-spoil	Spoiled
No cover	10.6	4.9	4.1	8.1	42.2	52.9	24.9	26.7	8.1	12.0
Plastic	10.1	7.2	3.9	7.0	45.4	49.3	23.2	27.4	8.2	12.0
Salt[3]	10.2	3.9	4.0	8.5	48.3	50.5	23.1	22.5	8.3	19.1
Solubles[4]	10.1	10.1	3.9	6.5	44.3	38.1	22.4	27.8	8.8	13.9

[1]Adapted from Yelden et al. (2010).
[2]Represented on a % of DM basis.
[3]Salt was added to solubles at rate of 1.0 lb/ft^2.
[4]Solubles were added to simulate a 3-in cover equivalent, 45 lb (as-is); 16 lb of DM.

http://beef.unl.edu, including articles on methods and design, videos for examples and an economic spreadsheet evaluating co-product storage. There has also been a manual published that discusses wet co-product storage in more detail that can be found on the website listed above.

Similar to silages, it is important that covers be evaluated for bunker storage methods to minimize shrink and spoilage. It is difficult to evaluate bunker covers without numerous bunkers or replication. Therefore, barrels may be a model for evaluating many cover treatments on spoilage and shrink when WDGS is stored. Spoilage amounts for a mix of 70% WDGS and 30% straw (DM basis) were evaluated in 55 gallon barrels with cover treatments including no cover, adding salt, covering with plastic and covering with distillers solubles (Christensen et al., 2010). The greatest proportion of DM loss and spoilage came as a result of not covering the mixes **(Table 3)**. When calculated to a 10 ft. bunker, this equaled 4.9% spoilage. Intermediate amounts of spoilage resulted from covering with salt (2.0% spoilage) and very small amounts of spoilage (less than 1%) resulted from covering with plastic and distillers solubles. Therefore, plastic and distillers solubles serve as the best covers to minimize spoilage and DM loss when storing WDGS in a bunker. However, when solubles are used as a cover, a DM loss of 25-50% of the solubles themselves are expected. Understanding amounts of spoilage and DM loss for storing co-products is relatively unimportant unless nutrient composition of the spoiled fraction is known. Yelden et al. (2010) analyzed spoiled and non-spoiled fractions of the same 70% WDGS and 30% straw mixture that was mentioned previously. In general, the spoiled feed results in decreased fat and increased pH, NDF, CP and ash compared to the unspoiled fractions **(Table 4)**. For the uncovered treatments, fat decreased from 10.6 to 4.9%, pH increased from 4.1 to 8.1, NDF increased from 42.2 to 52.9% and ash increased from 8.1 to 12.0% for the unspoiled and spoiled fractions, respectively. These differences are reduced when plastic and/or solubles are used as a cover treatment. During storage, microbes utilize organic materials (particularly fat) for fermentation growth, hence the nutrient composition changes.

The feeding value of stored WDGS mixed with straw was evaluated by Buckner et al. (2010) and was compared to feeding WDGS and straw mixed fresh at feeding (no storage) for growing cattle. Two mixtures were compared that included 30:70 WDGS:straw or 45:55 WDGS:straw (DM basis). The bagged mixes had been stored in silo bags for 45 days prior to trial initiation. To accurately determine the feeding value of the stored

Table 5.[1] **Steer performance for WDGS and Straw mixes fed fresh or ensiled.**

	WDGS: Straw Mix[2]			Storage Type[3]			
Performance	30:70	45:55	P-value	Fresh	Ensiled	P-value	Inter[4]
Initial BW, lb.	509	510	0.97	510	508	0.96	0.99
Ending BW, lb.	578	613	<0.01	585	597	0.43	0.71
DMI, lb./day	9.2	9.7	0.05	9.4	9.5	0.99	1.0
ADG, lb.	0.82	1.22	<0.01	0.89	1.07	0.02	0.16
F:G	11.3	8.0	<0.01	10.7	9.0	<0.01	0.10

[1]Adapted from Buckner et al. (2010).
[2]Main effects for WDGS and Straw mixtures.
[3]Main effects for the storage type of mixture fed.
[4]Interaction for mixture and type.
[ab]Means within type of mix effect and the same row without a common superscript differ ($P \leq 0.05$).

Table 6.[1] **Performance measurements for cattle fed increasing levels of WDGS[2].**

	CON	10WDGS	20WDGS	30WDGS	40WDGS
DMI, lb/d[3]	23.0	23.3	23.3	23.0	22.4
ADG, lb[3]	3.53	3.77	3.90	3.93	3.87
F:G[3]	6.45	6.17	5.95	5.85	5.78
12th Rib fat, in	0.48	0.52	0.54	0.55	0.55
Marbling score[4]	528	535	537	534	525

[1]Adapted from Bremer et al. (2010).
[2]CON = 0% WDGS, 10WDGS = 10% WDGS, 20WDGS = 20% WDGS, 30WDGS = 30% WDGS, 40WDGS = 40% WDGS. Represented as a % of diet DM.
[3]Quadratic response to level of WDGS in the diet ($P < 0.01$).
[4]Marbling score: 400 = Slight^0, 500 = Small^0, 600 = Modest^0.

mixes, cattle consuming the stored mixes were pair-fed to the cattle that were fed ad libitum with the fresh mixes. Cattle that consumed the 45:55 mixture had greater average daily gain (ADG) and dry matter intake (DMI), which calculated to improved feed to gain (F:G) **(Table 5)** due to more WDGS compared to straw. This suggested that increased levels of WDGS improves cattle performance in growing diets, which is well established.

Cattle fed the stored mixes had greater ADG with equal DMI (pair-fed based on methodology), thus decreased F:G. This difference in F:G calculated out to a 24% improvement in feeding value due to storing of WDGS with straw compared to feeding fresh. This improvement is likely due to improvement of the low-quality forage.

USE IN FEEDLOT CATTLE

Feeding Value

The first units of co-products added to a ration are primarily used to replace protein from urea or natural protein sources in the ration. Subsequent additions of co-products to the ration replace corn and other grains as energy sources. Feedlot diets that use DGS at levels less than 15 to 20% of diet DM serve as a protein source for the animal. Conversely, when DGS is added above these levels, the beef animal utilizes the DGS as an energy source.

The feeding value of DGS and CGF is dependent on whether the co-products are fed wet or dry and the level of dietary inclusion. Although the feeding value of WCGF is better than corn (100-112% the feeding value of corn), the feeding value of DCGF is 88% of dry-rolled corn (DRC) when fed at 25-30% of diet DM (Green et al., 1987; Ham et al., 1995).

There have been several research experiments conducted to evaluate inclusion levels of WDGS, MDGS and DDGS on cattle performance. To summarize these experiments, statistical meta-analyses were conducted to evaluate each of these types of DGS and account for differences observed across experiments conducted at the University of Nebraska (Bremer et al., 2010). The inclusion of DGS replaced equal DM portions of DRC and/or high-moisture corn (HMC).

In the meta-analysis that summarized 20 trials for feeding up to 40% WDGS (of diet DM), quadratic effects were observed for DMI, ADG and F:G **(Table 6)**. Optimum inclusion of WDGS was observed at 20% for DMI, 30% for ADG, and 40% for F:G. These improvements in F:G resulted in 30-50% greater feeding value for WDGS compared to corn at inclusions of 10-40%. Although these were quadratic relationships, feeding 40% WDGS resulted in greater ADG and lower F:G compared to a traditional corn-based diet. Greater 12th rib fat thickness and marbling scores result from feeding WDGS, which were also quadratic relationships. The meta-analysis that summarized MDGS in four feeding trials up to 40% diet DM also indicated quadratic relationships for DMI, ADG and F:G **(Table 7)**. Optimum inclusion of MDGS for DMI and ADG was at 20 and 30% inclusion and was at 40% for F:G. These improvements in cattle performance resulted in 15-30% greater feeding value for MDGS compared to corn, in which cattle had greater ADG and lower F:G for all inclusions up to 40%. A quadratic relationship was observed for 12th rib fat thickness and a linear relationship for marbling score for feeding MDGS. These cattle performance changes for MDGS were not as great as with WDGS.

Another meta-analysis that summarized DDGS in 4 trials also resulted in a quadratic effect for DMI as optimum inclusion was between 20 and 40% of diet DM **(Table 8)**. Linear relationships were observed for ADG and F:G as optimum inclusion was 40% DDGS. This resulted in a 13% improvement in feeding value when feeding DDGS compared to corn. A quadratic relationship resulted for 12th rib fat thickness, while no effect was observed for marbling score due to feeding DDGS compared to corn. This improvement in cattle performance was not as great as WDGS or MDGS, suggesting that drying DGS decreases its feeding value.

Table 7.[1] Performance measurements for cattle fed increasing levels of MDGS[2].

	CON	10MDGS	20MDGS	30MDGS	40MDGS
DMI, lb/d[3]	24.3	25.1	25.5	25.4	24.8
ADG, lb[3]	3.69	3.93	4.06	4.07	3.98
F:G[4]	6.58	6.41	6.25	6.17	6.17
12th Rib fat, in	0.51	0.57	0.60	0.60	0.58
Marbling score[5]	559	554	550	545	540

[1]Adapted from Bremer et al. (2010).
[2]CON = 0% MDGS, 10MDGS = 10% MDGS, 20MDGS = 20% MDGS, 30MDGS = 30% MDGS, 40MDGS = 40% MDGS. Represented as a % of diet DM.
[3]Quadratic response to level of MDGS in the diet ($P < 0.01$).
[4]Quadratic response to level of MDGS in the diet ($P = 0.07$).
[5]Marbling score: 400 = Slight^0, 500 = Small^0, 600 = Modest^0.

Table 8.[1] Performance measurements for cattle fed increasing levels of DDGS[2].

	CON	10DDGS	20DDGS	30DDGS	40DDGS
DMI, lb./day[3]	24.3	25.3	26.0	26.2	26.2
ADG, lb.[4]	3.46	3.59	3.71	3.84	3.96
F:G[4]	7.09	6.99	6.90	6.80	6.76
12th Rib fat, in.	0.44	0.49	0.51	0.51	0.48
Marbling score[5]	569	569	569	569	569

[1]Adapted from Bremer et al. (2010).
[2]CON = 0% DDGS, 10DDGS = 10% DDGS, 20DDGS = 20% DDGS, 30DDGS = 30% DDGS, 40DDGS = 40% DDGS. Represented as a % of diet DM.
[3]Quadratic response to level of DDGS in the diet (P = 0.03).
[4]Linear response to level of DDGS in the diet (P < 0.01).
[5]Marbling score: 400 = Slight[0], 500 = Small[0], 600 = Modest[0].

Table 9.[1] Performance measurements for cattle fed increasing levels of DGS[2].

	Level[3]			
	0	20	30	40
DMI, lb./day	24.6	26.3	25.9	26.2
ADG, lb.	3.58	4.08	4.05	4.19
F:G[4]	6.85	6.41	6.37	6.21
Carcass characteristics				
HCW, lb.	831	879	876	890
Marbling score[5]	607	609	599	603
12th Rib fat. In.	0.50	0.62	0.62	0.65

[1]Adapted from Nuttleman et al. (2010).
[2]Overall main effect for level of DGS including WDGS, MDGS, and DDGS.
[3]Level of distillers grains with solubles (DGS, % of diet DM).
[4]Linear response to level of DGS in the diet (P < 0.01).
[5]Marbling score: 400 = Slight[0], 500 = Small[0], 600 = Modest[0].

Table 10.[1] Performance measurements for cattle fed WDGS, MDGS, and DDGS[2].

Parameter	WDGS	MDGS	DDGS
DMI, lb./day	24.8[a]	26.4[b]	27.1[b]
ADG, lb.	4.11	4.17	4.05
F:G	6.06[a]	6.33[b]	6.67[c]
Carcass characteristics			
HCW, lb.	882	887	877
Marbling score[3]	610	599	602
12th Rib fat, in.	0.63	0.64	0.60

[1]Adapted from Nuttleman et al. (2010).
[2]Overall main effect of feeding DGS at 20, 30, and 40% DM inclusion.
[3]Marbling score: 400 = Slight[0], 500 = Small[0], 600 = Modest[0].
[abc]Means within the same row without a common superscript differ (P < 0.05).

Although all of these meta-analysis summaries have a large amount of data to support the results and are representative over many experiments, they were never fed in the same experiment to compare to one another and remove any trial biases, until recently. Nuttelman et al. (2010) fed WDGS, MDGS and DDGS in the same trial at 0, 20, 30 and 40% dietary DM inclusions. No interactions between co-product level (20, 30 or 40%) and type (WDGS, MDGS and DDGS) were observed. Therefore, only the main effects of co-product level **(Table 9)** and co-product type **(Table 10)** were summarized. Optimum inclusion of DGS for DMI resulted at 20-40% inclusion and 40% DGS was optimum for ADG and F:G. A linear increase was observed for fat depth and marbling score was unchanged as DGS inclusion increased. Therefore, these data suggest that cattle performance is enhanced the most with increasing levels of DGS up to 40%, similar to the meta-analyses. Within co-product type, no differences were observed for ADG, but DMI was greatest for DDGS, least for WDGS, and intermediate for MDGS. This suggests that cattle consume more feed to support the same gain as distillers are dried (DDGS) or partially dried (MDGS) compared to no drying (WDGS).

Distinct differences exist for WCGF, even within companies, due to plant-to-plant variation. Stock et al. (1999) divided WCGF into two main categories, depending on the ratio of steep to bran. Based on differences in the amount of steep added, WCGF has 100-109% the feeding value of DRC when fed at levels of 20-60% of diet DM (Stock et al., 1999). Higher feeding value (and protein) is associated with increases in steep added in WCGF. Sweet Bran (Cargill, Blair, NE) has more steep relative to corn bran and is of higher feeding value than traditional WCGF. However, feeding WCGF results in better performance than DCGF (Ham et al., 1995). A meta-analysis was conducted by Bremer et al. (2008) to evaluate increasing levels of Sweet Bran in feedlot diets. Cattle consume more DM, have greater ADG and lower F:G when fed Sweet Bran compared to corn **(Table 11)**. Each of these parameters resulted in a linear relationship, thus indicating that performance theoretically continues to increase up to 40% Sweet Bran (maximum included in this dataset). Cattle fed Sweet Bran had greater 12th rib fat thickness and marbling scores.

Table 11.[1] Performance measurements for cattle fed increasing levels of Sweet Bran WCGF[2].

	CON	10SB	20SB	30SB	40SB
DMI, lb./day[3]	21.8	22.3	22.9	23.4	24.0
ADG, lb.[3]	3.67	3.80	3.92	4.05	4.17
F:G[3]	5.96	5.90	5.85	5.80	5.74
12th Rib fat, in.	0.46	0.47	0.49	0.50	0.52
Marbling score[4]	492	497	501	506	511

[1]Adapted from Bremer et al. (2008).
[2]CON = 0% Sweet Bran, 10SB = 10% Sweet Bran, 20SB = 20% Sweet Bran, 30SB = 30% Sweet Bran, 40SB = 40% Sweet Bran. Represented as a % of diet DM.
[3]Linear response to level of SB in the diet ($P \le 0.03$).
[4]Marbling score: 400 = Slight^0, 500 = Small^0, 600 = Modest^0.

The improved animal feeding performance from co-product feeds translates into increased 12th rib fat thickness and either equal or greater marbling scores compared to corn. Cattle gain weight quicker when fed co-products compared to feedlot cattle fed corn. Therefore, cattle either require fewer days on feed to reach the same ending weight, backfat and marbling score or they will be slaughtered heavier and fatter with co-products in the diet. The improved fat thickness and marbling is presumably due to improved daily gains and energy content of the diets when co-products are fed.

Interaction of corn processing and co-product feeding

Feeding corn milling co-products in feedlot diets reduces acidosis-related challenges. Both WCGF and WDGS have little to no starch remaining following the milling process. Therefore, feeding these co-products will dilute dietary starch that is fed and influence rumen metabolism. Feeding WCGF helps prevent the risk of acidosis with high-grain diets as observed by greater rumen pH in metabolism steers (Krehbiel et al. 1995). In many studies, feeding WCGF resulted in increased DMI, which would be a common response to decreased subacute acidosis. However, processing corn increases the rate of digestion by rumen microbes. As a result, more rumen acid is produced, which increases the risk of acidosis (Stock and Britton, 1993). Feeding co-products may affect the feeding value and/or acidosis challenges with different corn processing types.

Numerous studies have been conducted at the University of Nebraska to determine if feeding values are improved in diets containing WCGF when corn is more intensely processed. Scott et al. (2003) evaluated various corn processing techniques and

Table 12.[1] Effect of corn processing when fed with wet corn gluten feed on cattle performance.

25% WCGF	Processing method[2]			
	DRC	RHMC	GHMC	SFC
ADG, lb.	4.23	4.21	4.24	4.33
F:G	5.49[c]	5.13[b]	5.05[b]	4.91[a]
NEg (corn), Mcal/cwt	70.0	76.4	77.7	80.4
Fecal starch, %	19.2[c]	10.6[ab]	8.4[b]	4.1[a]
32% WCGF with calves	Processing method[2]			
	Whole	DRC	RHMC	SFC
ADG, lb.	4.18	4.24	4.15	4.25
F:G	5.92[d]	5.52[c]	5.26[b]	5.18[a]
22% WCGF with yearlings	Processing method[2]			
	DRC	RHMC	SFC	
ADG, lb.	3.98[a]	4.02[a]	4.22[b]	
F:G	6.09[b]	5.97[b]	5.54[a]	

[1]Adapted from Scott et al. (2003) and Macken et al. (2006).
[2]DRC=dry rolled corn, RHMC=rolled high moisture corn, GHMC=ground high moisture corn, SFC=steam flaked corn, whole=whole corn.
[abcd]Means with different superscripts differ ($P < 0.05$).

observed improved F:G as processing intensity of the corn increased when fed to calves or yearlings **(Table 12)**. Ranking of processing based on F:G (lowest to highest) was whole corn, DRC, HMC and steam-flaked corn (SFC) when fed to finishing calves. Relative improvements in F:G for DRC, HMC and SFC compared to whole corn were 6.8, 11.1 and 12.5%, respectively. When fed to yearlings, response to processing was not as favorable as with calves. Feeding HMC did not significantly improve F:G compared to DRC. Macken et al. (2006) fed DRC, SFC and HMC processed as either rolled (roller mill, RHMC) and ground (tub grinder, GHMC) to calves, with all diets containing 25% WCGF. Whole corn was not fed in this study, but performance was improved as the corn was more intensely processed (Table 12). Net energy calculated from performance (NRC, 1996; Owens et al., 2002) was increased by 9.1, 11.0 and 14.9% for RHMC, GHMC and SFC, respectively, compared to DRC.

HMC appears to have greater feeding value when diets contain WCGF than what was previously observed in diets not containing WCGF. Because HMC has greater ruminal starch digestibility than DRC or SFC (Cooper et al., 2002), cattle fed HMC have a greater potential for acidosis when HMC is fed alone. However, feeding HMC in combination with WCGF appears to increase efficiency of HMC utilization, perhaps by reducing acidosis. For example, the feeding value of HMC in diets containing HMC as the only grain source is lower than that observed when fed in combination with other grains (Stock et al., 1991) or corn co-products. Previous reviews reported that HMC feeding resulted in 2% greater efficiency than DRC (Owens et al., 1997). However, based on research with HMC-based diets containing 20 to 35% WCGF, cattle are 5 to 10% more efficient than those fed WCGF and DRC. Our conclusion is that intense corn processing (HMC or SFC) has tremendous value in diets containing WCGF.

However, optimal corn processing in diets containing WDGS appears to be somewhat different than in diets containing WCGF. Vander Pol et al. (2008) fed diets containing 30% WDGS with either whole corn, DRC, HMC, a 50:50 blend of HMC and DRC (DM basis), or SFC to finishing steers for 168 days. Cattle fed DRC, HMC or a combination of HMC and DRC gained more and were more efficient than cattle fed whole corn **(Table 13)**. Interestingly, cattle fed SFC did not gain as efficiently.

Corrigan et al. (2009b) investigated feeding DRC, HMC or SFC in diets containing 0, 15, 27.5 or 40% WDGS. They found greater performance responses

Table 13.[1] Effect of corn processing on cattle performance when fed diets containing 30% WDGS.

	Processing method[2]				
	Whole	DRC	DRC/HMC	HMC	SFC
DMI, lb./day	23.1[a]	22.6[a]	21.5[b]	21.0[bc]	20.4[c]
ADG, lb.	3.85[a]	4.05[b]	3.91[ab]	3.89[ab]	3.59[c]
F:G	6.07[a]	5.68[bc]	5.61[bc]	5.46[c]	5.76[b]

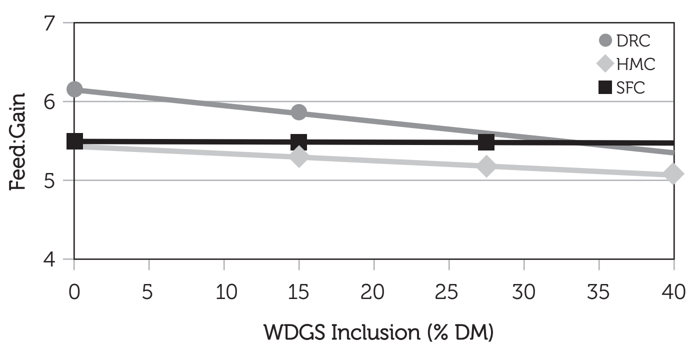
[1]Adapted from Vander Pol et al. (2006).
[2]Whole = whole corn, DRC = dry rolled corn, DRC/HMC = 50:50 blend of dry rolled corn and high moisture corn, HMC = high moisture corn, SFC = steam flaked corn.
[abcd]Means within a row with different superscripts differ ($P < 0.05$).

Table 14.[1] **Feeding value**[2] **of WDGS in DRC or DRC and HMC combination diets at 0 to 40% DM inclusion**[3] **for calves and yearlings.**

Diet:	0WDGS	10WDGS	20WDGS	30WDGS	40WDGS
Calves					
DRC	—	136	136	136	136
DRC:HMC	—	124	124	124	124
Yearlings					
DRC	—	167	159	151	143
DRC:HMC	—	154	146	138	132

[1]Adapted from Bremer et al. (2011).
[2]Calculated as difference in F:G between WDGS treatment level and 0% WDGS inclusion and divided by % of WDGS inclusion.
[3]0WDGS = 0% WDGS, 10WDGS = 10% WDGS, 20WDGS = 20% WDGS, 30WDGS = 30% WDGS, 40WDGS = 40% WDGS. Represented as a % of diet DM.

Figure 3.[1] **Feed: Gain of WDGS with different corn processing types**[2,3]



[1]Adapted from Corrigan et al. (2009b).
[2]Linear effect of WDGS within DRC (P<0.01)
[3]Linear effect of WDGS within HMC (P<0.05)

for greater WDGS inclusion in diets based on DRC and HMC **(Figure 3)**. Optimal ADG and F:G resulted for 40% WDGS in DRC based diets, 27.5% WDGS in HMC based diets and 15% WDGS in SFC based diets. In addition, when 40% WDGS was included in DRC diets, cattle performed just as efficiently as cattle fed any of the SFC diets. A greater performance response to WDGS inclusion in diets based on less intensely processed grain may render them as an economically attractive alternative compared to diets based on more intensely processed grains. It is unclear why steam flaking did not improve performance when diets contained WDGS, which is a completely different response than diets that contain WCGF.

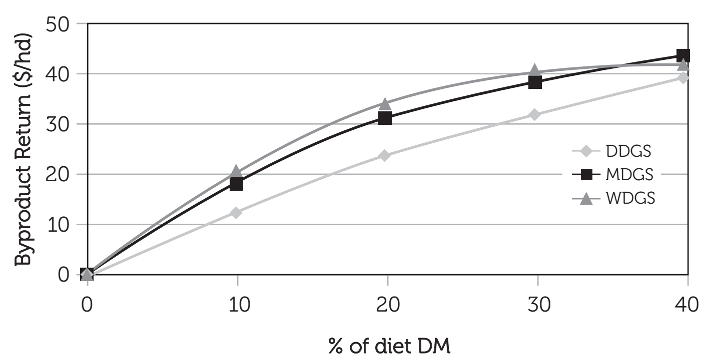
In the meta-analysis of 20 experiments for feeding increasing dietary levels of WDGS conducted by Bremer et al. (2011), they evaluated feeding value differences of WDGS when fed in either DRC or DRC and HMC blended diets and when fed to calves or yearlings. Feeding value was calculated based on the F:G difference between a diet including WDGS to the predominately corn based diet, then divided by the % inclusion of WDGS. For both calves and yearlings, greater feeding values resulted from including WDGS in DRC based diets compared to the DRC and HMC blended diets **(Table 14)**. This further agrees with previous research that greater performance responses are observed when WDGS is included in diets with less intensely processed corn. Greater feeding values were also observed when WDGS was included in DRC or DRC and HMC based diets for yearlings compared to calves. This suggests that cattle producers can feed WDGS to yearlings and get a greater performance response to WDGS compared to a predominately corn-based diet than with calves. It is unclear why the energy response to feeding WDGS is greater with yearlings than calves.

Economics for feeding co-products

Performance equations from the meta-analysis summaries that include the experiment that directly compared WDGS, MDGS and DDGS were used to design an economic model for determining co-product returns for feeding to cattle (Buckner et al., 2011). These equations are used to predict DMI, ADG and F:G, which are used to change days on feed for cattle that would be slaughtered at the same weight. A user defines their own inputs of cattle weights and prices, co-product inclusions, co-product trucking costs and yardage costs to allow flexibility in generating each producer's expected returns in any given feeding situation. This model can be downloaded in an Excel spreadsheet, called Cattle CODE, from the "by-products feed" section on the http://beef.unl.edu website.

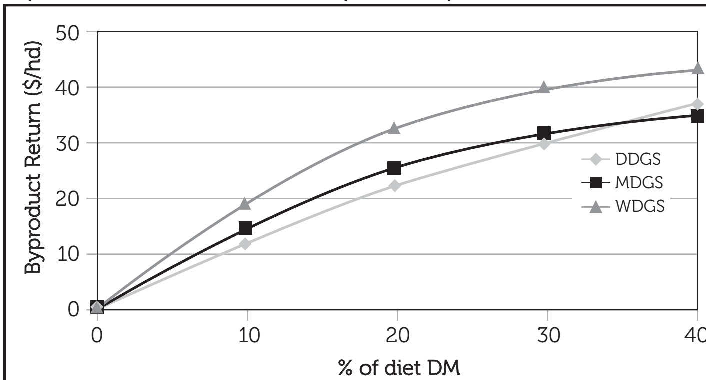
To explain some examples, current prices (Spring 2010) for corn and DGS were used in the first scenario. Corn was priced at $3.30/bu., WDGS at $34 per ton as-is (32% DM), MDGS at $46 per ton as-is (48% DM) and DDGS at $100 per ton as-is (90% DM). An assumption is that each product would be transported 50 miles to the feedlot with $3.50 per loaded mile trucking cost. These economic returns are presented in **Figure 4**. Positive economic returns (up to $40 per head) resulted from feeding WDGS, MDGS and DDGS, largely due to improved ADG, F:G and decreased days on feed resulting in less yardage costs. Within each DGS, DDGS resulted in the least economic returns and WDGS and MDGS had greater returns but were similar to one another. Although WDGS results in better cattle performance than MDGS, this was offset in the economic returns due to a cheaper cost for MDGS on a 100% DM basis.

Figure 4.[1] Economic returns for feeding DGS (up to 40% DM) based on current DGS prices compared to a conventional corn diet.



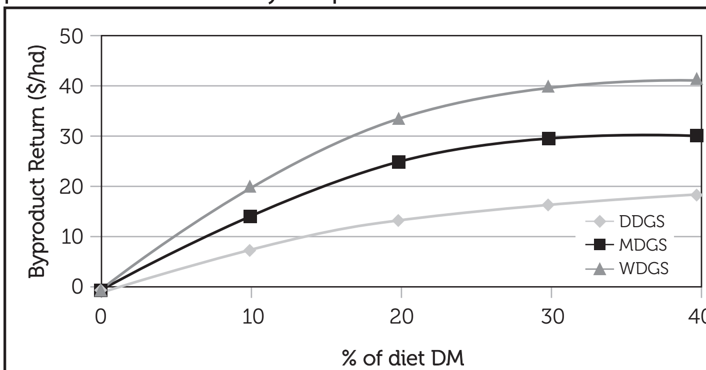
[1]Adapted from Buckner et al. (2011).

Figure 5.[1] Economic returns for feeding DGS (up to 40% DM) when DGS is priced equal at the feedlot.



[1]Adapted from Buckner et al. (2011).

Figure 6.[1] Economic returns for feeding DGS (up to 40% DM) when DGS is priced relative to drying costs that the ethanol plants must incur to dry the products.



[1]Adapted from Buckner et al. (2011).

Table 15. Escape protein values.

Source	% bypass protein
Soybean meal	30
Wet distillers grains	60-70
Dried distillers grains	60-70
Distillers solubles	20

In a second scenario, DGS was assumed to be purchased at the same price ($ per ton of DM) at the feedlot. Corn remained priced at $3.30/bu. and DGS was priced at 80% the price of corn on a DM basis. The economic returns for feeding DGS closely resembled the feeding values for these products **(Figure 5)**. Although each of these three co-products returned a profit compared to feeding corn, DDGS remained the lowest, followed by MDGS and feeding WDGS produced the greatest returns.

A third scenario was conducted to evaluate the cost of drying DGS from its original WDGS form and if producers had to purchase these products based on drying costs. Corn and WDGS were priced using the current prices of $3.30/bu. and $34 per ton as-is (32% DM), respectively. Therefore, WDGS price was $106.25 per ton of DM. Price of DDGS was based on the price for WDGS plus an additional $30 per ton (on a 90% DM basis) to dry this to 90% DM, equaling $139.58 per ton (100% DM basis). Price of MDGS was proportional to the added cost for drying WDGS to 48% DM, equaling $54.72 per ton as-is ($114.01 per ton on 100% DM basis). This scenario was conducted to evaluate what the benefit to producers could be if ethanol plants priced DGS based on drying costs incurred during production. Due to drying, economic returns for MDGS and DDGS decreased to less than $20 per head **(Figure 6)**. However, the returns for feeding WDGS remained greater ($30-40 per head) due to no drying costs and greater cattle performance.

Table 16. Wet and dry distillers grains for calves

Supplement	ADG	Protein efficency[1]	ADIN[2]
Urea	1.00	—	—
WG	1.46	2.6	—
DDGS	1.42	2.0	9.7
DDGS	1.47	1.8	17.5
DDGS	1.54	2.5	28.8

[1]Pounds gain/lb supplemental protein.
[2]Acid detergent insoluble N.

Protein needs

In certain production situations, light weight (less than 750 lb.) finishing cattle may need to be supplemented with UIP (bypass) protein to meet metabolizable protein (MP) requirements. Wet or dry DGS is an excellent source of UIP. The values obtained from feeding trials for UIP are shown in **Table 15**. Wet grains were compared to dry grains and the value of the protein was similar **(Table 16)**. This suggests that the high escape protein value of DGS is due to the innate characteristics of the protein and not to drying or moisture content, and does not appear to be influenced by acid-detergent insoluble protein (ADIN), which is a common measure of heat damaged protein.

Distillers grains contain approximately 65% UIP (% of CP), consequently diets that include DGS fed as an energy source (generally greater than 15% diet DM) are commonly deficient in degradable intake protein (DIP) but contain excess MP. Cattle convert excess MP to urea, which is potentially recycled to the rumen and can serve as a source of DIP. Vander Pol et al. (2005) fed DDGS to finishing cattle at either 10 or 20% of diet DM with or without added urea. No advantage was observed for cattle supplemented with urea (DIP) or not, suggesting recycling was occurring in finishing diets including 10 or 20% DDGS. However, some numerical differences suggested a conservative approach to balancing diets based on protein needs would be to follow NRC 1996 guidelines for DIP supplementation if DGS are provided at less than 20% of diet DM.

Jenkins et al. (2010) fed 0, 0.5, and 1.0% urea (DIP) to DRC based diets containing 25% WDGS. The diet containing 1.0% urea was the only diet that was calculated to meet DIP requirements. In the first 61 days on feed of the 142 feeding period, DMI was similar across urea levels, but ADG increased with added urea resulting in decreased F:G. However, there were no cattle performance differences over the entire feeding period. These data suggest that when DGS are fed with DRC at inclusions greater than 20% of diet DM, then recycling occurs and is sufficient to meet the DIP requirements.

Interactions of roughage and co-products feeding

Forages ("roughages") are often included at low levels (<12% of diet DM) to control acidosis and maintain intake in feedlot cattle (Stock and Britton, 1993). Since co-products reduce the occurrence of acidosis in feedlot cattle, then perhaps roughage levels can be reduced from conventional levels in diets containing co-products. Farran et al. (2004) fed either 0 or 35% WCGF with 0, 3.75 or 7.5% alfalfa hay at each level (i.e., treatments were factorialized with WCGF level and hay level). There was a significant interaction between WCGF and alfalfa level on F:G. Therefore, only simple effects were discussed **(Table 17)**. Increasing alfalfa hay level with 0% WCGF increased ADG and DMI with no effect on F:G. With 35% WCGF, increasing alfalfa hay increased ADG and DMI, but hindered (increased) F:G linearly. Roughages can perhaps be reduced in DRC-based diets containing 35% or more WCGF. However, ADG was reduced for the 0% hay and 35% WCGF treatment, so a small amount of roughage is recommended even when WCGF is included. Similar results have been observed with SFC-based diets where alfalfa can be reduced to 2% with at least 25% WCGF (Sindt et al., 2001). Parsons et al. (2001) observed no change in F:G when alfalfa hay was decreased from 9 to 0% in SFC diets containing 40% Sweet Bran, but DMI and ADG decreased linearly. Just as with data in conventional corn-based diets, the optimum amount of roughage appears to be dependent on grain processing and level of WCGF.

Alfalfa hay levels have also been fed to feedlot cattle at increasing levels of 3, 6, 9, 12 and 15% (of diet DM) in SFC-based diets containing 25% DDGS (Miller et al., 2009). A quadratic response was observed for DMI and ADG with increasing levels of alfalfa hay in diets, but with no response in F:G **(Table 18)**. The optimum inclusion level of alfalfa hay in this trial was 9-12%. A second trial evaluated alfalfa hay levels of 7.5, 10 and 12.5% (of diet DM) in SFC-based diets containing 15 or 30% WDGS in a 3 x 2 factorial arrangement of treatments (May et al., 2010). These treatments were also compared to a control diet containing 10% alfalfa hay with no WDGS. Regardless of 15 or 30% WDGS, greater inclusions of alfalfa hay promoted greater DMI and poorer F:G with no affect on ADG **(Table 19)**. The control diet resulted in the lowest DMI and ADG suggesting that WDGS promotes greater cattle performance. These data agree with Miller et al. (2009) that including increasing amounts of alfalfa hay up to 10% promotes greater DMI. Although DDGS and WDGS may offset some acidosis challenges, these trials suggest some roughage should remain in the diets to promote DMI and sometimes aid ADG and F:G.

Benton et al. (2007) fed alfalfa hay, corn silage or corn stalks as the roughage source in 30% WDGS (DM basis) diets. Each of the sources were included at a conventional level, one-half that level, and compared to a diet with no roughage **(Table 20)**. The normal level was equal to 8% alfalfa hay and the

Table 17.[1] **Effect of increasing alfalfa hay level in diets with and without WCGF for finishing yearlings fed dry-rolled corn based diets.**

	0 % WCGF			35% WCGF		
Alfalfa level	0	3.75	7.5	0	3.75	7.5
DMI, lb./day[2]	22.7	23.8	24.2	23.3	24.9	25.6
ADG, lb.[2]	3.68	4.01	4.01	3.94	4.07	4.07
F:G[3]	6.21	5.95	6.02	5.95	6.10	6.25

[1]Adapted from Farran et al. (2004).
[2]Non-significant interaction between WCGF and alfalfa level; Significant ($P < 0.10$) increase due to WCGF; Significant ($P < 0.03$) linear increase for alfalfa level.
[3]WCGF x alfalfa level interaction ($P < 0.09$); Linear effect ($P < 0.06$) of alfalfa level within 35% WCGF, no effect of alfalfa hay with 0% WCGF.

Table 18.[1] **Effects of increasing alfalfa hay in steam flaked corn diets containing 25% DDGS on cattle performance.**

	Alfalfa hay, %[2]				
	3	6	9	12	15
DMI, lb./day[3]	23.6	24.4	24.8	26.1	25.4
ADG, lb.[3]	3.39	3.49	3.56	3.65	3.55
F:G	6.96	6.99	6.97	7.16	7.16

[1]Adapted from Miller et al. (2009).
[2]Represted as a % of diet DM.
[3]Quadratic response to level of alfalfa hay in the diet ($P < 0.01$).

Table 19.[1] **Effect of alfalfa hay level in steam flaked corn diets containing 15 or 30% WDGS on cattle performance.**

	Treatment[2]						
	CON	15DG-L	15DG-M	15DG-H	30DG-L	30DG-M	30D-H
DMI, lb./day	19.5	19.8	19.8	20.7	19.6	19.7	20.2
ADG, lb.	3.26	3.38	3.35	3.49	3.38	3.22	3.33
F:G	5.95	5.81	5.92	5.99	5.78	6.13	6.02

[1]Adapted from May et al. (2010).
[2]Control = 0% WDGS with 10% alfalfa hay, 15DG-L = 15% WDGS with 7.5% alfalfa hay, 15DG-M = 15% WDGS with 10% alfalfa hay, 15DG-H = 15% WDGS with 12.5% alfalfa hay, 30DG-L = 30% WDGS with 7.5% alfalfa hay, 30DG-M = 30% WDGS with 10% alfalfa hay, 30DG-H = 30% WDGS with 12.5% alfalfa hay.

Table 20.[1] **Effects of roughage source and level compared to no roughage inclusion on performance of steers fed diets containing 30% WDGS.**

Treatments[2]	CON	LALF	LCSIL	LCSTK	NALF	NCSIL	NCSTK
Roughage, %[3]	0.0	4.0	6.1	3.0	8.0	12.3	6.1
DMI, lb./day	22.3[a]	24.4[b]	24.3[b]	25.0[bc]	25.7[c]	25.3[c]	25.6[c]
ADG, lb.	4.33[a]	4.52[ab]	4.52[a]	4.79[c]	4.75[bc]	4.75[bc]	4.80[c]
F:G	5.14	5.37	5.36	5.20	5.41	5.33	5.32
Profit over CON, $[4]	0[a]	9[ab]	9[ab]	31[c]	23[bc]	27[bc]	29[bc]

[1]Adapted from Benton et al. (2007).
[2]CON=Control, LALF=low alfalfa hay, LCSIL=low corn silage, LCSTK=low corn stalks, NALF=normal alfalfa hay, NCSIL=normal corn silage, and NCSTK=normal corn stalks.
[3]Inclusion level of each roughage source in the finishing diet (DM basis).
[4]Profit: treatment final steer profit accounting for initial steer cost, health cost, yardage, interest and death loss minus control finished steer profit.
[abc]Means in a row with unlike superscripts differ ($P < 0.05$).

low level was equal to 4% alfalfa hay. Corn silage and corn stalks diets were formulated to provide NDF (from roughages only) equal to the alfalfa hay diets. In general, conventional roughage levels increased DMI, ADG and profit. When roughage was eliminated from the 30% WDGS diets, F:G was improved but DMI, ADG and profit were decreased compared with diets containing normal levels of alfalfa (8%), corn stalks (6%) or corn silage (12%). Therefore, it is not beneficial to completely eliminate roughage sources from finishing diets containing 30% WDGS (DM basis). Interestingly, feeding corn stalks was at least as good or better in terms of performance. Feeding wet co-products allows for lower quality roughages to be used because protein is not needed due to higher protein in co-products compared to corn and mixing/palatability are aided with WDGS. The moisture in diets containing WDGS also allows for decreased sorting. As roughages contain different amounts of fiber content, roughages can be exchanged on the basis of NDF in the roughage (Galyean et al., 2003).

Using co-products in adaptation diets

Receiving cattle in feedlots can be a challenging period. Feedlot managers prefer to minimize forages (i.e. roughages) in diets as they are a high-shrink, bulky feed that is challenging to handle and is quite expensive most of the time relative to energy. As a general rule, half of the roughages needed by feedlots are used during the grain adaptation phase of transitioning cattle from a forage-based diet to a high concentrate diet. These transition diets are usually fed in the first 21-28 days that cattle are in feedlots and are used to help control acidosis. As co-products have little to no starch, there is a possibility to use these in adaptation diets and aid in acidosis control while removing most of the roughages in this transition period.

Traditionally, cattle start on adaptation diets with about 50% hay and 50% concentrate. Diets are then changed about every 3-7 days and hay is incrementally removed from the diets and replaced with concentrate, usually corn. These steps are continued until cattle begin to consume the final finishing diet, which is fed until the cattle are sent to market.

An initial experiment was conducted evaluating Sweet Bran in adaptation diets compared to the traditional method of using alfalfa hay (Huls et al., 2009b). Sweet Bran was included at 87.5% of diet DM in the first adaptation diet and was incrementally decreased in the following four adaptation diets to 35% in the finishing diet. The WCGF was replaced with DRC and 7.5% alfalfa hay was included in each diet. This adaptation system was compared to alfalfa hay in the first diet at 45% inclusion, which was decreased to 7.5% through four adaptation diets. The remainder of the diet contained DRC, which increased as alfalfa hay was reduced. DMI increased as cattle went through each system, suggesting ruminal adaptation to the diet changes. Rumen pH also decreased as alfalfa hay or Sweet Bran was removed in diets, likely due to increased starch content from DRC. Cattle that were fed the Sweet Bran diets had greater DMI, which was similar to the increased DMI observed in finishing trials compared to corn **(Table 21)**. Cattle fed the Sweet Bran diets also had decreased average pH and spent more time with a rumen pH below 5.6 (point for subacute acidosis). However, this decrease in pH might have been due to greater intakes and that Sweet Bran has more energy than hay.

A follow-up study was conducted to evaluate a Sweet Bran adaptation system to alfalfa hay on cattle performance (Huls et al., 2009a). The concept was similar to the metabolism trial. In the Sweet Bran system, Sweet Bran was included at 80% of diet DM in the first adaptation diet and was decreased to 35% in the finishing diet. In the hay system, alfalfa hay was included at 37.5% in the first adaptation

Table 21.[1] Effects of cattle performance when adapting cattle to finishing diets using a Sweet Bran system compared to a traditional alfalfa hay system[2].

	CON	Sweet Bran
Metabolism trial		
DMI, lb./day	16.1	21.8
Average rumen pH	6.28	5.84
Time pH < 5.6, minute	113	321
Finishing trial		
DMI, lb./day	20.8	20.8
ADG, lb.	3.30	3.46
F:G	6.30	6.01

[1]Adapted from Huls et al. (2009a and 2009b).
[2]Adaptation treatments where CON = decreasing alfalfa hay and increasing corn as steers go through adaptation periods; Sweet Bran = decreasing Sweet Bran and increasing corn as steers go through adaptation periods.

Table 22.[1] Effects of grain adaptation with WDGS or a traditional alfalfa hay system[2].

	CON	WDGS
DMI, lb./day	11.3	10.1
Average rumen pH	5.70	5.53
Average [H_2S]	5.6	13.2

[1]Adapted from Rolfe et al. (2010).
[2]Adaptation treatments where CON = decreasing alfalfa hay and increasing corn as steers go through adaptation periods; WDGS = decreasing WDGS and increasing corn as steers go through adaptation periods.

Table 23.[1] Effects of grain adaptation with a Sweet Bran or WDGS system[2].

	Sweet Bran	WDGS
DMI, lb./day	21.6	17.0
Average rumen pH	5.80	5.60
Average [H_2S]	3.63	7.20

[1]Adapted from Sarturi et al. (2010a).
[2]Adaptation treatments where Sweet Bran = decreasing Sweet Bran and increasing corn as steers go through adaptation periods; WDGS = decreasing WDGS and increasing corn as steers go through adaptation periods.

diet and was decreased to 0% in the finishing diet; Sweet Bran was held constant at 35% inclusion. In both of these systems, a 1:1 blend of DRC and HMC replaced equal portions of Sweet Bran and alfalfa hay in the adaptation diets, all adaptation diets contained 15% corn silage as a source of roughage, and cattle remained on the same final finishing diet of 35% Sweet Bran, 22.5% of each DRC and HMC, 15% corn silage and 5% dry supplement from day 27 to 173 for both adaptation systems. Therefore, any cattle performance effects were only due to the different adaptation diets. Cattle consumed the same amount of DM, but cattle that consumed the Sweet Bran adaptation diets had greater ADG and lower F:G (Table 21). From this trial, not only is there the possibility that cattle feeders can greatly decrease their forage needs during the adaptation period, but cattle performance can also be improved due to feeding Sweet Bran in place of alfalfa during adaptation.

WDGS was used in adaptation diets compared to alfalfa hay to evaluate intake and ruminal pH (Rolfe et al., 2010). In the WDGS adaptation system, WDGS was included at 87.5% in the first diet and was incrementally decreased through a series of four diets to 35% for the finishing diet; each adaptation diet contained 7.5% alfalfa hay. In the alfalfa hay system, 45% was included in the first diet and was decreased through four adaptation diets to 7.5% in the finishing diet; each adaptation diet included 35% WDGS. In both systems, the removal of WDGS and alfalfa hay was replaced with DRC. As with the Sweet Bran adaptation trial, DMI increased as cattle were transitioned through adaptation diets and the level of concentrate was increased. Conversely, rumen pH decreased as concentrate level increased, likely due to greater DMI and more rumen starch load. Cattle that consumed the WDGS adaptation diets had lower DMI and rumen pH compared to the traditional hay system **(Table 22)**. The decreased

DMI could be a result of not needing to consume as much feed due to higher energy content and little dietary roughage that would promote greater DMI.

Although these previous experiments indicated that Sweet Bran and WDGS might provide an opportunity for cattle producers to use these co-products in adaptation diets as a means of removing roughage needs, they never compared the two products together in the same experiment. Therefore, Sarturi et al. (2010a) evaluated Sweet Bran and WDGS in the same metabolism trial to compare them directly. In each of these systems, the individual co-product was included in the first diet at 87.5% DM with 7.5% alfalfa hay and 5% supplement. Subsequently, inclusion of co-products decreased over four adaptation diets to 35% DM inclusion in the finishing diet and was replaced with DRC. A common diet was then fed to both sets of cattle that included 17.5% of each Sweet Bran and WDGS to account for animal-to-animal variation (used as covariate). Similar to previous adaptation trials, DMI increased and rumen pH decreased as DRC in adaptation diets was increased. In direct comparison, feeding WDGS in adaptation diets resulted in lower DMI and rumen pH compared to Sweet Bran **(Table 23)**. Although feeding WDGS resulted in lower rumen pH through the initial adaptation diets, these values were not below those observed when cattle had similar rumen pH on the common finishing diet.

Cattle have lower rumen pH and DMI when they are fed WDGS compared to Sweet Bran or an alfalfa hay adaptation system. However, cattle appear to be able to control these pH levels in which the rumen does not become acidotic. Therefore, feeding Sweet Bran and WDGS appear to provide alternatives to feeding roughages in large amounts during the adaptation phase of transitioning cattle from forage to concentrate.

In conclusion, we are confident that WCGF (Sweet Bran in these studies) can be used to adapt cattle to finishing diets. Although WDGS appeared to be an appropriate alternative to using roughages in adaptation diets, cattle producers should perhaps be cautious of the risk for polio with higher S in WDGS. The research to date have been small metabolism studies. Larger-scale cattle performance experiments will be conducted with WDGS and some other new co-products to ensure this approach works well for feedlots.

Combinations of co-products

With the large number of ethanol plants in the Midwest, an option for many feedlots will be utilizing both WDGS and WCGF concurrently. In addition to their commercial availability, another reason for feeding a combination of WDGS and WCGF is their nutritional profiles. Complementary effects in feeding a combination of these co-products might be expected because of differences in fat, effective fiber, and protein components.

Loza et al. (2010) fed yearling steers a 50:50 blend of WDGS and Sweet Bran WCGF (DM basis) at inclusion levels of 0, 25, 50 and 75% DM. All inclusion levels of the blend were evaluated with 7.5% alfalfa hay in the diets. Additional treatments were also evaluated using a lower alfalfa hay level with each of the co-product diets, decreasing the forage inclusion as the rate of inclusion of co-products in the diets increased (i.e. 25% blend had 5% alfalfa, 50% blend had 2.5% alfalfa and 75% blend had 0% alfalfa in the lower forage treatments). Results indicated that there were no differences in cattle performance between forage levels within each co-product blend level. The lack of differences in performance with decreasing forage would indicate that the co-product inclusion was enough to prevent the negative consequences of sub-acute acidosis **(Table 24)**. The analysis of the pooled data from each co-

Table 24.[1] Effect of different inclusion levels of a 50:50 blend of WCGF and WDGS[2].

Blend[3]:	0%	25%		50%		75%	
Alfalfa[3]:	7.5	5	7.5	2.5	7.5	0	7.5
DMI, lb./day	24.3[a]	26.3[bc]	26.5[b]	25.4[c]	26.1[bc]	23.0[d]	23.6[ad]
ADG, lb.	3.99[a]	4.70[b]	4.57[b]	4.55[b]	4.56[b]	3.86[a]	3.93[a]
F:G	6.10[a]	5.60[c]	5.80[bc]	5.59[c]	5.73[bc]	5.97[ab]	6.01[ab]

[1]Adapted from Loza et al. (2010)
[2]All diets contain a 50:50 blend of DRC and HMC and 5% supplement.
[3]Represented as a % of diet DM.
[abcd]Means with different superscripts differ (P < 0.05).

Table 25.[1] Effect of feeding high levels of co-products on cattle performance[2].

	83corn	44DG:corn	33DG:33GF:corn	33DG:33GF:hulls	44DG:44GF	66DG:hay
DMI, lb./day	26.1[bc]	25.2[ab]	26.1[bc]	25.8[abc]	24.8[a]	26.6[c]
ADG, lb.	4.03[b]	4.47[c]	4.16[b]	3.73[a]	3.97[b]	4.03[b]
F:G	6.48[bc]	5.65[a]	6.28[b]	6.93[d]	6.26[b]	6.61[c]

[1]Adapted from Wilken et al. (2009).
[2]83corn = 83% corn-based control, 44DG:corn = 44% WDGS in corn based diet, 33DG:33GF:corn = 33% WDGS with 33% Sweet Bran and 22% corn, 33DG:33GF:hulls = 33% WDGS with 33% Sweet Bran and 22% soyhulls, 44DG:44GF = 44% WDGS with 44% Sweet Bran, 66DG:hay = 66% WDGS with 22% grass hay. Represented as a % of diet DM.
[abcd]Means within the same row without a common superscript differ (P ≤ 0.06).

product level indicated that the performance of the steers fed the maximum co-product level (75%), regardless of the forage level, was not different than a typical corn based diet (0% co-product blend). However, the diets including a 25 and 50% blend of WDGS and WCGF resulted in significantly better animal performance than the control.

In a second experiment reported by Loza et al. (2010), the same combination at 30 or 60% dietary DM was compared to feeding the co-products alone at 30% dietary DM or a 0% co-product diet. The 30% WDGS diet gave the best performance. No synergistic effects (i.e. greater performance) were observed for feeding the co-product blend at 30% compared to each co-product alone. However, feeding WCGF or WDGS in a blend (1:1 DM basis) or alone improved performance over control fed cattle. A third experiment reported by Loza et al. (2010) compared a 0% co-product diet to six other diets containing a constant amount of WCGF (30% diet DM) and additions of WDGS at 0, 10, 15, 20, 25 or 30% diet DM. Including WDGS at 15-20% of the diet with 30% WCGF resulted in the greatest ADG. This research agrees with their second experiment in that the 30% WCGF plus 30% WDGS diet gave better performance than the corn-based control diet. These three studies demonstrate that high levels of co-products, when fed in combination, can be fed to feedlot cattle without reducing performance compared to corn-based control diets.

Feeding a combination of WDGS and WCGF can also serve as a management tool. A major challenge facing some ethanol plants is not having co-product available for cattle feeders on a consistent basis. Cattle do not respond well if either WDGS or WCGF, as a sole co-product in the diet are removed and replaced with corn abruptly. Therefore, this makes for a difficult situation for feedlot managers, but one solution would be to feed a combination of co-products to ensure that at least one byproduct is consistently in the ration.

Feeding high amounts of co-products

Co-product feeds can be priced cheaply due to supply and demand and may be a very attractive feed when grain prices are priced high. For instance, corn prices reached more than $5.00/bu. in the last couple of years, but the price of co-products did not follow at the same proportional prices. Co-products are commonly priced at 80-95% the relative price to corn, but DGS was priced at about 50% the relative price to corn for a short period at that particular time. Although these expensive feed prices may result in an economic loss for cattle, including greater amounts of DGS at a cheaper cost compared to corn may be more economical for cattle returns. Therefore, some research has been conducted to evaluate feeding greater amounts (>50% diet DM) of WDGS in finishing diets to determine impact on performance. Without knowing performance, it is impossible to accurately predict impact on economics during these volatile price situations. Likewise, feeding greater inclusions of WDGS will increase risk related to high S and polio or high fat resulting in decreased cattle performance. Therefore, providing other low-fat co-products or greater roughage inclusions might offset these risks.

Wilken et al. (2009) evaluated four diets containing higher (>50% diet DM) amounts of co-products compared to a DRC based control diet and a DRC diet with 44% WDGS. All diets contained 7.5% alfalfa hay. The four experimental diets included: 1) 33% WDGS plus 33% Sweet Bran with 22% DRC; 2) 33% WDGS, 33% Sweet Bran and 22% soyhulls with no DRC; 3) 44% WDGS plus 44% Sweet Bran with no DRC or soyhulls, and 4) 66% WDGS with 22% brome grass hay. Cattle fed the diet containing 44% of each WDGS and Sweet Bran had the lowest DMI likely due to high dietary energy **(Table 25)**. Cattle fed the 66% WDGS with 22% grass hay had the greatest DMI. Cattle fed 44% WDGS with corn had the greatest ADG and lowest F:G. However, when cattle were fed diets containing a byproduct combination with no soyhulls or 66% WDGS with 22% grass hay, cattle performance was considered acceptable and similar to the corn-control diet. In general, these diets were economically advantageous (particularly the 66% WDGS with grass hay) if the WDGS was priced at 60% or less of corn price and corn price was greater than $5.50/bu. The 44% WDGS with DRC was always the most economical or close even with expensive corn.

Because the previous trial indicated that feeding a higher inclusion of WDGS with a higher amount of roughage indicated acceptable performance with no incidences of polio, a second trial was conducted by Rich et al. (2010) that evaluated high inclusions of WDGS with varying levels of wheat straw. Two dietary treatments were similar in this trial as Wilken et al. (2009) including a DRC based control diet and a DRC diet with 40% WDGS. Five other dietary treatments included: 1) 70% WDGS plus 8% straw with 17% DRC; 2) 77.5% WDGS plus 9% straw with 8.5% DRC; 3) 85% WDGS plus 10% straw replacing all corn; 4) 70% WDGS plus 25% straw replacing all corn, and 5) 77.5% WDGS plus 17.5% straw replacing all corn. Feeding more than 70% WDGS and no corn (elevated straw) resulted in the poorest cattle performance with the lowest DMI and ADG and greatest F:G (Table 26). In fact, daily gains were considerably less so that cattle had to remain on these diets for an additional 42 days in an attempt for those cattle to reach equal market weight. This suggests that low quality roughages should not be used to replace all corn inclusion in high WDGS diets to maintain adequate cattle performance. As expected, cattle fed 40% WDGS in a DRC based diet had the best cattle performance. Feeding 70% WDGS with 8% straw and 77.5% WDGS with 9%

Table 26.[1] Effect of feeding high levels of WDGS in combination with straw on cattle performance[2].

	83corn	40DG:corn	70DG:8straw	77DG:9straw	85DG:10straw	70DG:25straw	77DG:17straw
DMI, lb./day	22.6	22.9	20.2	19.	17.8	18.2	19.6
ADG, lb.	3.60[b]	4.33[a]	3.65[b]	3.57[b]	2.88[d]	2.49[e]	3.07[c]
F:G	6.29[c]	5.29[a]	5.52[b]	5.38[ab]	6.17[c]	7.30[d]	6.37[c]
Days on Feed, n	183	183	183	183	225	225	225
12th Rib fat, in.	0.42	0.61	0.48	0.43	0.43	0.27	0.50

[1]Adapted from Rich et al. (2010).
[2]83corn = 83% corn based control, 40DG:corn = 40%WDGS in a corn-based diet, 70DG:9straw = 70% WDGS with 8% straw, 77DG:9straw = 77% WDGS with 9% straw, 85DG:10straw = 85% WDGS with 10% straw, 70DG:25straw = 70% WDGS with 25% straw, 77DG:17straw = 77% WDGS with 17% straw. Represented as a % of diet DM.
[abcde]Means within the same row without a common superscript differ (P < 0.05).

straw resulted in similar ADG compared to the corn-control diet, but DMI was less, and F:G improved compared to the corn control. This study suggests that cattle fed 70-77% WDGS with less than 10% straw and some inclusion of DRC results in adequate performance. When WDGS is priced below 70% of expensive corn, these diets may become feasible up to 77% of diet DM. However, inclusion of poor quality roughage should be less than 10% with high inclusions of WDGS. No sulfur-induced polio was observed in this study.

Including roughages above normal levels appears to be an appropriate avenue of maintaining cattle performance compared to an all corn diet. The feasibility of these high-WDGS diets largely depend on the price feedlot owners are able to purchase their WDGS and forages and the hauling cost for WDGS. Both of these experiments proved to be appropriate means to feed high inclusions of WDGS in combination with Sweet Bran or roughage, as long as some corn remains in the diet.

Effects of high dietary sulfur on performance

Sulfur concentration in corn is 0.10-0.15% of DM, but sulfur content in DGS is commonly 0.7%. Normally, nutrients are concentrated in DGS by three-fold from that in corn, but ethanol plants typically use sulfuric acid to control pH thereby making the sulfur content in the DGS more concentrated. Therefore, diets can be high in sulfur if a large quantity of DGS is included in diets or if the sulfur content in DGS is abnormally high. The common concern with feeding high dietary sulfur is that sulfur can be converted to hydrogen sulfide (H_2S) in the rumen and result in polioencephalamalcia ("polio" or PEM). This condition is commonly referred to as brainers, in which cattle experience lack of coordination. Brainers is a general term that illustrates central nervous system problems that can be caused from numerous diseases, including PEM. Cattle that are chronic brainers do not recover from this condition and if they survive, they likely will not recover in terms of performance. The key to treating cattle with polio is early diagnosis and intravenous infusion of thiamine. The occurrence of polio appears to be fairly random, but is still highly correlated to dietary sulfur concentration (and probably better yet, to sulfur intake). It should be noted that while PEM is a concern, producers using less than 40% inclusion of any co-products (DM basis) should expect few if any cases of PEM. It should also be noted that a small incidence of PEM has been in the feedlot industry since early on (long before use of DGS). However, increasing sulfur intake exacerbates the challenge and can result in very high incidences of PEM if not monitored. Water should be routinely tested (annually or so) for sulfates.

Traditionally, the NRC (1996) states that 0.4% dietary sulfur is considered to be a concentration that can result in polio conditions. However, many research experiments have been conducted with co-products containing diets resulting in dietary sulfur concentrations above 0.4%, but with random polio incidences. Therefore, Vanness et al. (2009) summarized several research experiments containing 4,143 cattle in which co-products were fed to evaluate sulfur content in the diet and incidence of polio. Polio was defined as either identification and treatment of PEM by the health crew in the feedlot or death due to PEM confirmed by necropsy. Very little sulfates are present in the drinking water in this research feedlot (less than 100 ppm sulfate). A small incidence of polio (0.14%) was observed when diets contained 0.46% sulfur or less. Incidences of polio increased with increasing dietary sulfur. When dietary sulfur was 0.47-0.58%, occurrence of polio was 0.38%. This incidence increased to 6.06% when dietary sulfur was above 0.58%. A level of 0.47% S is typical when WDGS is included at 50% of diet DM. For producers it is important to be aware of the sulfur content in their co-products and their drinking water and perhaps monitor cattle closely for clinical signs of polio if dietary sulfur is above 0.47%.

There is evidence that high dietary sulfur concentration may also affect cattle intake and gain. Uwituze et al. (2009) evaluated feeding cattle two types of DDGS at 30% DM inclusion in either DRC or SFC finishing diets. These two types of DDGS included normal DDGS and DDGS that was spiked with sulfuric acid. The diets contained either 0.42 or 0.65% S. No interaction resulted from sulfur level and grain processing. Cattle fed diets with high S had 8.9% lower DMI and 12.9% poorer ADG, resulting in 4.3% lighter carcass weights. These cattle also had higher concentrations of ruminal hydrogen sulfide gas concentration. These data suggest that although cattle may not exhibit clinical signs of polio, cattle consume less feed to offset high sulfur intakes and weight gain is hindered.

Sulfur level in DGS was evaluated as both DDGS and WDGS at increasing levels in the diet (Sarturi et al., 2010b). WDGS and DDGS were fed at 20, 30 and 40% of DM and compared to a 0% corn control. Each DGS contained either 0.82 or 1.16% S and were from two different ethanol plants. Cattle were individually fed (120 steers) with treatments arranged as a 2x2x3+1 factorial with factors of moisture (DDGS and WDGS), sulfur concentration (0.82 or 1.16%), and three inclusions (20, 30 and 40%). A linear increase in DMI was observed for co-product level when feeding the low sulfur DDGS, but DMI was not affected for low sulfur WDGS. Feeding high S decreased DMI quadratically for DDGS and linearly for WDGS. These intake differences are likely due to differences in energy content between DDGS and WDGS as DDGS has a lower energy value. Feeding the high sulfur DGS decreased ADG at inclusions of 30-40% DM for WDGS and 40% for DDGS. However, feeding DGS with low sulfur content resulted in ADG equal to or above cattle fed the corn control diet. Feeding DDGS at either low or high S resulted in similar F:G compared to the corn control diet. However, feeding WDGS resulted in improved F:G at 20 and 30% DM inclusion, but was not different from the control diet at 40% inclusion. These results indicate that high sulfur content in WDGS and DDGS decreases feed intake to offset the high dietary sulfur intake, which likely leads to decreased ADG and no impact on F:G. In this study, feeding WDGS improved F:G compared to DDGS similar to previous studies.

These data suggest that although no clinical signs of polio were observed, high sulfur content in DGS can negatively impact intake and gain, with little effect on feed conversions. The elevated sulfur may be more challenging in WDGS than DDGS since cattle ate less and gained less at lower inclusions of high-sulfur WDGS compared to high-sulfur DDGS. Metabolism results support these findings in terms of H_2S produced in the rumen.

Effect of fat in distillers and fat metabolism

Research has illustrated that feeding DGS improves cattle performance. One likely reason that DGS results in better performance than corn is due to the high fat content in DGS. The fat content of DGS can be impacted by the process and how many solubles are added back to the wet grains. Another factor that can impact the fat content of DGS is whether some of this corn oil is isolated in the process (similar in concept to complete removal in the wet milling industry). Numerous processes are currently being explored by ethanol plants to remove a portion of the corn oil for other purposes. Therefore, it is important to know the impact of the fat content in DGS on performance.

Table 27.[1] **Effect of feeding a low or high fat WDGS at 35% DM inclusion compared to a corn-based control diet on cattle performance.**

	Control	Low-fat WDGS	Normal-fat WDGS
DMI, lb./day	24.6	24.6	24.6
ADG, lb.	3.41[a]	3.41[a]	3.71[b]
F:G	7.20[a]	7.18[a]	6.59[b]

[1]Adapted from Gigax et al. (2011).
[ab]Means within the same row without a common superscript differ ($P < 0.05$).

Therefore, Gigax et al. (2011) evaluated feeding 35% WDGS (DM basis) with normal fat content (13.0% of DM) or low fat (6.7% of DM) and compared this to a DRC and HMC based control diet. Cattle consumed equal DMI, but feeding the high fat WDGS improved ADG and F:G **(Table 27)**. Cattle fed the low fat WDGS had equal ADG and F:G compared to cattle fed the corn control diet. These data suggest that the improved performance due to feeding WDGS is at least partially due to higher fat content in the WDGS. In this study, the primary differences in these two products were the amount of distillers solubles added back to wet grains.

Although WDGS typically has 11-13% fat, this amount can vary due to the amount of distillers solubles (18-26% fat) that is added back to the wet distillers grains (WDG, ~8% fat). Godsey et al. (2009) conducted a feeding trial evaluating the proportion of solubles added to WDG at ratios of 100:0, 85:15 and 70:30 for WDG and solubles, respectively. They fed these ratios in DRC based diets at 0, 20 and 40% of diet DM. No interactions resulted for ratio of grains to solubles and level of WDG±S fed. Although there was no effect for DMI, linear improvements were observed for ADG and F:G as level of WDG±S was fed **(Table 28)**. Optimum inclusion was observed at 40% DM inclusion. No effects of WDG to solubles ratio were detected in this experiment, suggesting level of WDGS is more important than grains to solubles ratio for improving cattle performance.

The fat in DGS is corn oil originating from the corn grain. Corn oil is high in unsaturated fatty acids (double bonds within the fatty acids). Feeding unsaturated fat sources to cattle generally negatively impacts the rumen microbes (particularly forage digesting microbes). During rumen fermentation, rumen microbes will saturate the fatty acids by biohydrogenation and produce saturated fatty acids that leave the rumen and are available for absorption in the small intestine. Therefore, unless the fat is "protected" from biohydrogenation by the microbes, the majority of the fat will be saturated fatty acids at the small intestine. It is important to note that fat is not absorbed in the rumen or metabolized by the rumen microbes, except biohydrogenation. The primary site of corn oil is in the corn germ, which may be "protected" from rumen microbes and warranted study.

Table 28.[1] Effect of feeding increasing levels of WDG with or without distillers solubles and the ratio of WDG to distillers solubles on cattle performance.

	Level of WDG ± S[2]			Ratio of WDG:DS[3]		
	0	20	40	100:0	85:15	70:30
DMI, lb./day	25.6	25.5	25.1	25.4	25.1	25.5
ADG, lb.[4]	3.69	3.88	3.90	3.88	3.84	3.96
F:G[4]	6.94	6.58	6.42	6.54	6.49	6.41

[1]Adapted from Godsey et al. (2009).
[2]Level of wet distillers grains with or without distillers solubles. Represented as a % of diet DM.
[3]Ratio of wet distillers grains (WDG) to distillers solubles (DS). Represented as a proportion of the total WDGS product.
[4]Linear effect for level of WDG±S fed ($P < 0.02$).

Vander Pol et al. (2009) evaluated different fat sources including wet distillers grains plus solubes in both feeding and metabolism studies. The ratio of unsaturated fatty acids relative to saturated fatty acids increases at the small intestine in steers fed WDGS compared to corn based diets or corn based diets with added tallow (saturated fat) or added corn oil (unsaturated fatty acids). These data suggest that a portion of the fatty acids are "protected" in the rumen in WDGS and remain intact at the small intestine. Similar results were observed by Bremer et al. (2010) where the unsaturated:saturated fatty acid ratio increased from approximately 0.40-0.50 for corn, corn oil, tallow and distillers solubles to 0.83 for WDGS. All diets in this study were approximately 8.5% fat except the corn control (3.6%) and all were greater than 93% fatty acid digestibility. The fat in WDGS appears to be protected from biohydrogenation in the rumen whereas distillers solubles are not protected. Likewise, all fat sources are quite digestible. This change in fatty acids may have positive and negative impacts on beef.

New ethanol industry co-products

The evolving ethanol industry is continually striving to maximize ethanol production efficiency. Changes associated with this progress will provide innovative new co-product feeds for producers to utilize that may be quite different nutritionally when fed to cattle. One example of a new co-product feed is Dakota Bran Cake.

Bran cake is a distillers co-product feed produced as primarily corn bran plus distillers solubles produced from a pre-fractionation dry milling process. On a DM basis, bran cake contains less protein than WDGS and WCGF, similar NDF to both feeds and slightly less fat content than WDGS. Bremer et al. (2007) evaluated Dakota Bran Cake in a finishing diet by comparing inclusion levels of 0, 15, 30 and 45% of diet DM. Results indicated improved final weight, ADG, DMI and F:G compared to feeding a blend of high-moisture and dry-rolled corn, suggesting this specific feed has 100-108% of the feeding value of corn. Buckner et al. (2007c) compared dried Dakota Bran Cake to DDGS supplementation in growing calf diets. They fed each of the two products at 15 or 30% of the diet, which replaced a 70:30 blend of brome grass hay and alfalfa haylage (DM basis). Animal performance improved as the inclusion of the co-products increased. Dried DGS had improved performance compared to the dried Dakota Bran Cake at both inclusion levels. Dried Dakota Bran Cake had 84% the feeding value of DDGS with growing steers. Previous research has shown that DDGS has about 127% the feeding value of corn in forage based diets. Therefore, dried Dakota Bran Cake appears to have an energy value equal to 103%

of corn. Dakota Bran Cake is only one example of how new ethanol industry co-products will perform relative to traditional finishing rations.

Another example of a new co-product feed that may be produced from the dry milling ethanol industry is a product referred to as E-corn. An experiment was conducted to evaluate feeding E-corn compared to DRC (Godsey et al., 2010). E-corn is lower in fat (almost devoid) and lower in starch, greater in fiber than DRC and was included at 0, 20, 40 or 60% of diet DM and replaced DRC. These combinations of DRC and E-corn were fed in either 30% WDGS or 30% Sweet Bran diets (DM basis). Cattle that consumed WDGS had lower DMI but improved F:G compared to those fed Sweet Bran. Feeding a combination of E-corn and DRC resulted in increased DMI compared to feeding these products alone. Little other effects were observed for feeding these two products on cattle performance. However, marbling score and 12th rib fat decreased with increasing levels of E-corn in the diet. Therefore, it is unclear why carcass traits differed when E-corn replaced DRC without negatively impacting DMI, ADG or F:G.

Each new co-product feed is different from the next. Therefore, each new feed needs to be analyzed individually for its correct feeding value. Changes to plant production goals and production efficiency will likely have significant impacts on the feeding value of co-products produced.

Impact on beef products

As discussed earlier, fat is at least partially protected when WDGS are fed which leads to greater amounts of unsaturated fatty acids reaching the small intestine. Therefore, it is plausible that more unsaturated fatty acids are deposited in the fat depots on the carcass. de Mello et al. (2009) found that polyunsaturated fatty acids increased in three separate muscles when cattle were fed 30% WDGS compared to a corn control diet. Increases in polyunsaturated fatty acids lead to increased oxidation and decreases shelf life of beef cuts when WDGS are fed (Senaratne et al., 2009a,b). Feeding vitamin E at 500 IU per day for 100 days mitigates these two challenges (Senaratne et al., 2009 a,b). While feeding WDGS does not appear to negatively impact marbling or quality grade, it does likely increase subcutaneous fat deposition. The protection of unsaturated fatty acids also increases those fatty acids in the carcass. Unfortunately, the increase in unsaturated fatty acids decreases shelf-life by approximately 10% (1 or 2 days depending on packaging, aging and muscle cut). Feeding vitamin E (and presumably other antioxidants) decreases the negative impact of the elevated polyunsaturated fatty acids in meat from cattle fed DGS.

LITERATURE CITED

The following research articles were cited in this publication. The reader is encouraged to view individual citations for a more in-depth discussion of individual trial details. University of Nebraska Beef Cattle Reports discussing ethanol co-product feeds for cattle and other cow/calf, growing, feedlot, beef products, and new beef technology are available at http://beef.unl.edu.

- Adams, D.R., M.F. Wilken, B.L. Nuttelman, L.M. Kovarik, J.R. Benton, M.A. Greenquist, G.E. Erickson, T.J. Klopfenstein, and R.J. Rasby. 2008. Evaluation of storage methods for wet distillers grains plus solubles with added forages. Nebraska Beef Rep. MP91: 23-25.
- Benton, J.R., G.E. Erickson, T.J. Klopfenstein, K.J. Vander Pol, and M.A. Greenquist. 2007. Effect of roughage source and level with the inclusion of wet distillers grains on finishing cattle performance and economics. Nebraska Beef Rep. MP90: 29-32.
- Benton, J.R., G.E. Erickson, and T.J. Klopfenstein. 2010. Review: Nutrient composition and variation of corn milling co-products used in beef finishing rations. Prof. Anim. Sci. In press.
- Blanchard, P.H. 1992. Technology of corn wet milling and associated processes. Industrial Chemistry Library, Vol. 4. Elsevier, New York.
- Bremer, V.B., G.E. Erickson, T.J. Klopfenstein, M.L. Gibson, K.J. Vander Pol, M.A. Greenquist. 2007. Evaluation of a low protein distillers by-product for finishing cattle. Nebraska Beef Rep. MP88-A: 57-58.
- Bremer, V.R., G.E. Erickson, and T.J. Klopfenstein. 2008. Meta-analysis of UNL feedlot trials replacing corn with WCGF. Nebraska Beef Rep. MP91: 33-34.
- Bremer, V.R., K.J. Hanford, G.E. Erickson, and T.J. Klopfenstein. 2010a. Meta-analysis of feeding winter calf-feds or summer yearlings wet distillers grains with solubles based finishing diets. J. Anim. Sci. (Suppl. 2) In press.
- Bremer, V. R., K. M. Rolfe, C. D. Buckner, G. E. Erickson, and T. J. Klopfenstein. 2010b. Metabolism characteristics of feedlot diets containing different fat sources. Nebraska Beef Rep. MP93:74-76.
- Buckner, C.D., T.J. Klopfenstein, G.E. Erickson, K.J. Vander Pol, K.K. Karges, and M.L. Gibson. 2007. Comparing a modified dry by-product to dry distillers grains with solubles in growing calf diets. Nebraska Beef Rep. MP90: 15-16.
- Buckner, C.D., T.J. Klopfenstein, G.E. Erickson, V.R. Bremer, and D.R. Mark. 2011. Economics for feeding distillers grains to finishing cattle. Nebraska Beef Rep. (In press).
- Buckner, C.D., T.J. Klopfenstein, G.E. Erickson, W.A. Griffin, and J.R. Benton. 2010. Comparing ensiled or fresh mixed wet distillers grains with solubles with straw at two inclusions in growing calf diets. Nebraska Beef Rep. MP93: 42-43.
- Buckner, C.D., M.F. Wilken, J.R. Benton, S.J. Vanness, V.R. Bremer, T.J. Klopfenstein, G.E. Erickson, B. Adkins, P.J. Kononoff. 2010. Evaluation of methods to determine dry matter content of ethanol byproducts and nutrient variability for wet distillers grains plus solubles. Prof. Anim. Sci. Submitted.
- Christensen, D.L., K.M. Rolfe, T.J. Klopfenstein, and G.E. Erickson. 2010. Evaluation of storage covers when wet distillers byproducts are mixed and stored with forages. Nebraska Beef Rep. MP93: 21-25.
- Cooper, R.J., C.T. Milton, T.J. Klopfenstein, T.L. Scott, C.B. Wilson, and R.A. Mass. 2002. Effect of corn processing on starch digestion and bacterial crude protein flow in finishing cattle. J. Anim. Sci. 80: 797-804.
- Corrigan, M. E., T. J. Klopfenstein, G. E. Erickson, N. F. Meyer, K. J. Vander Pol, M. A. Greenquist, M. K. Luebbe, K. K. Karges, and M. L. Gibson. 2009a. Effects of level of condensed distillers solubles in corn dried distillers grains on intake, daily body weight gain, and digestibility in growing steers fed forage diets. J. Anim. Sci. 87:4073–4081.
- Corrigan, M. E., G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, K. J. Vander Pol, N. F. Meyer, C. D. Buckner, S. J. Vanness, and K. J. Hanford. 2009b. Effect of corn processing method and corn wet distillers grains plus solubles inclusion level in finishing steers. J. Anim. Sci. 87: 3351-3362.
- de Mello, Jr., A. S., C. R. Calkins, B. E. Jenschke, L. S. Senaratne, M. E. R. Dugan, T. Carr, and G. E. Erickson. 2009. Fatty acid profile of three beef muscles from yearlings and calf-fed steers fed wet distillers grains plus solubles. Nebraska Beef Rep. MP92:107-109.
- Farran, T.B., G.E. Erickson, T.J. Klopfenstein, C.N. Macken, and R.U. Lindquist. 2004. Wet corn gluten feed and alfalfa levels in dry-rolled corn finishing diets. Nebraska Beef Rep. MP80-A: 61-63.
- Galyean, M.L. and P.J. Defoor. 2003. Effects of roughage source and level on intake by feedlot cattle. J. Anim. Sci. 81(Suppl. 2): E8-E16.
- Gigax, J. A., B. L. Nuttelman, W. A. Griffin, G. E. Erickson, and T. J. Klopfenstein. 2011. Comparison of low fat and normal fat, wet distillers grains on performance and carcass characteristics of finishing steers. Nebraska Beef Rep. (in press).
- Godsey, C.M., M.K. Luebbe, J.R. Benton, G.E. Erickson, and T.J. Klopfenstein. 2009. Effect of the grains-to-solubles ratio in diets containing wet distillers grains ± solubles fed to finishing steers. Nebraska Beef Rep. MP92: 59-61.
- Godsey, C.M., M.K. Luebbe, J.R. Benton, G.E. Erickson, T.J. Klopfenstein, C. Ibanez, P. Guiroy, M. Greenquist, and J. Kazin. 2010. Evaluation of feedlot and carcass performance of steers fed different levels of E-corn, a potential new feed product from ethanol plants. Nebraska Beef Rep. MP93: 63-65.

- Green, D., R. Stock, and T. Klopfenstein. 1987. Corn gluten feed – a review. Nebraska Beef Rep. MP52: 16-18.
- Ham, G.A., R.A. Stock, T.J. Klopfenstein, and R.P. Huffman. 1995. Determining the net energy value of wet and dry corn gluten feed in beef growing and finishing diets. J. Anim. Sci. 73: 353–359.
- Huls, T.J., M.K. Luebbe, W.A. Griffin, G.E. Erickson, T.J. Klopfenstein, and R.A. Stock. 2009a. Using wet corn gluten feed to adapt cattle to finishing diets. Nebraska Beef Rep. MP92: 53-55.
- Huls, T.J., N.F. Meyer, G.E. Erickson, T.J. Klopfenstein, and R.A. Stock. 2009b. The effects on ruminal pH, feed intake and digestibility when using wet corn gluten feed to adapt cattle to finishing diets. Nebraska Beef Rep. MP92: 56-58.
- Jenkins, K.H., G.E. Erickson, J.T. Vasconcelos, and S.A. Furman. 2010. Effects of urea level on performance and carcass characteristics of finishing cattle fed dry-rolled corn-based diets containing wet distiller's grains with solubles. Plains Nutrition Council Spring Conference. AREC 10-57: 80-81.
- Loza, P. L., C. D. Buckner, K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein, R. A. Stock. 2010. Effect of feeding combinations of wet distillers grains and wet corn gluten feed to feedlot cattle. J. Anim. Sci. 88:1061-1072
- Macken, C., G. Erickson,T. Klopfenstein, and R. Stock. 2006. Effects of corn processing method and crude protein level with the inclusion of wet corn gluten feed on finishing steer performance. Prof. Anim. Sci. 22(1): 14-22.
- May, M.L., M.J. Quinn, N. DiLorenzo, D.R. Smith, and M.L. Galyean. 2010. Effects of roughage and wet distillers grains with solubles concentrations in steam-flaked corn-based diets on feedlot cattle performance and carcass characteristics. Plains Nutrition Council Spring Conference. AREC 10-57: 107.
- Miller, K., M. Shelor, G. Parsons, and J. Drouillard. 2009. Optimal roughage level in finishing diets containing combinations of flaked corn and dried distillers grains with solubles. Plains Nutrition Council Spring Conference. AREC 09-18: 97-98.
- NRC. 1996. Nutrient Requirements of Beef Cattle (7th Ed.). National Academy Press. Washington, DC.
- Nuttelman, B.L., W.A. Griffin, J.R. Benton, K.M. Rolfe, G.E. Erickson, and T.J. Klopfenstein. 2010. Comparing dry, wet, or modified distillers grains plus solubles on feedlot cattle performance and metabolism characteristics. Plains Nutrition Council Spring Conference. AREC 10-57: 110-111.
- Owens, F.N., D.S. Secrist, W.J. Hill, and D.R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: a review. J. Anim. Sci. 75: 868-879.
- Owens, F.N., M.A. Hinds, and D.W. Rice. 2002. Methods for calculating diet energy values from feedlot performance of cattle. J. Anim. Sci. 80(Suppl. 1): 273.
- Rich, A.R., G.E. Erickson, T.J. Klopfenstein, M.K. Luebbe, J.R. Benton, and W.A. Griffin. 2010. Effect of feeding greater than 70% wet distillers grains plus solubles on feedlot cattle performance and nutrient mass balance. Plains Nutrition Council Spring Conference. AREC 10-57: 116.
- Rolfe, K.M., G.E. Erickson, T.J. Klopfenstein, J.T. Vasconcelos. 2010. Effects of using wet distillers grains with solubles to adapt cattle to finishing diets on feed intake, ruminal pH, and ruminal hydrogen sulfide concentration. Nebraska Beef Rep. MP93: 66-67.
- Sarturi, J.O., J.T. Vasconcelos, G.E. Erickson, T.J. Klopfenstein, K.M. Rolfe, V.R. Bremer, M.G. Dib, and C.D. Buckner. 2010a. Effects of wet corn gluten feed and wet distillers grains plus solubles on ruminal pH, feed intake, and ruminal hydrogen sulfide during grain adaptation. J. Anim. Sci. (Suppl. 2). In press.
- Sarturi, J.O., G.E. Erickson, T.J. Klopfenstein, J.T. Vasconcelos, K.M. Rolfe, and W.A. Griffin. 2010b. Sulfur content of wet or dry distillers grains plus solubles in beef cattle finishing diets: Performance, metabolism, and hydrogen sulfide production. Plains Nutrition Council Spring Conference. AREC 10-57: 117-118.
- Scott, T., T. Klopfenstein, R. Stock, and M. Klemesrud. 1997. Evaluation of corn bran and corn steep liquor for finishing steers. Nebraska Beef Rep. MP 67-A: 72-74.
- Scott, T.L., C.T. Milton, G. E. Erickson,T. J. Klopfenstein, and R. A. Stock. 2003. Corn processing method in finishing diets containing wet corn gluten feed. J. Anim. Sci. 81: 3182-3190.
- Senaratne, L. S., C. R. Calkins, A. S. de Mello Jr., and G. E. Erickson. 2009a. Vitamin E mitigates the boost in lipid oxidation of beef due to wet distillers grains feeding. Nebraska Beef Rep. MP92:113-115.
- Senaratne, L. S., C. R. Calkins, A. S. de Mello Jr., G. A. Sullivan, and G. E. Erickson. 2009b. Effect of wet distillers grain feeding supplemented with vitamin E on case life of beef. Nebraska Beef Rep. MP92:116-117.
- Sindt, J.J, J.S. Drouillard, E.C. Titgemeyer, S.P. Montgomery, C.M. Coetzer, T.B. Farran, J.N. Pike, J.J. Higgins, and R.T. Ethington. 2003. Wet corn gluten feed and alfalfa hay combinations in steam-flaked corn finishing cattle diets. J Anim Sci. 81: 3121-3129.
- Stock, R., M. Sind, R. Cleale, and R. Britton. 1991. High-moisture corn utilization in finishing cattle. J. Anim. Sci. 69: 1645-1656.
- Stock, R.A. and R.A. Britton. 1993. Acidosis in Feedlot Cattle. In: Scientific Update on Rumensin/Tylan for the Professional Feedlot Consultant. Elanco Animal Health, Indianapolis, IN. p A_1.
- Stock, R.A., J.M. Lewis, T.J. Klopfenstein, and C.T. Milton. 1999. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. Proc. Am. Soc. Anim. Sci. Available at: http://www.asas. org/jas/symposia/proceedings/0924.pdf.

- Trenkle, A. 1997. Substituting wet distillers grains or condensed solubles for corn grain in finishing diets for yearling heifers. Beef Research Report - Iowa State Univ. ASRI 451.
- Uwituze, S., M.K. Shelor, G.L. Parsons, K.K. Karges, M.L. Gibson, L.C. Hollis, and J.S. Drouillard. 2009. High sulfur content of dried distiller's grains with solubles impacts ruminal fermentation, feedlot cattle performance, and carcass characteristics. Plains Nutrition Council Spring Conference. AREC 09-18: 105-106.
- Vander Pol, K., G. Erickson, and T. Klopfenstein. 2005. Degradable intake protein in finishing diets containing dried distillers grains. Nebraska Beef Rep. MP83-A: 42-44.
- Vander Pol, K. J., M. A. Greenquist, G. E. Erickson, T. J. Klopfenstein, and T. Robb. 2008. Effect of corn processing in finishing diets containing wet distillers grains on feedlot performance and carcass characteristics of finishing steers. Prof. Anim. Scient. 24:439-444.
- Vander Pol, K. J., M. K. Luebbe, G. I. Crawford, G. E. Erickson, and T. J. Klopfenstein. 2009. Performance and digestibility characteristics of finishing diets containing distillers grains, composites of corn processing coproducts, or supplemental corn oil. J. Anim. Sci. 87:639-652.
- Vanness, S.J., T.J. Klopfenstein, G.E. Erickson, and K.K. Karges. 2009. Sulfur in distillers grains. Nebraska Beef Rep. MP92: 79-80.
- Wilken, M.F., M.K. Luebbe, G.E. Erickson, T.J. Klopfenstein, and J.R. Benton. 2009. Effects of feeding high levels of byproducts in different combinations to finishing steers. Nebraska Beef Rep. MP92: 76-78.
- Yelden, J.R., C.D. Buckner, K.M. Rolfe, D.L. Christensen, T.J. Klopfenstein, and G.E. Erickson. 2010. Nutrient composition of spoiled and non-spoiled wet by-products mixed with straw after storage. J. Anim. Sci. (Suppl. 3). 146.

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