Using Distillers Grains in the U.S. and International Livestock and Poultry Industries

Edited by

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List of Acronyms and Abbreviations

ADG	average daily gain
CCDS	condensed corn distillers solubles
CLA	conjugated linoleic acid
CP	crude protein
DDGS	distillers dried grains with solubles
DE	digestible energy
DGS	distillers grains with solubles
DM	dry matter
DMI	dry matter intake
DRC	dry-rolled corn
EFSA	European Food Safety Authority
FDA	Food and Drug Administration
FSU	Former Soviet Union
GE	gross energy
GM	genetically modified
GMO	genetically modified organism
HMC	high-moisture corn
HP-DG	high protein distillers grains
HP-DDG	high protein distillers dried grains (without solubles)
HP-DDGS	high protein distiller dried grains with solubles
HPLC	high-performance liquid chromatography
IAPC	Interagency Agricultural Projections Committee
mt	metric ton
mmt	million metric tons
NDF	neutral detergent fiber
NRC	National Research Council
PEM	polioencephalomalacia
ppb	parts per billion
ppm	parts per million
PUFA	polyunsaturated fatty acids
RDP	ruminally degradable protein
RFS	Renewable Fuel Standard
RUP	ruminally undegradable protein
TME	true metabolizable energy
TMR	total mixed rations
USDA	U.S. Department of Agriculture
USGC	U.S. Grains Council
WDGS	wet distillers grains with solubles

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Chapter 1

Introduction

Dermot J. Hayes

Figures 1.1 and 1.2 help explain the motivation for this book. Figure 1.1 shows the August 2008 projections of production, consumption, and trade of U.S. distillers dried grains with solubles (DDGS) by the Food and Agricultural Policy Research Institute (FAPRI). Production ramps up very quickly, from 15 million tons in 2006/07 to more than 35 million tons in 2009/10, and eventually reaches about 43 million tons by 2013/14. To put this quantity in perspective, the amount of DDGS that will need to be marketed in 2013/14 will be approximately equal to the amount of soybean meal produced in 2006/07. This means the DDGS market will have to grow to absorb as much product over a five-year period as the soybean meal market has absorbed over several decades.

These FAPRI projections are probably conservative. They assume that U.S. ethanol production grows to 16.8 billion gallons by 2013/14, an amount that only slightly exceeds the 15 billion gallons mandated under the Energy Independence and Security Act of 2007. If crude oil prices remain in excess of $100 per barrel and ethanol prices eventually rise to meet their energy value, and if corn prices decline from weather-related highs in 2008, it is possible that U.S. ethanol production could dramatically exceed this amount. In fact, a study by Togkoz et al. (2007) that uses the same model but different assumptions has projected U.S. ethanol production at about 30 billion gallons. This level would almost double the projected DDGS production shown in Figure 1.1.

Figure 1.2 shows how FAPRI expects this rapid growth to come about. Figure 1.2 projects DDGS prices as a percentage of corn prices and shows that the enormous supply of DDGS will drive the value of this product well below the value of corn even though, as later chapters in this

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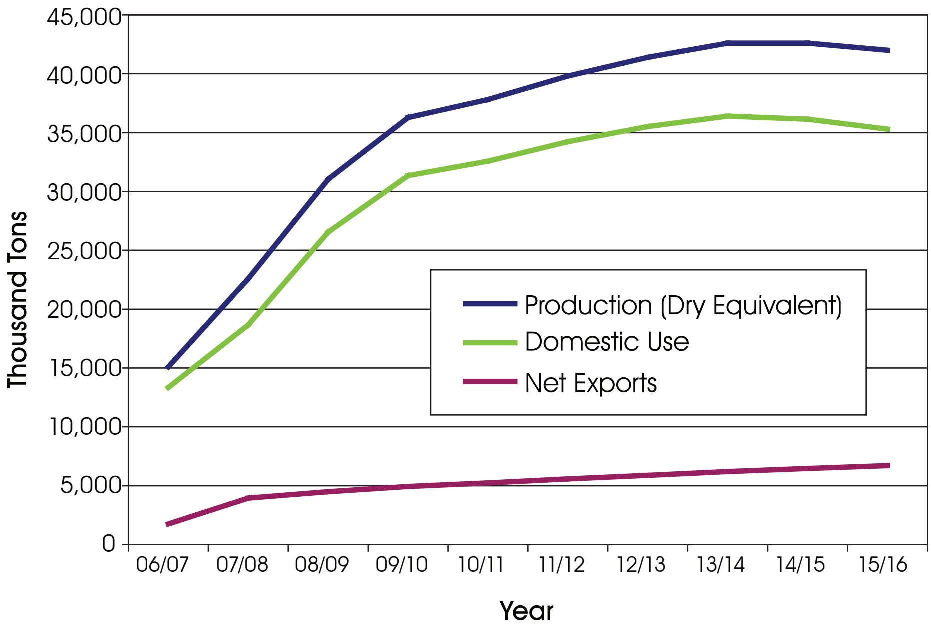

Figure 1.1. U.S. DDGS production, consumption, and exports as projected by FAPRI in August 2008

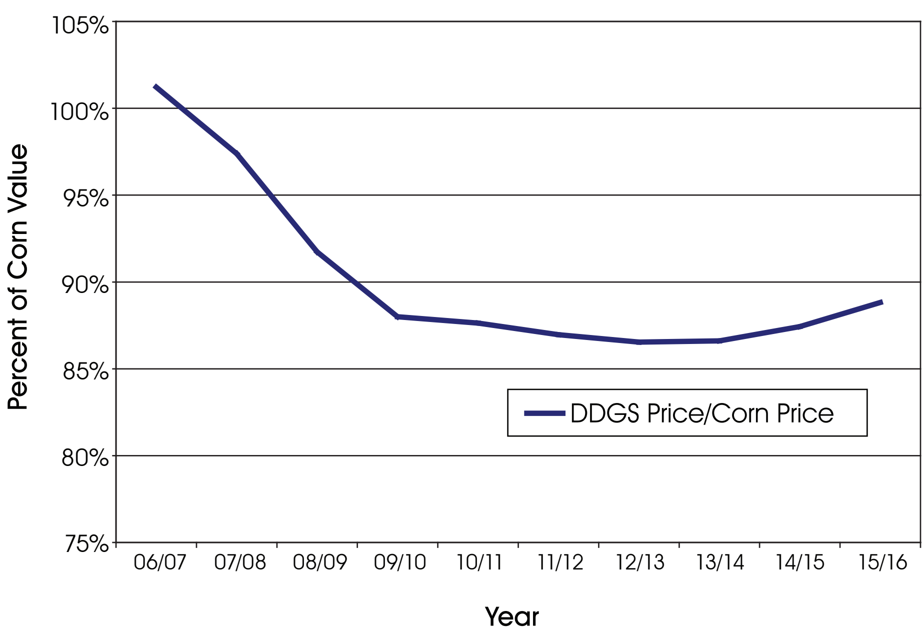

Figure 1.2. DDGS price/corn price

book will show, the feed value of DDGS is well above that of corn for several species. The intuition here is that free markets will absorb almost any change if the price incentive is high enough.

The expected discount of DDGS prices below their energy value will work to the detriment of the U.S. ethanol industry and ultimately U.S. crop growers and U.S. energy consumers. This is true because a depressed DDGS market will reduce the incentive to build new ethanol plants, and less ethanol will mean lower corn prices and domestic energy production than would otherwise have been the case. On the surface, it is true that a depressed DDGS market will benefit livestock producers because it will reduce their feed costs. However, this is only true if these livestock feeders know how to utilize the DDGS to their full extent and if the suppliers of DDGS understand how best to modify the DDGS output to best suit the individual needs of each species.

The purpose of this book is to bring together into a single publication the available knowledge of internationally renowned experts to help market participants understand how best to utilize this product in either world export markets or the domestic U.S. market. The book discusses how to optimize the DDGS products to best suit the needs of beef cattle, dairy cattle, swine, and poultry, and how each species can best take advantage of current and improved DDGS products. The book also lays out export opportunities for DDGS and describes several of the logistic hurdles that need to be resolved to ensure that the product is transported to the place that can best use it. Finally, the book includes a description of new technologies being used to improve DDGS as a feed ingredient for livestock and poultry.

Reference

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Chapter 2

Use of Distillers Co-products in Diets Fed to Beef Cattle

Terry J. Klopfenstein, Galen E. Erickson, and Virgil R. Bremer

Consumers in the United States purchase 64 pounds of beef per year. That beef is considered "high quality" by international standards. In the distant past in the United States, beef was produced with forages, and it still is in most countries of the world today. Beef cattle are ruminants and therefore are able to convert grasses, hays, and crop residues into tasty, nutritious meat. Even today in the United States, about 80% to 90% of the feed required to produce "grain-fed" beef is forage. The U.S. beef produced today is "high quality" because the cattle are fed corn just prior to harvest. How did feeding corn to cattle develop and what are the consequences of much of that corn being converted to fuel ethanol and its associated by-products?

Historical Increase in Corn Production

In 1935, 82 million acres of corn were harvested in the United States, mostly by hand. The average yield was 24.2 bushels per acre, so the total production was 2 billion bushels. Farms were small, labor requirements were high, and most farms had several livestock species, including some cattle. The national cow herd was about 10 million, and American per capita beef consumption was 51 pounds. From 1935 to 1945 the United States was engaged in a world war, which dramatically increased food demand. At the same time, hybrid seed corn was being produced and sold commercially, and Haber-Bosch technology was being used to produce nitrogen fertilizer for corn. By 1950, corn acres had declined but yields had increased to 38.2 bushels per acre, and total production had increased to 2.6 billion bushels.

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Because of the war effort to produce corn, as well as technological developments, corn production exceeded demand. In 1956, the U.S. government addressed the “farm problem” of too much corn, by encouraging farmers to “soil-bank” cropland, paying them not to produce corn. The same farmers realized that it was profitable, in most cases, to feed the cheap corn to cattle—marketing the corn through the cattle. Feeding the corn to beef cattle produced the high-quality beef to which U.S. consumers have since become accustomed. By 1950, the cow herd increased to 16.7 million, and beef consumption increased to 64 pounds per person.

Until 2006, the farm problem was too much corn. The cheap corn further encouraged cattle feeding, with segmentation of the cattle feeding into feedlots, separating it from farming. For example, about 3.3 million cattle were fed for harvest (finished) in 1965 in Iowa. Only 3.9% of the cattle were produced in feedlots of 1,000-head capacity or larger. By 1980, about 2.7 million cattle were finished in Iowa, and 37.6% were finished in feedlots of 1,000-head capacity. Over the same period, the number of cattle finished yearly in Texas increased from 1.1 million in 1965 to 4.2 million in 1980, with 98.7% in feedlots over 1,000-head capacity. In 2006, 93.9% of Nebraska cattle were fed in feedlots over 1,000-head capacity, and 38.4%, in feedlots over 16,000-head capacity. This growth in cattle feeding was supported primarily by cheap corn. Americans are currently consuming 64 pounds per person of high-quality (i.e., corn-fed) beef.

Corn production has continued to increase so that yield was 149 bushels per acre and total production was 267 million tons (10.5 billion bushels) in 2006. Because of technological advances, corn production has increased by nearly 2 bushels per acre each year since 1960. With the growth of the ethanol industry, the demand for corn has increased. During the last half of 2006, the corn price increased from about $2 per bushel to above $4 per bushel. With more acres planted to corn and good yields, the price of corn in 2007 declined to a range of $3.00 to $3.75 per bushel. However, the price increased to $6 per bushel in early 2008. Therefore, the cattle industry is faced with the prospect of producing cattle under the constraints of high corn prices after sixty years of “cheap corn.” And the farm problem has changed from too much corn to a debate about food versus fuel.

Protein Supplements for Feedlot Cattle

The nutrition of cattle has been well researched, and advances have increased production efficiency and reduced costs of production. Research determined that cattle needed supplemental protein to complement the energy in grains and lower-protein forages. Several by-products were used for this purpose: soybean meal, cottonseed meal, tankage, and distillers grains from the beverage alcohol industry. With the development of the Haber-Bosch process for producing ammonia, it became commercially feasible to produce urea. It was determined that urea could be used as a protein substitute for ruminants. Protein supplements cost cattle feeders 2 to 2.5 times the price of corn. This is the reason urea was used widely—it supplied protein (nitrogen) less expensively than did protein supplements such as soybean meal. Beef cattle nutritionists formulated diets as economically as possible and generally believed that energy was cheap and protein was expensive.

With the use of corn for production of ethanol, the resulting by-product, distillers grains, became readily available for cattle feeders. When corn is used to produce ethanol, the starch in the corn is fermented into ethanol, and the distillers grains are the unfermented materials remaining—fiber, protein, and fat. Corn is about two-thirds starch, so when starch is removed (fermented), the remaining nutrients are concentrated in the distillers grains by a factor of three. Corn has about 10% protein while distillers grains contain about 30%. Therefore, corn, primarily a source of energy (starch), is converted into a protein source. With more corn used for ethanol, more distillers grains are produced. Because of supply and demand, the distillers grains are generally not more expensive than corn. Therefore, producers have turned to distillers grains as an energy source for feed. This is a major paradigm shift for cattle nutritionists and cattle feeders. Protein is no longer more expensive than energy. In fact, because energy in corn is being used for fuel, the large supply of energy for livestock has decreased and has been replaced by a large supply of protein.

Cereal grains have been fermented to produce beverage alcohol for centuries. By the late nineteenth century, the resulting by-product, distillers dried grains with solubles (DDGS), was being used as a feedstuff (Henry, 1900). Morrison (1939) and Garrigus and Good (1942) refer to a liquid form of the by-product supplied to beef cattle as "distillers slop." Individuals involved in the beverage distilling industry formed the Distillers Feed Research Council in 1945 to "expand the, then, meager knowledge available on the nutrient composition of distillers feeds and to better understand how these feeds would be best used in a variety of livestock feeding systems." The Distillers Feed Research Council was replaced in 1997 with the Distillers Grains Technology Council (Louisville, KY). Both of these organizations have held annual conferences, and the proceedings contain a wealth of information about the traditional uses of DDGS.

Stock et al. (2000) described the dry milling process whereby grain, mainly corn, is fermented to produce ethanol. Again, about two-thirds of corn is starch, which is the component that is fermented into ethanol in the dry milling process. The remaining nutrients are recovered in the stillage, and water is removed to produce DDGS. Protein increases from about 10% to 30%, fat from 4% to 12%, neutral detergent fiber (NDF) from 10% to 30%, and phosphorus from 0.3% to 0.9% of dry matter.

Because of the increased concentration of protein in the DDGS compared to corn, the DDGS were used primarily as a protein source (Klopfenstein et al., 1978). Aines, Klopfenstein, and Stock (1987) reviewed reports on rumen protein escape values of DDGS and found them to be variable, likely because of the measurement technique. Average protein escape values for DDGS were 2.6 times greater than those for soybean meal, and values for dry distillers grains minus solubles were 2.3 times greater than those for soybean meal. Klopfenstein et al. (1978) used the slope ratio technique in growth studies to determine protein values relative to soybean meal. Aines, Klopfenstein, and Stock summarized several experiments showing 2.4 times the value of distillers dried grains protein compared to that from soybean meal, and DDGS had 1.8 times the value of soybean meal. DeHaan et al. (1982) observed that distillers solubles had 0.45 times the escape protein of soybean protein. One might expect that the protein in distillers solubles would be completely rumen degradable, especially when distillers solubles are produced by centrifugation, which would remove most grain particles. However, much of the protein in distillers solubles is composed of yeast cells, which have been heated during distillation and concentration. In their experiment, Bruning and Yokoyama (1988) showed that heat denatured the yeast cells, rendering them resistant to lysis and microbial degradation. Herold (1999) showed only 20% protein degradation in the rumen of wet milled distillers solubles, which contained mostly yeast cells. Therefore, some escape of protein in distillers solubles from dry milling should be expected.

In addition to protein, NDF is concentrated in DDGS compared to corn and comprises most of the carbohydrate in distillers grains with solubles (DGS). Quicke et al. (1959) found high in vitro digestion of cellulose in corn fiber. DeHaan, Klopfenstein, and Stock (1983) demonstrated that corn bran (corn grain pericarp) is primarily NDF (69%) and that the NDF has a high extent (87%) and rate (6.2%/h) of digestion. Sayer (2004) reported similar extents of corn bran NDF digestion (79% to 84%) in situ in fistulated cattle fed finishing diets. Rates of digestion of NDF in these finishing diets were less (1.7% to 2.1%/h) than those reported by DeHaan, Klopfenstein, and Stock, likely because of relatively low ruminal pH in the finishing diets.

Distillers Grains in Feedlot Diets

Wet Distillers Grains with Solubles

Perhaps the first study designed to include DGS as an energy source was conducted by Farlin (1981). He fed wet distillers grains without solubles, replacing 25%, 50%, and 75% of the corn in a finishing diet. Even though the perceived energy nutrient (starch) in corn had been removed, the resulting by-product actually had more energy per pound than the corn it replaced. Firkins, Berger, and Fahey (1985) and Trenkle (1996, 1997, 2008) found similar results with wet distillers grains with solubles (WDGS).

Larson et al. (1993) conducted a series of experiments designed to evaluate WDGS fed as a protein source or as an energy source. The hypothesis was that locating an ethanol plant adjacent to a feedlot would allow feeding of the product wet, eliminating the necessity of drying the by-product. The WDGS were fed at 5.2% and 12.6% of diet dry matter to supply metabolizable protein or crude protein needs, and at 40% of the diet (dry matter basis) to supply protein and replace corn in the diet as an energy source. At the 40% level, feed efficiency of the diet was increased 14% compared to the corn control (Table 2.1). Assuming the increase in efficiency was due to WDGS, the WDGS had 35% greater feeding value than corn.

Table 2.1. Calf performance when fed different dietary inclusions of wet distillers grains with solubles for protein and energy

	WDGS level, % of diet dry matter[a]				P-value		
Item	**0**	**5.2**	**12.6**	**40.0**	**SE**	**Linear**	**Quadratic**
Dry matter intake, lb/day	18.57	19.27	18.61	17.44	0.29	< 0.01	0.21
Average daily gain, lb	2.87	3.06	3.09	3.22	0.07	< 0.01	0.13
Gain/feed[b]	0.155	0.158	0.164	0.177	0.003	<0. 01	0.54
Hot carcass wt, lb	714	734	741	754	7	0.01	0.15
Fat thickness, in	0.51	0.55	0.55	0.55	0.04	0.21	0.27
Marbling score[c]	497	530	530	580	20	0.01	0.51

Source: Adapted from Larson et al., 1993.

[a]Wet grains:thin stillage = 1.67:1, dry matter basis.

[b]Accounts for ethanol consumption.

[c]When 400 = Slight^0 and 500 = Small^0.

Vander Pol et al. (2006) fed 0%, 10%, 20%, 30%, 40%, and 50% WDGS as a replacement for corn. They found quadratic responses to average daily gain (ADG) and feed efficiency and a cubic response in feeding value according to the WDGS level (Table 2.2). Feed efficiency at all levels of WDGS inclusion was better than the 0% WDGS corn control diet.

Nine experiments conducted in the same feedlot under relatively similar conditions were used for a meta-analysis (Klopfenstein, Erickson, and Bremer, 2008). Levels of WDGS replacing dry-rolled corn, high-moisture corn, or replacing a combination of the two ranged from 5.2% to 50%. The most common levels were 30% and 40%, and there was only one comparison at 50%. Experiments had 10 (individually fed) to 50 steers per treatment, and most had more than 40 steers per treatment. The nine experiments included 34 treatment means representing 1,257 steers.

There were quadratic responses to ADG and dry matter intake (DMI) (Table 2.3), with ADG and DMI being maximized at about 30% WDGS. The quadratic relationship for ADG from feeding WDGS is $y = -0.0005x^2 + 0.028x + 3.47$, where y = ADG in lb and x = percent inclusion in the diet on a dry basis. Therefore, the maximum ADG is achieved at an inclusion of 27.9% of the diet based on these nine experiments. The feed efficiency of the diet was maximized at 30% to 50% of diet, and the relationship tended to be quadratic ($P<0.09$). The equation for a quadratic response for feed efficiency from feeding WDGS is $y = -0.00000093x^2 + 0.000847x + 0.156$, where y = feed efficiency and x = percent inclusion in the diet on a dry basis. Therefore, feed efficiency is maximized at 45.6% inclusion of WDGS on a dry matter basis. Feeding values were calculated from the feed efficiency values and show decreasing feeding value as the level of WDGS in the diet increased. The feed efficiency values did not decrease for the diets at the high inclusion levels but, because of accounting for inclusion level in the diet, the feeding values decreased with inclusion level. Because the cattle gained more rapidly when fed WDGS compared to corn, they were fatter with equal days on feed. Consistent with the quadratic increase in rib fat was a quadratic increase in quality grade.

Distillers Dried Grains with Solubles

Drying of distillers grains is expensive because of the cost of fuel and the capital investment in equipment. Fuel ethanol is an energy source designed

Table 2.2. Cattle performance when fed different dietary inclusions of wet distillers grains with soluble to finishing yearling steers

WDGS Inclusion:[a]	CON	10WDGS	20WDGS	30WDGS	40WDGS	50WDGS	SEM	Lin[b]	Quad[c]	Cubic[d]
Dry matter intake, lb/day	24.03	24.70	25.14	26.02	24.48	23.37	0.31	0.09	< 0.01	0.81
Average daily gain, lb	3.66	4.08	4.12	4.32	4.28	3.92	0.09	0.01	< 0.01	0.45
Gain/feed[e]	0.153	0.165	0.164	0.173	0.176	0.169	0.002	< 0.01	< 0.01	0.43
Feeding value, %[f]	100	178	138	144	137	121	7	0.81	< 0.01	< 0.01
Hot carcass wt, lb	778	803	809	829	827	798	8.2	< 0.01	< 0.01	0.18
12th Rib fat, in	0.45	0.54	0.49	0.52	0.46	0.50	0.03	0.80	0.08	0.01
Longissimus muscle area, in[a]	12.35	12.77	12.82	12.51	12.38	12.35	0.19	0.36	0.09	0.13
Marbling score[g]	515	538	520	523	501	505	11.6	0.11	0.29	0.22

Source: Adapted from Vander Pol et al., 2006.

[a]Dietary treatment levels (dry matter basis) of WDGS, CON = 0% WDGS, 10WDGS = 10% WDGS, 20WDGS = 20% WDGS, 30WDGS = 30% WDGS, 40WDGS = 40% WDGS, 50WDGS = 50% WDGS.

[b]Contrast for the linear effect of treatment P-value.

[c]Contrast for the quadratic effect of treatment P-value.

[d]Contrast for the cubic effect of treatment P-value.

[e]Calculated as total gain over total DMI.

[f]Calculated from feed efficiency relative to control, divided by WDGS inclusion.

[g]400 = Slight^0, 500 = Small^0.

Table 2.3. Wet distillers grains plus solubles meta-analysis predicted cattle performance and carcass characteristics

	WDGS level (% of diet dry matter)						t-statistic	
	0	**10**	**20**	**30**	**40**	**50**	**Linear**	**Quadratic**
Dry matter intake, lb/day	22.31	22.73	22.78	22.49	21.83	20.82	0.01	0.01
Average daily gain, lb	3.46	3.70	3.84	3.88	3.81	3.66	< 0.01	< 0.01
Gain/feed	0.155	0.162	0.168	0.172	0.174	0.175	< 0.01	0.09
Feeding value, %[a]	100	145	142	137	131	126		
Fat thickness, in	0.49	0.52	0.54	0.54	0.52	0.49	< 0.01	0.04
Yield grade	2.85	2.95	3.02	3.04	3.01	2.94	< 0.01	0.06
Marbling score[b]	518	528	533	532	526	514	0.05	0.05

Source: The dataset included treatment means from Buckner et al., 2006; Corrigan et al., 2007; Al-Suwaiegh et al., 2002; Ham et al., 1994; Larson et al., 1993; Luebbe et al., 2008; and Vander Pol et al., 2006, 2008b.

[a]Value relative to corn, calculated by difference of feed efficiency, divided by by-product inclusion.

[b]500 = Small^0.

to replace fossil fuel (CAST, 2006). Thus, use of fossil fuel for drying is counterproductive. While many feedlot cattle are located in close proximity to dry milling plants, many are too far from plants to allow transportation of the WDGS to feedlots. In those cases, it may be logical and economical to produce DDGS to facilitate transportation.

Ham et al. (1994) compared feeding values of DDGS to WDGS in feedlot diets. The DGS were included at 40% of diet dry matter to replace corn. The WDGS were produced in a separate plant from the DDGS. The DDGS were from 11 sources and were combined into composites based on the content of acid detergent insoluble nitrogen. Cattle fed both WDGS and DDGS were more efficient than the control, corn-fed cattle (Table 2.4). Cattle fed WDGS were more efficient than cattle fed DDGS. The amount of acid detergent insoluble nitrogen did not affect feed efficiency. WDGS contained 47% higher feeding value than corn and DDGS contained 24% higher value.

Buckner et al. (2008b) conducted a feedlot study comparing 10%, 20%, 30%, and 40% levels of DDGS to a corn control. A trend for a quadratic response was observed for feed efficiency (Table 2.5). The quadratic response in gain-feed was similar to that found for WDGS by Vander Pol et al. (2006), but the feed efficiency response was somewhat less, and optimal inclusion was 20% of diet dry matter. These data were combined with four other experiments in a meta-analysis (Klopfenstein, Erickson,

Table 2.4. Effect of wet distillers grains with solubles or distillers dried grains with solubles on finishing cattle performance

		By-product and ADIN level[a]				
			DDGS			
Item	**Control**	**WDGS**	**Low[a]**	**Medium[a]**	**High[a]**	**SEM**
Average daily gain, lb[b,c]	3.22	3.73	3.66	3.70	3.77	0.26
Dry matter intake, lb/day[d,e]	24.23	23.55	25.31	25.05	25.86	1.21
Gain/feed[b,c,e]	0.133	0.158	0.144	0.148	0.145	0.004

Source: Adapted from Ham et al., 1994; all diets contained 40% distillers grains.
[a]ADIN = acid detergent insoluble nitrogen.
[b]Control vs. WDGS ($P < .05$).
[c]Control vs. average of DDGS composites ($P < 0.05$).
[d]Control vs. average of DDGS composites ($P < 0.10$).
[e]WDGS vs. average of DDGS composites ($P < 0.05$).

Table 2.5. Cattle performance when fed increasing levels of distillers dried grains with solubles to finishing steers[a]

							P-value	
Parameter	**0DDGS**	**10DDGS**	**20DDGS**	**30DDGS**	**40DDGS**	**SEM**	**Lin[b]**	**Quad[c]**
Dry matter intake, lb/day	20.40	20.88	20.99	21.41	20.88	0.37	0.23	0.30
Average daily gain, lb	3.31	3.55	3.70	3.57	3.51	0.11	0.26	0.05
Gain/feed[d]	0.162	0.171	0.177	0.168	0.168	0.005	0.61	0.14
Feeding value[e]	100	156	146	112	109			
Hot carcass wt, lb	774	798	816	803	792	12	0.32	0.04
12th Rib fat, in	0.56	0.54	0.59	0.55	0.58	0.03	0.48	0.99
Longissimus muscle area, in[a]	12.40	12.49	12.80	12.60	12.60	0.20	0.42	0.37
Marbling score[f]	533	537	559	527	525	12.7	0.50	0.18

Source: Adapted from Buckner et al., 2008b.

[a]DDGS= 0% DDGS, 10DDGS = 10% DDGS, 20DDGS = 20% DDGS, 30DDGS = 30% DDGS, 40DDGS = 40% DDGS.

[b]Contrast for the linear effect of treatment P-value.

[c]Contrast for the quadratic effect of treatment P-value.

[d]Calculated as total gain over total DMI.

[e]Value relative to corn, calculated by difference of feed efficiency, divided by by-product inclusion.

[f]400 = Slight^0, 500 = Small^0.

and Bremer, 2008). The meta-analysis showed a quadratic response in ADG and a cubic response in feed efficiency as the level of DDGS in the diet increased from 0% to 40% (Table 2.6). Maximum ADG was at 25.7% DDGS and maximum feed efficiency was between 10% and 20% DDGS. Compared to the meta-analysis for WDGS, the inclusion level for maximum response in feed efficiency was lower for DDGS than for WDGS; however, the inclusions to maximize ADG were similar. In addition, the feeding value of DDGS declined from the 20% inclusion level (123%) to the 40% inclusion level (100%). In contrast, the feeding value of WDGS at the 20% inclusion level was 142% and it declined to only 131% at the 40% inclusion level. There appears to be an interaction between DDGS and WDGS in feeding values at different levels of inclusion. At the 20% level of inclusion, the two types of distillers grains differed in feeding values by 19 percentage units but differed by about 31 percentage units at the 40% level of dietary inclusion. The biological basis for the interaction of distillers grains processing method and feeding value is not understood.

Modified Wet Distillers Grains with Solubles

Some ethanol plants are producing a partially dried wet distillers feed called modified wet distillers grains with solubles (MWDGS). The wet grains are partially dried, which increases dry matter content from about 35% to 42%–48%. The advantages of MWDGS relative to WDGS are the ability to add all of the solubles to the wet grains and lower transportation cost. However, there is the added cost of the partial drying. Because DDGS have lower feeding value than WDGS, the effect of "partial" drying to produce MWDGS was studied (Huls et al., 2008). MWDGS were fed at 0% to 50% of diet dry matter, replacing dry-rolled and high-moisture corn. Cattle ADG responded quadratically to increasing the level of MWDGS, with the greatest gains at the 20% inclusion level (Table 2.7). Feeding values decreased from 123% of corn at 10% inclusion to 109% at 50% inclusion.

A direct comparison of MWDGS to conventional WDGS has not been made. However, the data of Huls et al. (2008) suggest the feeding value of MWDGS is less than that of WDGS. In two studies, Trenkle (2007, 2008) also found generally lower feeding values for MWDGS than previously observed with WDGS. These observations all suggest that partial drying of MWDGS causes the feeding value to fall somewhere between those of DDGS and WDGS.

Table 2.6. Distillers dried grains with solubles meta-analysis predicted cattle performance and carcass characteristics

	DDGS level (% of diet dry matter)					t-statistic		
	0	**10**	**20**	**30**	**40**	**Linear**	**Quadratic**	**Cubic**
Daily feed, lb/day	22.42	22.93	23.22	23.28	23.13	0.01	0.08	0.68
Daily gain, lb	3.44	3.64	3.73	3.75	3.66	<0.01	<0.01	0.54
Gain/feed	0.152	0.160	0.159	0.155	0.152	0.07	0.02	< 0.01
Feeding value, %[a]	100	153	123	107	100			
Yield grade	2.87	2.91	2.94	2.98	3.01	0.04	0.51	0.90
Marbling score[b]	540	535	529	524	518	0.07	0.13	0.79

Source: Data set included treatment mean observations from Buckner et al., 2008b Bremer et al., 2006; Benson et al., 2005; Ham et al., 1994; and May et al., 2007a.

[a]Value relative to corn, calculated by difference of feed efficiency, divided by by-product inclusion.

[b]500 = Small^0.

Table 2.7. Calf-fed steer finishing feedlot performance when fed varying levels of modified wet distillers grains with solubles[a]

	CON	10MDG	20MDG	30MDG	40MDG	50MDG	SEM	Lin[b]	Quad[c]
Performance									
Initial body weight, lb	748	749	748	745	747	748	27	0.32	0.32
Final body weight[d] lb	1395	1411	1448	1439	1418	1398	38	0.82	<0.01
Dry matter intake, lb/day	23.0	23.1	23.5	23.2	22.8	21.6	0.7	0.03	0.01
Average daily gain, lb	3.67	3.75	3.97	3.94	3.81	3.69	0.10	0.73	<0.01
Gain/feed[e]	0.161	0.164	0.169	0.170	0.168	0.172		<0.01	0.28
Carcass characteristics									
Hot carcass weight, lb	879	889	912	906	893	881	24	0.82	<0.01
Marbling score[f]	520	513	538	498	505	490	17	0.10	0.42
12th Rib fat, in	0.57	0.57	0.61	0.62	0.57	0.54	0.04	0.54	0.12
Longissimus muscle area, in[b]	12.8	12.5	12.8	12.8	12.7	12.7	0.2	0.98	0.97
Calculated yield grade[g]	3.68	3.91	3.92	3.91	3.84	3.64	0.17	0.69	0.04

[a]Dietary treatment levels (dry matter basis) of MWDGS, CON= 0% MWDGS, 10MDG= 10% MWDGS, 20MDG= 20% MWDGS, 30MDG= 30% MWDGS, 40MDG= 40% MWDGS, 50MDG=50% MWDGS.
[b]Contrast for the linear effect of treatment P-value.
[c]Contrast for the quadratic effect of treatment P-value.
[d]Calculated from hot carcass weight, adjusted to a 63% yield.
[e]Calculated from total gain over total DMI.
[f]450 = Slight 50, 500 = Small 0.
[g]Where yield grade = 2.5 + 2.5(fat thickness, in) – 0.32(LM area, in^2) + 0.2(KPH fat, %) + 0.0038(hot carcass weight, lb).

Metabolism and Digestion of Distillers Grains

It is a paradox that both DDGS and WDGS appear to have greater feeding values than corn and yet are less digestible because of the NDF in the distillers grains. Lodge et al. (1997b) attempted to determine the reason for this apparent paradox. They developed a "composite" distillers grains with composition as similar as possible to DDGS. The ingredients in the composite were wet corn gluten feed (corn bran and steep liquor), corn gluten meal, and tallow. The feeding value of the composite when fed at 40% of diet dry matter was 124% of the corn it replaced (Table 2.8). This feeding value is comparable to the meta-analysis of WDGS described previously. When either corn gluten meal or tallow were removed, feed efficiency decreased a similar amount numerically, indicating that both the escape protein in the corn gluten meal and the tallow were equally responsible for the high feeding value of the composite. It is unlikely but possible that the corn gluten meal met a metabolizable protein deficiency. The response is more likely from the greater energetic efficiency of undegradable intake protein compared to degraded protein or carbohydrates. Certainly the higher energy value of lipid for ruminants (Zinn, 1989) explains the response to tallow. Larson et al. (1993) estimated that the undegraded protein and fat in WDGS would increase the feeding value by about 20% compared to that of corn. This is less than the value of 30% in the meta-analysis and does not account for the lower digestibility of NDF in WDGS compared to the digestibility of starch in corn. Therefore, the paradox remains unexplained.

Metabolism of the lipid in distillers grains is important from an energetic as well as a meat composition standpoint. Vander Pol et al. (2008b)

Table 2.8. Effect of wet grains composite on finishing steer performance

	Treatment[a]					
Item	**DRC**	**WCGF**	**COMP2**	**-FAT**	**-CGM**	**SEM**
Dry matter intake, lb/day	21.50[b]	20.90[bc]	19.96[c]	20.02[c]	20.79[bc]	1.19
Average daily gain, lb	2.93	2.87	2.98	2.91	2.93	0.29
Gain/feed	0.136[b]	0.136[b]	0.149[c]	0.146[bc]	0.146[bc]	0.023

Source: Adapted from Lodge et al., 1997b.

[a]WCGF = wet corn gluten feed; COMP2 = wet corn gluten feed, corn gluten meal, and tallow; -FAT = composite minus tallow; -CGTM = composite minus corn gluten meal.

[b, c]Means within a row with unlike superscripts differ ($P < .10$).

conducted a feedlot study and a metabolism study to elucidate the role of lipid in distillers grains. Adding 5% corn oil to the corn control diet reduced feed efficiency by 10%. Conversely, adding a similar amount of lipid from WDGS increased feed efficiency by 8%. Fat added as corn oil was 70% digested while fat added in WDGS was 81% digested. Fatty acid profiles were measured in duodenal contents (Table 2.9). Unsaturated fatty acids were higher (30.9% of total fat) in duodenal contents of steers fed WDGS than in steers fed similar amounts of corn oil (10.8% of total fat). This suggests that some of the oil in WDGS was protected from rumen hydrolysis/hydrogenation. Plascencia et al. (2003) showed that fat digestion decreases with hydrogenation. Therefore, these data (Vander Pol et al., 2008b) are consistent by showing reduced hydrogenation and increased digestibility of the lipid in WDGS compared to those qualities of free corn oil. The metabolism data are also consistent with the feeding study in which the lipid response was positive from WDGS and negative from oil. This negative influence could be due to the influence of lipid on either rumen fermentation or fat digestion. Plascencia et al. (2003) reported that intestinal fatty acid digestion decreased with the level of total fatty acid intake, regardless of saturation. That might suggest that the declining feeding value of distillers grains as inclusion levels in the diet increase is at least partially due to declining fatty acid digestion.

Carcass Characteristics and Meat

In the meta-analysis of Klopfenstein, Erickson, and Bremer (2008), cattle fed WDGS gained more rapidly than the corn-fed cattle. More rapid gains resulted in greater fat levels because the cattle were fed the same number

Table 2.9. Fatty acid profiles of duodenal fat content of steers fed wet distillers grains with solubles or supplemental corn oil

	Treatment[a]		
Item	**WDGS**	**CON**	**CON + OIL**
Fatty acids[b]			
16 and 18 C unsaturated	30.9	20.1	18.4
14 to 18 C saturated	64.0	71.7	75.3
Other	5.1	8.2	6.3
Unsaturated:saturated	0.48	0.28	0.24

Source: Adapted from Vander Pol et al., 2008b.
[a]WDGS = wet distillers grains plus soluble (WDGS) diet, CON = average of control diet and composite diet, CON + OIL = average of control + corn oil diet and composite + corn oil diet.
[b]Expressed as proportion of fat reaching the duodenum.

of days. Marbling scores followed a similar pattern to that of ADG and fatness. In all three measurements, there was a quadratic response to the level of WDGS. Maximum ADG, fatness, and marbling were reached at about 30% of diet dry matter. Gain, fatness, and marbling were less at 50% of diet dry matter compared to 30% inclusion but not different from the corn control diet. Results were generally similar for the meta-analysis with DDGS feeding except the optimum was at a lower level of dietary DDGS inclusion. May et al. (2007a,b), Gordon et al. (2002a), and Sims et al. (2008) found similar results with steam-flaked corn diets, in that the degree of fattening and marbling paralleled that of ADG.

Gordon et al. (2002b) fed (153 d) increasing levels of DDGS with steam-flaked corn and evaluated steaks from the finished cattle. They found subtle positive differences in steak tenderness with increasing levels of DDGS as reported by a trained panel, but the researchers concluded that consumers would likely not detect differences. Steaks were displayed for seven days, and while redness decreased with time of display, there was no effect of level of DDGS feeding. Flavors were not affected by the level of DDGS feeding, and there was also no evidence of off-flavors or lipid oxidation, even at 75% DDGS in the diet.

Roeber, Gill, and DiCostanzo (2005) evaluated steaks from Holstein steers fed distillers grains at levels up to 40% and 50% in two experiments. Feeding distillers grains up to 50% of diet dry matter did not affect tenderness or sensory traits. However, the researchers noted a tendency for high levels of distillers grains feeding to have a negative effect on color during retail display. Lancaster et al. (2007) fed distillers grains at a relatively low level (15% of dry matter) and evaluated fatty acids in the resulting meat. There was no effect of distillers grains on fatty acid composition of the triacylglycerol fraction, but polyunsaturated fatty acids (PUFA) were increased in the phospholipids fraction. Gill et al. (2008) also evaluated steaks when distillers grains were fed at 15% of the diet. They found no effects due to distillers grains feeding on sensory attributes or Warner-Bratzler shear force values. They found several small changes in proportions of PUFA.

Jenschke et al. (2007) evaluated steaks from the cattle used by Vander Pol et al. (2006) that were fed 0% to 50% WDGS. The level of WDGS did not affect off-flavor intensity. Liver-like off flavor was always numerically lower in steaks from cattle fed WDGS. Jenschke et al. (2008) showed that roughage source and type did not affect fatty acid profiles or sensory properties of meat from steers fed 30% WDGS.

The data of Vander Pol et al. (2008b) show that more unsaturated fatty acids are absorbed from the intestine. De Mello, Jenschke, and Calkins (2008b) have clearly demonstrated that unsaturated fatty acids increase in beef fat with feeding of distillers grains. However, this does not appear to influence marbling observed by USDA graders, as De Mello, Jenschke, and Calkins (2008a) found that there is no change in the relationship of intramuscular fat content and marbling score in multiple experiments in which 0%, 15%, or 30% WDGS were fed.

The increased level of PUFA in beef from cattle fed DGS is a bit of a catch-22. Beef fat has been criticized for being saturated, so the greater PUFA content with DGS feeding makes beef potentially more "healthy." Conversely, De Mello, Jenschke, and Calkins (2008c) have shown that PUFA cause more rapid discoloration of meat in the display case. Senaratne et al. (in press) have demonstrated that feeding vitamin E with distillers grains restores the shelf life of the meat. Many factors such as time in the display case, type of packaging, and oxygen content of gas in packaging will interact with the effect of PUFA from distillers grains on shelf life of beef. It is not clear at the present time whether there is a discoloration problem or whether vitamin E feeding is necessary.

Roughage Levels and Sources

Starch is removed in the production of ethanol, so when distillers grains are included in the diet, especially at levels above 20% of dry matter, the amount of starch in the diet is decreased while fiber, protein, and fat are increased. This suggests that sub-acute acidosis should be reduced and roughage (forage) content of the diet could be reduced when distillers grains are included in diets above 20%. Acidosis control (Krehbiel et al., 1995) and reduced roughage needs (Farran et al., 2006) have been demonstrated with corn gluten feed, which has a similar amount of corn fiber to that in distillers grains. In addition to supplying NDF and reducing starch in the diet, WDGS add moisture and protein to the diet. The moisture and physical characteristics (stickiness) aid markedly in palatability and reduce separation and sorting of less palatable ingredients. The protein in WDGS reduces the need for (value of) protein in the roughage. Therefore, less expensive, lower digestible forages may be acceptable in diets with reasonably high levels of WDGS.

A feedlot study tested the response to roughage level and source in diets containing 30% WDGS (Benton et al., 2007). Alfalfa was used as the "gold standard" roughage and was fed at 4% and 8% of diet dry matter. Cornstalks were evaluated at amounts of NDF similar to the alfalfa (3% and 6% of diet dry matter). Corn silage was included as the third roughage source. The theory was that corn silage could be harvested and stored less expensively as silage compared to harvesting corn and cornstalks separately, yet it would provide both components. The silage was also included on an equal NDF basis at 6% and 12% of diet dry matter. An all-concentrate diet (no roughage) was included as a control. There was a 2- to 3-pound increase in daily DMI due to roughage inclusion while ADG increased by 0.20 to 0.50 pound (Table 2.10). These increases in DMI and ADG are typical of those observed in studies evaluating roughage levels in diets without WDGS (Shain et al., 1999). These data suggest WDGS did not supply "roughage" even though the by-product supplied NDF. However, cornstalks were as effective as alfalfa and corn silage in diets containing WDGS in providing roughage in terms of response in DMI, ADG, and feed efficiency. This is contrary to the results of Shain et al. (1999) in which wheat straw fed on an equal NDF basis to alfalfa in dry-rolled corn diets was not as efficiently utilized as alfalfa. This suggests that the moisture and protein in WDGS do in fact supply characteristics to the diet that allow utilization of low-quality roughages that are often less expensive compared to alfalfa.

Grain Processing

All of the data discussed have evaluated distillers grains in feedlot diets based on dry-rolled corn or high-moisture corn. Vasconcelos and Galyean (2007b) put together a very insightful survey of feedlot nutritionists. They reported that 65.5% of nutritionists surveyed stated that steam flaking was the most common method of corn processing. This doesn't mean that 65% of the corn fed to feedlot cattle is steam-flaked corn, only that 65% of the nutritionists in their survey responded accordingly. Their publication was not designed to quantify the amount of steam-flaked corn fed in feedlots. The total amount of steam-flaked corn may be greater than or less than

Table 2.10. Finishing performance of cattle fed diets containing wet distillers grains with solubles with three types of roughage at low or normal neutral detergent fiber levels

	CON	LALF	LCSIL	LCSTK	NALF	NCSIL	NCSTK	SE
Dry matter intake, lb/day	22.27^{a}	24.48^{b}	24.26^{b}	24.92^{bc}	25.80^{c}	25.36^{c}	25.58^{c}	0.44
Average daily gain, lb	4.32^{a}	4.54^{ab}	4.52^{a}	4.78^{c}	4.76^{bc}	4.74^{bc}	4.81^{c}	0.11
Gain/feed	0.195	0.186	0.186	0.192	0.185	0.188	0.188	0.003

Source: Adapted from Benton et al., 2007.
Note: CON = Control, LALF = low alfalfa hay (4%), LCSIL = low corn silage (6%), LCSTK = low corn stalks (3%), NALF = normal alfalfa hay (8%), NCSIL = normal corn silage (12%), and NCSTK = normal corn stalks (6%).
[a,b,c]Means within a row with unlike superscript differ ($P < 0.05$).

65%. Regardless, steam-flaked corn represents a large proportion of grain fed to feedlot cattle, especially in the Southern High Plains. Feeding dry-rolled corn, high-moisture corn, and high levels of distillers grains is more common in Corn Belt states where many ethanol plants are in production or under development.

Vander Pol et al. (2008a) fed dry-rolled, steam-flaked, and high-moisture corn with 30% WDGS to finishing cattle. From the meta-analysis, this 30% inclusion level with dry-rolled or high-moisture corn would be optimal for rate and efficiency of gain. Feed efficiency for high-moisture corn was 4% greater (P= 0.08) than that for dry-rolled corn (Table 2.11). With each corn at 61% of diet dry matter, the high-moisture corn has 6.5% higher feed value than dry-rolled corn, which is consistent with data for these corn products when they are fed with wet corn gluten feed (Macken et al., 2006). Scott et al. (2003) and Macken et al. (2006) suggested that steam-flaked corn has 10% to 15% higher feeding value than dry-rolled corn, the higher values when fed with wet corn gluten feed. However, Vander Pol et al. (2008a) found similar feed efficiency for cattle fed steam-flaked and dry-rolled corn when 30% WDGS was included in the diet, and ADG was significantly decreased for cattle fed steam-flaked compared to dry-rolled or high-moisture corn. Drouillard et al. (2005) also obtained less response to the combination of WDGS and steam-flaked corn than

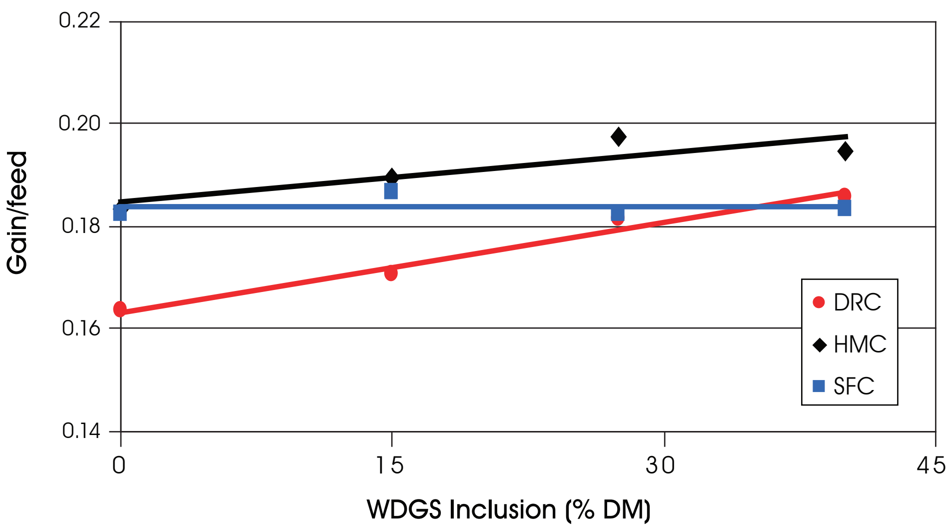
Table 2.11. Performance and carcass characteristics of steers fed 30% wet distillers grains with solubles and corn from three different processing methods

	SFC	HMC	DRC	SEM	F-test
Dry matter intake, lb/day	20.46[f]	21.01[ef]	22.67[e]	0.22	<0.01
Average daily gain, lb[a]	3.59[f]	3.90[e]	4.06[e]	0.07	<0.01
Gain/feed[a,b]	0.176[f]	0.185[e]	0.179[ef]	0.002	<0.01
Fecal starch, %[c]	4.2[f]	8.7[e]	12.0[e]	1.3	<0.01
Hot carcass wt, lb	822[f]	853[e]	871[e]	7	<0.01
12^{th} Rib fat, in	0.51[f]	0.58[e]	0.62[e]	0.02	<0.01
Longissimus muscle area, in[b]	12.60	13.19	13.00	0.20	0.16
Marbling score[d]	496[f]	544 [e]	540[e]	10	<0.01

Source: Adapted from Vander Pol et al., 2008a.
[a]Calculated from adjusted final body weight.
[b]Calculated as total feed intake (dry matter basis) divided by total gain.
[c]Percentage of fecal dry matter.
[d]Where 400 = $Slight^0$, 500= $Small^0$.
[e,f,g,h]Means within a row with unlike superscripts differ (P <0.05).

expected and suggested the optimal level of WDGS was less than the 30% level used by Vander Pol et al. (2008a).

Corrigan et al. (2007) evaluated the interaction between level of WDGS inclusion and grain processing method. WDGS were fed at 0%, 15%, 27.5%, and 40% rates of dry matter in diets consisting of dry-rolled, high-moisture, or steam-flaked corn (3x4 factorial design). Interactions for ADG and feed efficiency were observed between level of WDGS and grain processing type (Figure 2.1). At 0% WDGS, the steam-flaked corn had 14% greater feeding value than that of dry-rolled corn, which is consistent with Cooper et al. (2002) and Owens et al. (1997). When WDGS were added to dry-rolled corn, there was a linear increase ($P < 0.01$) in feed efficiency such that at 40% inclusion, efficiency was similar to that of the steam-flaked corn diets. When WDGS was added to the steam-flaked corn diets, there was no change in feed efficiency. The feeding value for WDGS in steam-flaked corn diets appears to be equal to that of steam-flaked corn, which was 14% greater than that of dry-rolled corn in this



Source: Adapted from Corrigan et al., 2007.

Figure 2.1. Feed efficiency of finishing steers fed differing levels of wet distillers grains with solubles (WDGS) with dry-rolled corn (DRC), high-moisture corn (HMC), or steam-flaked corn (SFC). Linear effect of WDGS level with DRC ($P < 0.01$), linear effect of WDGS level with HMC ($P < 0.05$), and corn processing method by WDGS level interaction ($P < 0.01$)

trial. However, WDGS had a 34% higher feeding value than dry-rolled corn averaged across levels in this trial. The high-moisture corn diet with 0% WDGS gave feed efficiency values similar to those of the steam-flaked corn diet without WDGS. However, addition of WDGS to high-moisture corn gave a linear ($P < 0.05$) improvement in feed efficiency. While this experiment clearly showed the interaction between WDGS level and grain type on cattle performance, it certainly did not explain possible mechanisms. The relatively poor response to WDGS in steam-flaked corn diets has also been shown by May et al. (2007b).

Feeding Value of Sorghum Distillers Grains

While corn is the primary grain used for ethanol production, grain sorghum has been and continues to be used as a feedstock. The grains have similar amounts of starch and therefore have similar ethanol yields. Sorghum is usually less expensive than corn so it is an attractive feedstock for ethanol plants. Lodge et al. (1997a) suggested that sorghum distillers grains had less feeding value than corn distillers grains. However, their comparison was somewhat indirect. Al-Suwaiegh et al. (2002) made a direct comparison of sorghum and corn distillers grains from the same ethanol plant. The two distillers grains were fed at 30% of the diet with dry-rolled corn. Although feed efficiency was not significantly different, it favored corn distillers grains by 3%, giving the WDGS from corn a 10% higher feeding value compared to WDGS from sorghum. Two additional experiments have been reported in which sorghum distillers grains were compared to corn distillers grains in steam-flaked corn diets. Levels of DGS fed were lower than those reported by Al-Suwaiegh et al. (2002) so the distillers grains were used primarily as a protein source. In addition, the two types of distillers grains were produced by different ethanol plants. Vasconcelos et al. (2007c) reported statistically similar responses for sorghum and corn distillers grains (0.169 vs. 0.176 gain-feed), but the feeding value of the corn distillers grains was 40% greater than that of the sorghum distillers grains. Depenbusch et al. (2005) did not show a significant difference between sorghum and corn distillers grains (0.148 vs. 0.153 gain-feed), but the feeding value of corn distillers grains was 25% greater than that of sorghum distillers grains. Considering the four experiments reported, one might conclude that sorghum distillers grains are equal to corn distillers grains based on non-significant differences. However, the corn distillers grains were superior numerically in all experiments, so it is risky to conclude the two are equivalent in feeding value.

Combinations of By-products

With the large-scale expansion of ethanol plants in the Midwest, an option for many feedlots will be to utilize both WDGS and wet corn gluten feed concurrently. In addition to their commercial availability, another reason for feeding a combination of WDGS and wet corn gluten feed is their nutritional profiles. Complementary effects in feeding a combination of these by-products might be expected because of differences in fat, effective fiber, and protein components. Loza et al. (2005) fed yearling steers a 50:50 blend of WDGS and wet corn gluten feed (dry matter basis) at inclusion levels of 0%, 25%, 50%, and 75% of diet dry matter. 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 level with each of the by-product diets. Therefore, forage inclusion decreased as the rate of inclusion of by-products in the diets increased (i.e., 25% blend had 5% alfalfa in the lower forage treatment, 50% blend had 2.5% alfalfa, and 75% blend had 0% alfalfa). Results indicated that there were no differences in cattle performance between forage levels for each by-product's blend level. The lack of differences in performance with decreasing forage would indicate that the inclusion of the by-products was enough to prevent the negative consequences of sub-acute acidosis (Table 2.12). The analysis of the pooled data from each co-product level indicated that the performance of the steers fed the maximum by-product level (75%), regardless of the forage level, was not different from a typical corn-based diet (0% co-products blend). However, the diets including a 25% and 50% blend of WDGS and wet corn gluten feed resulted in significantly better animal performances than the control diet.

Table 2.12. Effect of different inclusion levels of a 50:50 blend of wet distillers grains with solubles and wet corn gluten feed and forage levels fed to yearling steers

Blend:	**0%**	**25%**		**50%**		**75%**	
Alfalfa:	**7.5**	**5.0**	**7.5**	**2.5**	**7.5**	**0.0**	**7.5**
Dry matter intake, lb/day	24.30[a]	26.30[bc]	26.50[b]	25.40[c]	26.10[bc]	23.00[d]	23.60[ad]
Average daily gain, lb	3.99[a]	4.70[b]	4.57[b]	4.55[b]	4.56[b]	3.86[a]	3.93[a]
Gain/feed	0.164[a]	0.179[c]	0.172[bc]	0.179[c]	0.175[bc]	0.168[ab]	0.166[ab]

Source: Adapted from Loza et al., 2005.

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

Buckner et al. (2006) fed the same combination of WDGS and wet corn gluten feed at 30% or 60% dietary dry matter compared to feeding the by-products alone at 30% dietary dry matter or a 0% by-product diet. The 30% WDGS diet gave the best performance. However, feeding wet corn gluten feed or WDGS in a blend (1:1 dry matter basis) or alone improved performance over cattle fed a corn-based diet (0% by-product). A second trial by Loza et al. (2007) compared a 0% by-product diet to six other diets containing a constant amount of wet corn gluten feed (30% diet dry matter) and additions of WDGS at 0%, 10%, 15%, 20%, 25%, or 30% diet dry matter. Including WDGS at 15% to 20% of the diet with 30% wet corn gluten feed had the greatest ADG. This research agrees with Buckner et al. (2006) in that the 30% wet corn gluten feed plus 30% WDGS gave better performance than the corn-based control diet. These three studies demonstrate that high levels of by-products, when used in combination, can be fed to feedlot cattle without reducing performance compared to corn-based control diets. Vasconcelos and Galyean (2007a) found a combination of 20% wet corn gluten feed and 7% DDGS worked well in a steam-flaked corn diet.

Feeding a combination of WDGS and wet corn gluten feed can also serve as a management tool. A major challenge facing some ethanol plants is not having by-products available for cattle feeders on a consistent basis. Cattle do not respond well if either WDGS or wet corn gluten feed, as a sole by-product in the diet, is removed and replaced with corn abruptly. Therefore, one approach would be to feed a combination to ensure that at least one by-product is consistently in the ration.

Sulfur

Buckner et al. (2008c) took 1,200 samples of WDGS from six ethanol plants over a ten-month period. The average sulfur content was 0.78%. However, there was some variation among samples, with one sample at 1.72%. Corn contains 0.14% to 0.16% sulfur. This suggests that distillers grains would have about 0.45% of the sulfur that is in the corn. The sulfur from the corn is primarily in the form of sulfur amino acids, and it may be only 40% degraded in the rumen. The remaining sulfur is from sulfuric acid and sulfamic acid used for pH control and cleaning of distillation columns. The sulfur is reduced in the rumen to H_2S, which is absorbed. The H_2S may directly or indirectly cause polioencephalomalacia (PEM)

(Gould, 1998). The PEM condition is referred to among feedlot personnel as "brainers" because the cattle experience neurological problems.

The National Research Council (1996) suggests the upper limit for sulfur in the diet is 0.4% of dry matter. That level is based on very little data. More recently, the National Research Council (2005) suggested that beef cattle fed forage-based diets could tolerate 0.5% sulfur, and cattle fed concentrate (less than 40% forage) could tolerate 0.3% sulfur (dry matter basis). Over the past several years, numerous experiments have been conducted at the University of Nebraska in which various levels of by-products have been fed, providing numerous, and sometimes high, levels of sulfur. Data were summarized on 4,143 cattle finished in experiments involving by-products. There were 23 animals diagnosed by the feedlot health crew as being "brainers" (PEM suspects). Some responded to thiamine therapy. (All diets contained 75 to 150 mg/day thiamine.) Those that died were necropsied and diagnosed as PEM. We assume that all 23 were suffering from PEM, but the survivors were not diagnosed clinically, which requires inspection for brain lesions.

Eleven of the 24 "brainers" were on one dietary treatment. The diet had 0.47% sulfur and no roughage. It is presumed that the lack of roughage was a predisposing factor in the development of the 11 PEM cases. These cases are excluded from the following analysis.

In diets with less than 20% by-product, sulfur levels were relatively low, and 0.1% of the cattle were diagnosed with PEM. We assume this is a normal baseline level of PEM and includes cattle on diets with no by-products. In diets with greater than 20% by-products and less than 0.46% sulfur, 0.14% of the cattle were diagnosed with PEM. This appears to be similar to the baseline level. Between 0.46% and 0.58% levels of sulfur, 0.38% of the cattle were diagnosed with PEM, and above 0.58% sulfur, 6.06% were diagnosed with PEM.

We conclude that the risk of PEM is low when diet sulfur levels are below 0.46%. Above 0.46% sulfur, the risk increases quite dramatically. A diet with 50% of the dry matter as WDGS is about 0.47% sulfur if the WDGS has 0.72% sulfur. Knowing the sulfur level of the by-product is very important if high levels of by-products are being fed. Water can be an additional source of sulfur and should be checked before high levels of by-products are fed (DeWitt et al., 2008).

Feeding Distillers Grains and E. coli Shedding

There were only eight recalls due to *E. coli* O157:H7 in ground beef in 2006, and all of them were initiated because of company sampling. However, in 2007 there were 20 recalls, and nine of those recalls resulted from illness investigation. Health officials looked for reasons why *E. coli* O157:H7 (referred to simply as *E. coli* hereafter) seemed to be a greater problem in 2007 compared to the previous four years. Because the ethanol industry grew in 2007 and feeding ethanol by-products increased, some theorized feeding ethanol by-products was the cause of the *E. coli* recalls. Late in 2007, research (Jacob et al., 2008b) showing a relationship between distillers grains feeding and *E. coli* shedding was reported.

Jacob et al. (2008c) reported a study using 370 feedlot cattle sampled at 122 and 136 days on feed. Prevalence overall was fairly low (under 10%). On day 122, cattle were statistically more likely to shed *E. coli* when fed 25% distillers grains in the diet. On day 136, there was no effect on shedding from feeding distillers grains. Jacob et al. (2008b) sampled cattle for twelve weeks during the feeding period. Fecal samples were collected from the pen floor. Feeding distillers grains significantly increased *E. coli* shedding, although there was no difference in 5 of the 12 sampling periods.

Jacob et al. (2008d) conducted a challenge experiment in which calves were inoculated with nalidixic-acid-resistant *E. coli*, allowing researchers to estimate the number of the *E. coli* shed. Fecal samples were collected for forty-two days. *E. coli* shedding was not different for calves fed distillers grains during the first five weeks but was statistically greater during the last week of sampling. Based on these three studies, researchers concluded that feeding distillers grains increased *E. coli* shedding. In each of the three experiments there were sampling times when distillers grains statistically increased shedding; however, as with most results in *E. coli* research, the results were somewhat inconsistent, making interpretation of the results somewhat difficult.

Recently, Jacob et al. (2008a) reported results of an experiment using 700 cattle fed for 150 days, and with half being fed distillers grains. Pen floor samples were collected weekly or every two weeks, and a total of

3,560 samples were collected and analyzed. Overall prevalence of *E. coli* was fairly low (5.1%). Although prevalence in pen floor fecal samples was numerically higher on some sampling weeks in cattle fed distillers grains, there was no significant effect (P = 0.2).

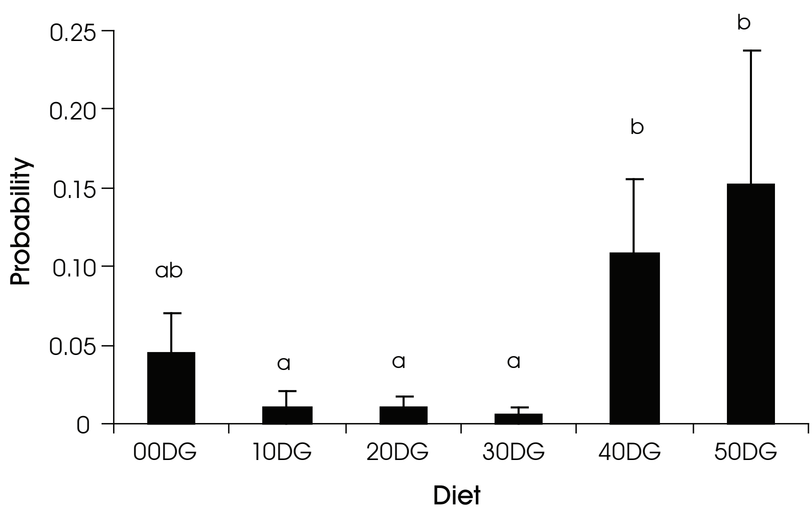
All of the previous studies were conducted with steam-flaked corn diets with or without 25% distillers grains (dry matter basis). This may be important as we compare other research projects and results. Corrigan et al. (2007) have reported that distillers grains do not respond the same in steam-flaked corn diets compared to dry-rolled or high-moisture corn diets. If cattle gains and efficiencies respond differently to distillers grains levels in steam-flaked, dry-rolled, or high-moisture corn diets, then it is possible that any effects on *E. coli* vary as well. Our *E. coli* research is with dry-rolled or high-moisture corn only.

It is logical that the diet fed to cattle could influence the growth of *E. coli* in the hindgut. Research has shown that the primary reservoir of *E. coli* is the hindgut and that the *E. coli* attach to the intestinal wall of the hindgut. Interestingly, the *E. coli* have no effect on cattle performance. There are two opposing theories on how the diet affects *E. coli* in the hindgut. The first theory is that starch escaping digestion in the rumen and small intestine is fermented in the hindgut, producing volatile fatty acids and lowering pH-inhibiting growth of the *E. coli*. Fox et al. (2007) showed support for this theory: steam flaking reduced starch in the hindgut and increased *E. coli* shedding. However, Depenbusch et al. (2008) said "*E. coli* O157:H7 was not related to fecal pH or starch." We reanalyzed the data of Peterson et al. (2007a), in which diets with decreasing amounts of corn were fed—decreasing the amount of starch in the diet. The amount of starch in the diet was not related to *E. coli* shedding (P = .22).

The opposing theory is that starch in the hindgut is the substrate for *E. coli*, so by reducing the amount of starch getting to the hindgut, *E. coli* would be reduced. Reports of Peterson et al. (2007a) and Folmer et al. (2003) did not support this theory. While it is logical that diet affects *E. coli* growth in the hindgut, clearly neither of the two opposing starch theories has been proven.

Peterson et al. (2007b) focused on vaccination as an *E. coli* intervention. Because the study was superimposed on a nutrition study, we reanalyzed the data (Figure 2.1). Wet distillers grains were fed as 0%, 10%, 20%, 30%, 40% and 50% of diet dry matter replacing dry-rolled and high-moisture corn. In this experiment, samples of the hindgut mucosa were analyzed, as were fecal samples. Results were similar but more consistent for the mucosal samples (Figure 2.2). There was a significant effect of level of distillers grains on *E. coli* shedding; however, it was not a linear relationship. None of the levels of distillers grains feeding was statistically different from the control (no distillers grains). The 10%, 20%, and 30% distillers grains levels numerically decreased the shedding of *E. coli*. Interestingly, this is within the range of feeding (25%) discussed previously with steam-flaked corn. Our research is with dry-rolled and high-moisture corn while the previous research was with steam-flaked corn, which may make a difference.

At the 40% and 50% distillers grains feeding levels, *E. coli* shedding numerically increased compared to the control. Note that the statistical difference is between the 10%, 20%, and 30% distillers grains levels and the 40% and 50% levels. So does feeding distillers grains decrease or increase *E. coli* shedding?

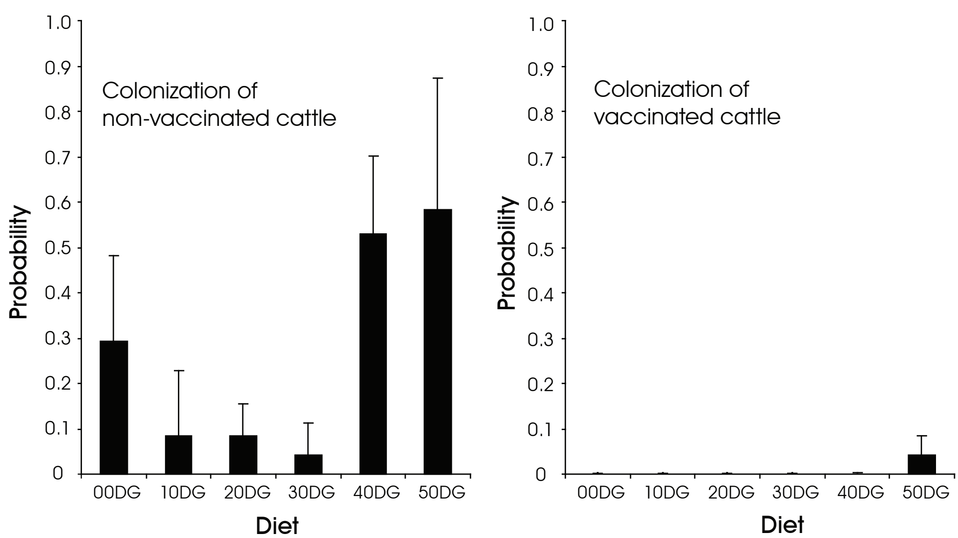


Source: Adapted from Peterson et al., 2007b.
[a,b,c]Treatment means with unlike letters differ.

Figure 2.2. Effect of level of wet distillers grains with solubles (WDGS) on *E. coli* O157:H7 colonization by cattle, 00DG = corn control diet with no WDGS, 10DG = 10% WDGS, 20DG = 20% WDGS, 30DG = 30% WDGS, 40DG = 40% WDGS, 50DG = 50% WDGS

In the Peterson et al. (2007b) study with *E. coli* vaccination, the pattern of *E. coli* in hindgut mucosa for unvaccinated cattle was similar to that discussed previously (Figure 2.3). However, there was only one steer that tested positive among the vaccinated cattle and that was one fed distillers grains at the 50% level. In four studies involving 1,784 cattle, vaccination reduced *E. coli* shedding by 65%. This is equivalent to the effect of winter versus summer on shedding. Feeding a direct-fed microbial (Peterson et al., 2007a) reduced shedding over two years by 35%. These two interventions plus others being researched have considerable merit.

The data on the effect of distillers grains on *E. coli* O157:H7 shedding are inconclusive at best. The compiled data do not indicate that distillers grains feeding significantly affects *E. coli* shedding. Studying *E. coli* O157:H7 requires many observations and substantial resources. Focusing future research on the development and implementation of these interventions will be the most beneficial way to improve pre-harvest food safety.



Source: Adapted from Peterson et al., 2007b, J. Food Prot. 70: 2568-2577.

Figure 2.3. Effect of level of wet distillers grains with solubles (WDGS) on *E. coli* O157:H7 colonization of unvaccinated or vaccinated against *E. coli* O157:H7. 00DG = corn control diet with no WDGS, 10DG = 10% WDGS, 20DG = 20% WDGS, 30DG = 30% WDGS, 40DG = 40% WDGS, 50DG = 50% WDGS

Use of Distillers Grains in Forage-Fed Cattle

Beef calves (from weaning until they enter feedlots), developing heifers, and beef cows are fed primarily forage diets. Forages are low in protein and phosphorus, especially in the winter. Stocker calves, developing heifers, and cows on low-quality forage need supplemental phosphorus and protein. Cows may also need energy supplementation. It is advantageous if the same commodity can be used for supplemental energy as well as for protein and any phosphorus that may be needed. By-product feeds can be used to meet these requirements of cattle in pasture and range situations. An additional advantage for distillers grains is that these feeds contain very little starch and therefore should not depress fiber digestion as corn does in some situations.

Animal Performance

An experiment was conducted with 120 crossbred heifers to determine the value of DDGS in high-forage diets and to evaluate the effect of supplementing daily compared to three times weekly (Loy et al., 2008). Heifers were supplied with ad libitum access to grass hay and supplemented with DDGS or dry-rolled corn. Supplements were fed at two levels and offered either daily or three times per week in equal proportions. Heifers supplemented daily ate more hay, gained faster (1.37 vs. 1.24 lb per day), but were not more efficient than those supplemented on alternate days (Table 2.13). At both levels of supplementation, heifers fed DDGS gained more and were more efficient than heifers fed dry-rolled corn. The calculated feeding values for DDGS were 30% and 18% greater than for dry-rolled corn when fed at 10% and 34% of diet dry matter.

Ten ruminally cannulated heifers received no supplement, DDGS daily, DDGS on alternating days, dry-rolled corn daily, or dry-rolled corn on alternating days (Loy et al., 2007). Hay intake was higher for non-supplemented than for supplemented heifers (Table 2.14). No intake differences were observed between DDGS and dry-rolled corn supplemented heifers. Heifers supplemented daily had higher and more consistent intakes than those in alternate-day treatments, particularly within corn-supplemented heifers. Ruminal pH and hay fiber disappearance were greater in non-supplemented heifers. Corn-supplemented heifers had slower rates of fiber digestion than DDGS-supplemented heifers.

Table 2.13. Growing calf performance over eighty-four days when fed native grass hay (CP = 8.7%) supplemented with either corn or distillers dried grains with solubles for two levels of gain

		Low[a]	High[b]
Average daily gain, lb/d	Corn	0.81 ± 0.06	1.57 ± 0.05
	DDGS	0.99 ± 0.05	1.89 ± 0.05
Gain/feed	Corn	0.063 ± 0.007	0.102 ± 0.007
	DDGS	0.078 ± 0.007	0.125 ± 0.007

Source: Adapted from Loy et al., 2008.
[a]Low = supplement fed at 0.21% BW, about 10% of diet, DDGS 130% feeding value of corn.
[b]High = supplement fed at 0.81% BW, about 34% of diet, DDGS 118% feeding value of corn.

Table 2.14. Treatment effects on intake, neutral detergent fiber disappearance, ruminal pH, and intake pattern

Item	CON	DRC-D	DRC-A	DDGS-D	DDGS-A
Hay dry matter intake, % of body weight[a,b]	1.88	1.69	1.58	1.69	1.66
Total dry matter, % of body weight[a,b]	1.88	2.10	1.98	2.09	2.06
NDF disappearance, %/hour[a,c]	4.34	3.43	3.65	4.09	4.01
Average ruminal pH[a,c]	6.30	6.22	6.22	6.12	6.19
Meals per day[b,d]	5.9	6.6	4.0	6.0	5.1

Source: Adapted from Loy et al., 2007.
Note: CON = no supplement; DRC-D = dry rolled corn supplement fed at 0.46% of body weight daily; DRC-A = DRC at 0.92% of body weight on alternate days; DDGS-D = DDGS supplement fed at 0.45% of body weight daily; DDGS-A = DDGS at 0.90% of body weight on alternate days.
[a]CON vs. supplemented treatments, $P < 0.05$.
[b]Supplementation frequency effect, $P < 0.10$.
[c]DDGS vs. DRC, $P < 0.05$.
[d]Supplement x frequency interaction, $P < 0.08$.

Dry distillers grains contain approximately 65% undegradable intake protein (% of crude protein); consequently, forage-based diets that include DDGS fed as an energy source are commonly deficient in degradable intake protein but contain excess metabolizable protein. Cattle convert excess metabolizable protein to urea, which is potentially recycled to the rumen and can serve as a source of degradable intake protein. Many factors influence urea recycling, and the amount of urea that is recycled when DDGS are included in a forage-based diet is not known.

Two experiments evaluated requirements for supplemental degradable intake protein when feeding DDGS as an energy source in forage-based diets (Stalker, Adams, and Klopfenstein, 2007). Diets were formulated to be deficient by more than 100 grams per day in degradable intake protein but to have excess metabolizable protein. No response in performance was observed when urea was added to the diet (Table 2.15). Sufficient urea was probably recycled to correct the degradable intake protein deficiency. These studies indicate adding urea to meet the degradable intake protein requirement is not necessary when feeding DDGS as an energy source in forage-based diets.

Given recent drought conditions in many areas of the United States and the price of pasture and hay, these by-products may be very competitive as energy supplements for use by ranchers. When forage quality is poor (winter) or quantity is limited (drought), by-products may provide opportunities for producers to maintain or improve forage and cattle productivity.

Table 2.15. Performance of animals fed diets in which 0%, 33%, 67%, 100%, or 133% of the National Research Council predicted degradable intake protein requirement was met with supplemental urea

	Diet						F-Test
Item	**0**	**33**	**67**	**100**	**133**	**SEM**	**P-Value**
Individually fed							
Initial body weight, lb	611	611	615	617	614	11	0.99
Final body weight, lb	694	697	680	702	702	15	0.85
Average daily gain, lb	1.06	1.03	0.93	1.01	1.04	0.07	0.77
Total dry matter intake, lb/day	11.3	11.4	11.4	11.5	11.4	0.2	0.95
Gain/feed	0.090	0.085	0.076	0.085	0.085	0.007	0.54
Pen fed							
Initial body weight, lb	452			449		1	0.10
Final body weight, lb	579			585		4	0.38
Average daily gain, lb	1.53			1.63		0.05	0.17
Total dry mater intake, lb/day	11.9			11.6		0.5	0.76
Gain/feed	0.102			0.110		0.004	0.33

Source: Adapted from Stalker, Adams, and Klopfenstein, 2007.

A meta-analysis of grazing trials in which cattle were supplemented DDGS was conducted to determine the effects of DDGS supplementation on ADG and final body weight in pasture grazing situations (Griffin et al., in press). Additionally, pen studies were evaluated to determine the effect of DDGS supplementation on cattle intake, forage replacement, ADG, and final body weight. Treatment means were compiled from trials in which cattle were allowed to graze pasture and supplemented DDGS (n = 35) and for trials in which cattle were pen-fed a forage-based growing ration and supplemented DDGS (n = 28). Supplementation of DDGS ranged from 0 to 8 pounds per animal daily with an average supplementation of 2.8 pounds per animal daily. Studies in which cattle were pen-fed and supplemented DDGS used 348 cattle that were fed either hay or a forage mix containing 60% sorghum silage and 40% alfalfa hay. The mix was used to simulate the diet that cattle would consume if grazing high-quality forage.

Supplementing DDGS to cattle grazing pasture increased final body weight and ADG (Figure 2.4) with increased supplementation. Supplementing DDGS in growing rations consistently increased final body weight and ADG quadratically (Figure 2.4; $P < 0.01$) as the level of DDGS supplementation increased. Total intake increased quadratically (Table 2.16; $P < 0.01$) as the level of DDGS supplementation increased. As DDGS supplementation increased, forage intake decreased quadratically. Cattle grazing pasture and consuming similar levels of DDGS had lower ADG compared to pen-fed cattle. Since DDGS supplementation was at the same level for both pasture- and pen-fed cattle, this leaves forage intake as the variable input. Forage replacement could have been greater in pasture-fed animals compared to the pen-fed studies, leading to an overall decrease in intake in the pasture studies compared to the pen studies. In both pasture and pen studies, forage quality was similar. Therefore, the amount of forage replaced could be a logical explanation for the increased ADG response in the pen studies compared to the pasture studies. The replacement of forage by DDGS increased as the level of DDGS supplementation increased (Table 2.16).

Heifer Development

An experiment was conducted using 1,353 heifers to evaluate the use of DDGS supplementation to reduce wintering costs in an extended-grazing heifer development system (Stalker, Adams, and Klopfenstein, 2006).

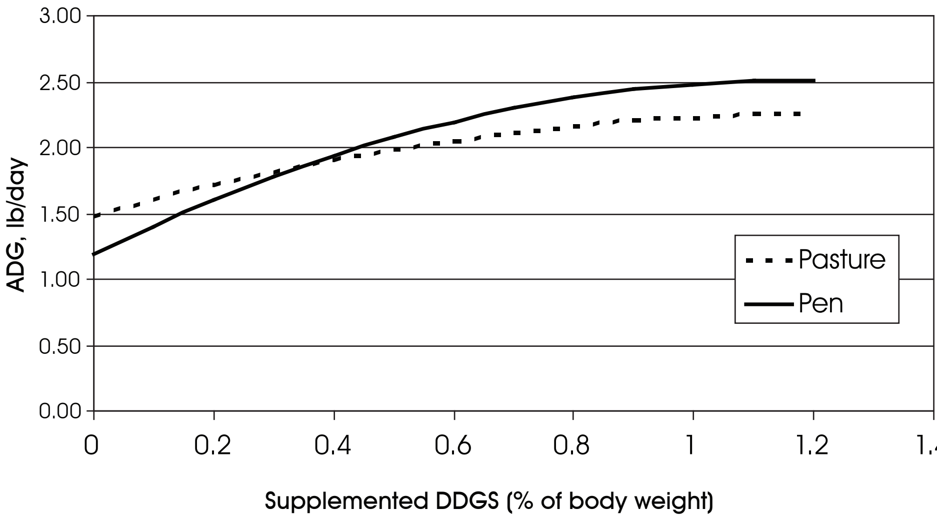


Figure 2.4. Effect of distillers dried grains with solubles supplementation on average daily gain of growing cattle. x = supplemented distillers dried grains as a percentage of steer body weight. Pasture ADG = 1.4736 + 1.2705x - 0.5156x². Pen fed steer ADG = 1.1828 +2.2703x - 0.9715 x²

Because of the higher energy content of DDGS, a smaller amount of hay was needed to meet protein and energy requirements of DDGS-fed bred heifers. Feeding DDGS and grazing winter range led to slightly better winter gains and improved body condition compared to the hay-fed control heifers. The pregnancy rate was 97% for both treatments. Most importantly, $10.47 per heifer was saved in feed costs by using DDGS and winter range versus a conventional system of hay, supplement, and range. A two-year study (Martin et al., 2007) evaluated DDGS compared to a control supplement that provided similar crude protein, energy, lipid, and fatty acids to developing heifers. The protein degradability of the supplements differed such that the amount of undegradable intake protein supplied by DDGS exceeded heifer requirements, and the protein supply from the control supplement did not meet heifer requirements. The heifers were program-fed to gain 1.5 pounds per day and reach 60% of mature weight at the time of breeding. Heifer pubertal development and overall pregnancy rate were not affected by supplement type and averaged 89% for each treatment. However, artificial insemination conception and pregnancy rates were improved by feeding DDGS in the heifer development diet. The proportion of heifers detected in estrus that conceived to

Table 2.16. Effect of supplemental level of distillers dried grains with solubles on intake of growing cattle

DDGS Supplementation:[a]	0.0	1.5	3.0	4.5	6.0	7.5	Lin[b]	Quad[b]
Total intake, lb/day	12.7	13.9	14.9	15.7	16.3	16.6	< 0.01	< 0.01
Forage intake, lb/day	12.7	12.4	11.9	11.2	10.3	9.1	0.31	< 0.01
Forage replacement,[d] lb/day	0.0	0.3	0.8	1.5	2.4	3.6	---	---
Forage replaced/DDGS,[d] lb/lb	0.00	0.20	0.27	0.33	0.40	0.48	---	---

Source: Adapted from Griffin et al., in press.

[a]Supplementation level of DDGS (dry matter basis) in lb/steer daily.

[b]Estimation equation linear and quadratic term t-statistic for variable of interest response to DDGS supplementation level.

[c]Forage replacement calculated using forage intake at 0.0 lb/d supplementation and subtracting forage intake value for respective level of supplementation.

[d]The amount of forage replaced per lb of DDGS supplemented.

artificial insemination service was higher for the DDGS treatment than for the control treatment. These data indicate that utilizing DDGS as a protein and energy source in heifer-developing diets to promote moderate gains gives highly acceptable pregnancy rates and may enhance artificial insemination conception and pregnancy rates.

Corn Stalk Grazing

The last forage situation that may fit well with use of by-products is corn stalk grazing. Incremental levels of DDGS were fed to calves grazing corn residues. Based on statistical and economical analysis of the data collected, feeding DDGS (5.0–6.5 lb per steer daily, dry matter basis) will increase stocking rate on corn residue and may reduce winter cattle costs (Gustad et al., 2006). Given that feeding 3.5 pounds of DDGS dry matter will meet the protein and phosphorus needs of calves, and feeding above 6.0 pounds daily will not increase gains, DDGS should be fed at 3.5 to 6.0 pounds of dry matter per steer daily, which should produce gains of 1.4 to 1.7 pounds of ADG.

Storage of Wet Distillers Grains with Solubles

One problem that can be encountered is storage of wet feeds. Bagging of WDGS can be successful 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. MWDGS (45% dry matter) and wet corn gluten feed bag well, even with pressure.

Erickson et al. (2008) conducted two experiments to determine methods to store WDGS (34% dry matter), 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 wet corn gluten feed mixed with WDGS. The products were mixed in feed trucks and placed into 9-foot 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 (dry matter basis) are 15% grass hay, 22.5% alfalfa hay, 12.5% wheat straw, 50% DDGS, and 60% wet corn gluten feed. 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 (dry matter 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 for more than forty-five days, and the apparent quality did not change. Wet distillers grains can be stored in a silo bag or bunker silo when mixed with drier or bulkier feedstuffs. More information is available at http://beef.unl.edu.

Storage allows cattle feeders with smaller numbers of animals to use wet by-products and not have the products deteriorate with extended time between deliveries of fresh material from the plant. Wet by-products are often more available and less expensive in the summer. Storage allows for purchase of wet by-products in the summer and subsequent feeding in the winter.

Ensiled mixtures of WDGS with either wheat straw or cornstalks have been fed to stocker calves. The palatability of forages seems to have been enhanced by storage. The feeding value is at least equal to what would be expected from the mathematical blend of WDGS and wheat straw. Further, the resulting mix after storage can be fed on the ground in range and pasture situations where cubes (cake) are normally fed on the ground. South Dakota State researchers (Kalscheur et al., 2002, 2003, 2004) have successfully ensiled WDGS in silo bags in combination with corn silage, soybean hulls, or wet beet pulp. Fermentation characteristics were excellent with several ratios of WDGS with the other products.

By-product Economics

The type of by-product, dietary inclusion level, moisture content, trucking costs, feeding costs, and price relationship between by-products and corn price affect cattle feeding profit or loss when using by-products. The Co-product Optimizer Decision Evaluator (Cattle CODE, at http://beef.unl.edu; Buckner et al., 2008a) is a model designed to evaluate these factors and estimate profit or loss from feeding by-products in feedlot diets.

Cattle CODE requires cattle inputs of feeder and finished body weight and their respective prices. DMI and feed conversion for cattle fed a corn-based diet with no by-products are required inputs. Cattle processing and medical costs, death loss, yardage costs, and loan interest are also required. Feed ingredient prices, ingredient percent dry matter, and dietary inclusion level on a dry matter basis are needed for corn, by-products, roughages, and supplement. Inputs of semi-truck load size, cost/loaded mile, and miles hauled to the feedlot are needed for trucking costs.

With these inputs, the model predicts DMI and feed conversion for each by-product type inclusion based on equations from research trials. With predicted DMI and feed conversion, the model calculates ADG. Feeder and fat cattle body weights do not change in the model with inclusion of by-products. Therefore, days on feed are calculated based on ADG.

Yardage costs are divided into two parts. The model assumes one-third of yardage cost was for feeding costs while the other two-thirds was for non-feeding yardage costs. The feeding yardage cost component accounts for costs associated with feeding wetter diets due to wet by-product inclusions.

The model adds urea (and associated cost) to diets when supplemental protein is needed to obtain at least 13.5% dietary crude protein. The model calculates dietary dry matter content with the inputs of feed ingredient dry matter and percent inclusion, which is important for calculating feeding yardage costs. By-product hauling costs are calculated with load size, cost/loaded mile, and miles delivered to the feedlot.

A few by-product feeding scenarios were evaluated to illustrate how this model can calculate profit/loss with any given inputs. Assumptions for inputs included 740-pound feeder steer at breakeven price to cause the corn diet to have $0 profit, 1,300-pound finished steer at $90/cwt, 24 pounds DMI and 0.154 feed efficiency for cattle consuming a corn-based diet. Transportation cost was assumed to be $3.90 per 25 tons of as-is by-product per loaded mile.

The distance between the ethanol plant and the feedlot affected cattle returns when feeding WDGS. Feeding WDGS (priced at 70% of $5.50/bu corn price) increased returns quadratically, as WDGS inclusion levels increased up to 50% of the diet dry matter compared to feeding corn alone (Figure 2.5). If the feedlot was at the ethanol plant, the optimum WDGS inclusion level was 50% of diet dry matter and returns were $109 more per finished steer compared to feeding corn. As the distance from the ethanol plant to the feedlot increased from 0 to 100 miles, the returns decreased for feeding WDGS when compared to corn alone. The optimum inclusion of WDGS also decreased as distance from the ethanol plant to the feedlot increased. The optimum inclusion of WDGS is 40%–50% if the feedlot is 100 miles away from the plant. The distance from the ethanol plant to the feedlot has an increased impact on economic returns as dietary inclusion level increases.

With a constant corn price ($5.50/bu) and distance (60 miles), economic returns were sensitive to the price of WDGS relative to corn. With WDGS priced at 90% of the corn price, optimum inclusion of WDGS was 30% to 40% (Figure 2.6). This returned $45/steer. The optimum inclusion of WDGS was 40% to 50% of diet dry matter when WDGS were priced at 75% of the price of corn, and returns were $75/steer. When pricing WDGS at 60% of corn price, the optimum inclusion level

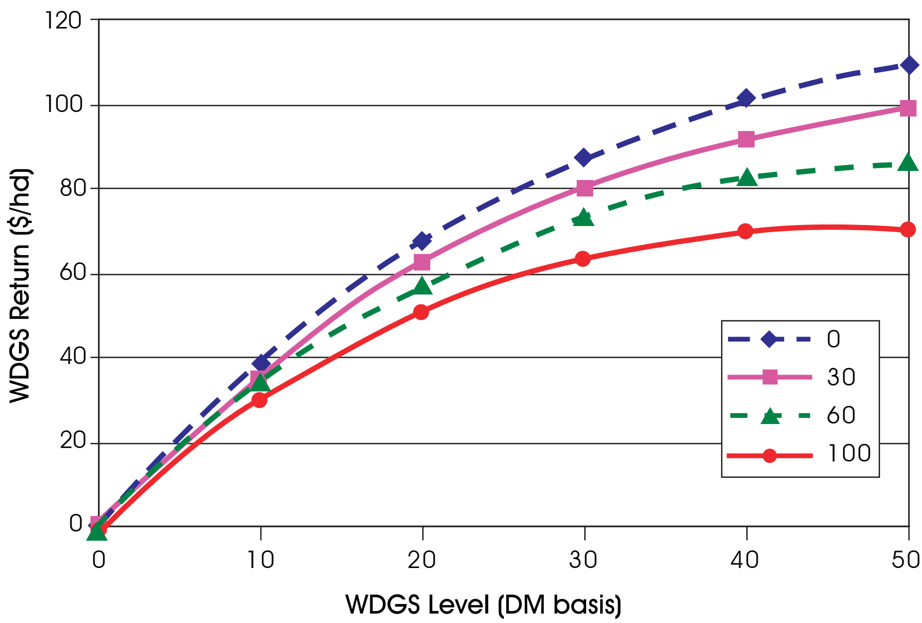


Figure 2.5. Economic returns from feeding wet distillers grains with solubles at 70% the price of corn ($5.50/bu corn) at 0, 30, 60, and 100 miles from the ethanol plant

increased to 50% diet dry matter and returned $105/steer. Pricing WDGS at a lower cost relative to corn improves economic returns as inclusion of WDGS increases.

Corn prices of $4.50, $5.50, $6.50, and $7.50 were evaluated for WDGS priced at 70% of the price of corn, and with a feedlot that is 60 miles from the ethanol plant. Returns to WDGS feeding increased quadratically as the level of WDGS inclusion increased for all corn prices (Figure 2.7). However, as the corn price increased, the returns to feeding WDGS increased. In addition, as the corn price increased, the optimum inclusion of WDGS increased, from 40% to 50% of diet dry matter for $4.50 corn to 50% of diet dry matter at $5.50 to $7.50 corn.

We determined the effect on cattle profitability of corn prices at $3.50, $4.50, or $5.50 per bushel with DDGS priced at 82% of the corn price, and with a constant 60-mile hauling distance for DDGS. Feeding DDGS resulted in a quadratic improvement in cattle profitability as the

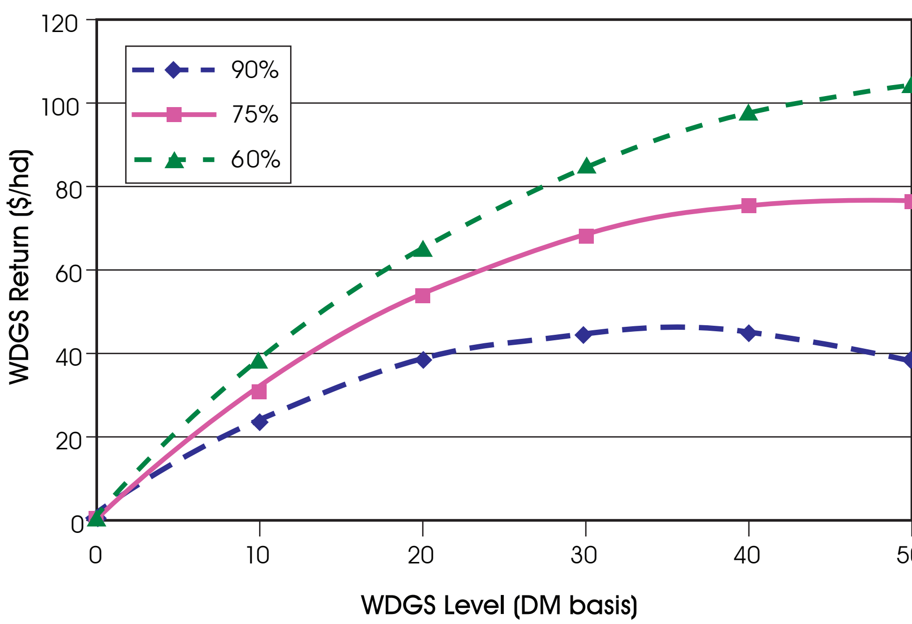


Figure 2.6. Economic returns from feeding wet distillers grains with solubles (WDGS) with $5.50/bu corn at 60 miles from the ethanol plant with WDGS at 90%, 75%, and 60% the price of corn (dry matter basis)

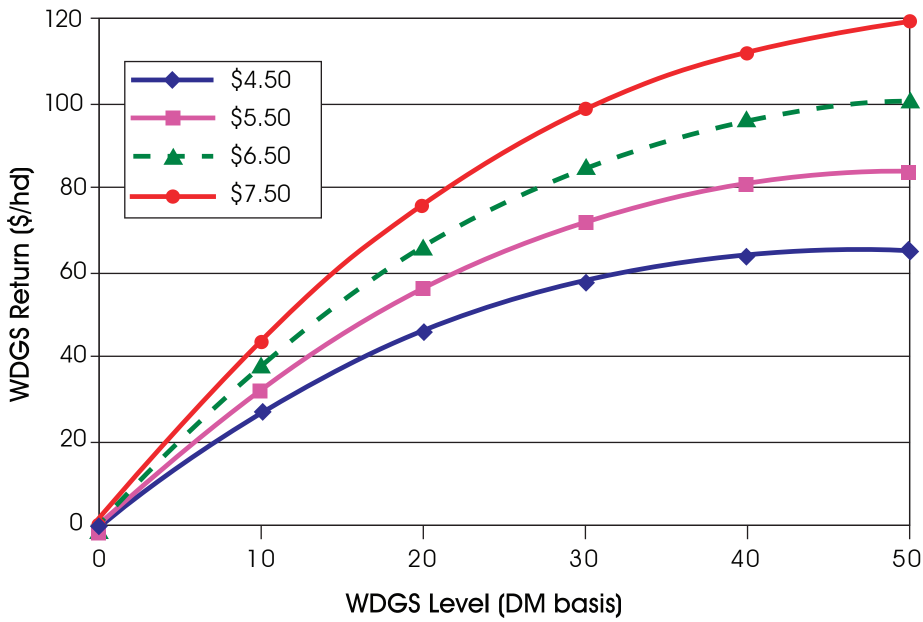


Figure 2.7. Economic returns from feeding wet distillers grains with solubles (WDGS) at 60 miles from the ethanol plant with WDGS priced at 70% the price of corn, when corn is priced at $4.50, $5.50, $6.50, and $7.50/bu

level of DDGS increased (Figure 2.8). As the corn price increased, the optimum DDGS inclusion level remained relatively constant at 20%–25% of diet dry matter. The DDGS increased returns by $27 to $40 per finished steer at each corn price. Increasing corn prices improved returns for feeding DDGS, and the most beneficial returns were observed at intermediate dietary inclusion levels of DDGS. Similar relationships were observed with feeding WDGS and increasing corn prices; that is, as the corn price increases, more profit results from greater inclusion of WDGS.

Based on these limited examples, feeding by-products increased cattle economic returns compared to feeding corn. However, returns were affected by the type of by-product used, inclusion level in the diet, distance from the ethanol plant, corn price, and by-product price relative to corn. This model should allow producers to use their own inputs and improve their decision-making ability about using by-products. The model can be downloaded at the University of Nebraska Beef Extension Web site (http://beef.unl.edu located under the "by-product feeds" tab).

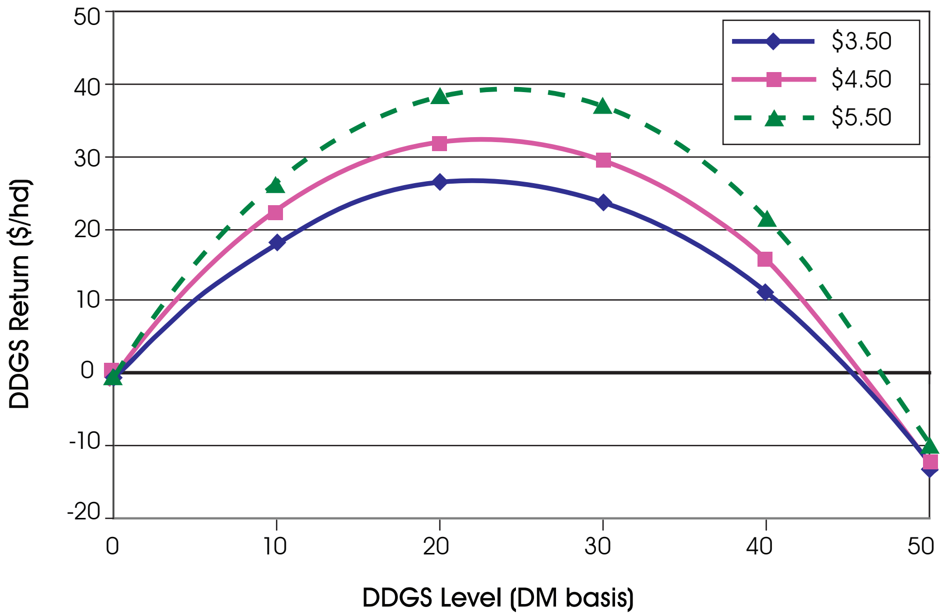


Figure 2.8. Economic returns from feeding distillers dried grain with solubles (DDGS) at 60 miles from the ethanol plant with DDGS priced at 82% the price of corn, when corn is priced at $3.50, $4.50, and $5.50 per bushel

New Ethanol Industry By-products

The evolving ethanol industry is continually striving to maximize ethanol production efficiency. Changes associated with this progress will provide innovative new by-product feeds for producers to utilize that may be quite different nutritionally when fed to cattle. One example of a new by-product feed is Dakota Bran Cake. Bran cake is a distillers by-product feed produced as primarily corn bran plus distillers solubles produced from a prefractionation dry milling process. On a dry matter basis, bran cake contains less protein than WDGS or wet corn gluten feed, similar NDF to both feeds, and similar to slightly less fat content than WDGS. Bremer et al. (2006) evaluated Dakota Bran Cake in a finishing diet by comparing inclusion levels of 0%, 15%, 30%, and 45% of diet dry matter. Results indicated improved final body weight, ADG, DMI, and feed efficiency 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. (2007) 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 replacing a 70:30 blend of brome grass hay and alfalfa haylage (dry matter basis). Animal performance improved as the inclusion of the by-products increased. DDGS had improved performance compared to the dried Dakota Bran Cake at both inclusion levels. Dried Dakota Bran Cake had 84% of the feeding value of DDGS with growing steers. Previous research has shown DDGS to have about 127% of the feeding value of corn in forage-based diets. Therefore, dried Dakota Bran Cake appears to have an energy value approximately equal to 103% of corn.

Dakota Bran Cake is only one example of how new ethanol industry by-products will feed relative to traditional finishing rations. Each new by-product feed needs to be analyzed individually for correct feeding value. Changes to plant production goals and production efficiency have a significant impact on the feeding value of the by-products produced.

Conclusions

Distillers grains offer many feeding options to producers when included in feedlot and forage diets. These by-product feeds may effectively improve cattle performance and operation profitability. Distillers grains provide an excellent protein source for cattle, but as supplies increase, a greater amount is being used as an energy source, replacing grain (primarily corn) that is being used as a feedstock by ethanol plants. The feeding value of WDGS is greater than that of dry-rolled corn in beef finishing diets, and the feeding value is dependant upon the level of inclusion. Drying appears to reduce the feeding value of by-products when fed to feedlot cattle. The ability to keep cattle on feed and acidosis control are likely responsible for the higher apparent feeding values and may be the primary advantages of using WDGS in feedlot diets. Understanding and managing variations in fat and sulfur levels in distillers grains products may help optimize distillers grains inclusion in feedlot diets. There appears to be an interaction between the level of distillers grains in the diet and the type of corn processing used. As with many aspects of cattle nutrition, it is difficult to explain all of the interacting factors of distillers grains inclusion in diets. This provides a great opportunity for researchers and practicing nutritionists. The quality and quantity of roughages may be minimized in finishing diets containing by-products. In the future, with a greater supply of by-products, feeding combinations of WDGS and wet corn gluten feed may be advantageous. The high undegradable intake protein value of distillers grains makes the by-products excellent protein sources for young, rapidly growing cattle and lactating cows. Alternate-day (or three days per week) feeding appears to be feasible, and DGS may have an advantage over grains, non-protein nitrogen sources, and more degradable protein sources in alternative-day feeding systems. Innovative ways of storing wet products offer opportunities for smaller producers to capture the value of by-product feeds. It also appears that new by-products will be available in the future as the processes of making ethanol and other products from corn evolve. These "new" feeds should be evaluated with performance data to determine their respective feeding values.

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Chapter 3

Use of Distillers Co-products in Diets Fed to Dairy Cattle

David J. Schingoethe

This chapter reviews research results from feeding ethanol by-products (co-products) to dairy cattle. While the main emphasis is on feeding the milking herd, the use of ethanol co-products in diets of calves, growing heifers, and dry cows is also discussed. The emphasis here is on distillers grains with solubles (DGS), both wet and dried, but other by-products such as condensed corn distillers solubles, corn germ, and some potential new products for which data are available are mentioned. Co-products that result when fermenting other grains or feed sources are mentioned, although research data are limited for many of those sources.

There is a tremendous amount of DGS and other distillers co-products available at competitive prices for feeding to livestock. Most of this is currently available as DGS, but in the future we will see a completely new list of distillers co-products from which to choose. Some of these products for which animal performance data are available are mentioned later in the chapter.

Nutrient Content of Ethanol By-products

Other chapters in this book give details of the nutrient composition of DGS; however, some items of special concern to those formulating diets for dairy cattle are also mentioned in this chapter. Distillers grains have been fed for more than 100 years, but it is only recently that large quantities are becoming available and at competitive prices. In addition, the products available today usually contain more protein and energy (Birkelo, Brouk and Schingoethe, 2004) than older "book values," even more than listed in the recent dairy nutrient requirements report of the National Research Council (NRC, 2001), and can be of uniformly good

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quality. This reflects the improved fermentation efficiency of the new-generation ethanol plants (Spiehs, Whitney, and Shurson, 2002). See the University of Minnesota (2008) distillers grains Web site (www.ddgs.umn.edu), which includes current updates on compositional analyses of distillers dried grains with solubles (DDGS) from a large number of ethanol plants in the U.S. Midwest.

Nutrient content of DGS and distillers solubles are presented in Table 1. These tabular values reflect primarily values reported in the dairy NRC report (NRC, 2001) as modified by more recently reported analytical information such as data from Spiehs, Whitney, and Shurson (2002) for new-generation DGS and Birkelo, Brouk, and Schingoethe (2004) for the energy values of distillers grains. Such products tend to contain more protein, energy, and available phosphorus than distillers grains from older ethanol plants, which likely reflects increased fermentation efficiency in

Table 3.1. Nutrient content of corn distillers dried grains with solubles (DDGS) and distillers solubles

	Product	
Item	**DDGS**	**Distillers Solubles**
	(% of Dry Matter)	
Crude protein	30.1	18.5
RUP[a] % of crude protein	55.0	30.0
$NE_{maintenance}$, Mcal/kg	2.07	2.19
NE_{gain}, Mcal/kg	1.41	1.51
$NE_{Lactation}$, Mcal/kg	2.26	2.03
Neutral detergent fiber (NDF)	39.0	20.0
Acid detergent fiber (ADF)	16.1	5.0
Ether extract	10.7	21.5
Ash	5.2	12.5
Calcium	0.22	0.30
Phosphorus	0.83	1.35
Magnesium	0.33	0.60
Potassium	1.10	1.70
Sodium	0.30	0.23
Sulfur	0.44	0.37

Source: Most data are from NRC, 2001; Spiehs, Whitney, and Shurson, 2002; and Birkelo, Brouk, and Schingoethe, 2004.

[a]RUP is ruminally undegradable protein.

today's ethanol plants. Distillers grains from new-generation plants contain very little starch versus as much as 5% to 10% starch in DGS from older, less-efficient ethanol plants. Corn DGS contains relatively high amounts of a quite digestible phosphorus (Mjoun et al., 2007), which can be a plus—if additional phosphorus is needed in diets—or a minus—if excess phosphorus in manure needs to be disposed at times when additional phosphorus is not needed for soil fertility. Sulfur content is usually not a concern; however, there have been reports of high levels of sulfur (as much as 1%) in DGS from some plants. Recent surveys (Schingoethe et al., 2008) indicate that an average of 0.5% to 0.6% sulfur in DGS may be more the norm than the NRC report value of 0.44% listed in Table 1. Higher sulfur may be related to amounts of acid used in pH control and cleaning operations that get added to the DGS. In some cases, high sulfur content of the water used may also be a contributor.

Virtually all of the distillers grains available today are in the form of DGS but this may change in the future as processors do more fractionating of the DGS. The composition of corn distillers grains is essentially the same with or without solubles added, except for a lower phosphorus content (~0.4%) without solubles because the solubles are quite high in phosphorus (~1.3% to 1.5%). Therefore, most animal performance studies use data for distillers grains with or without solubles interchangeably. If a DGS product contains substantially more fat (e.g., >15%) and/or phosphorus (e.g., >1.0%) than the values listed in Table 1, it is likely that more-than-normal amounts of distillers solubles were blended with the distillers grains, or that the processor had problems with separation of materials during the handling of solubles. When Noll, Brannon, and Parsons (2007) added incremental amounts from 0% to 100% of the solubles generated from a batch of distillers grains back into the distillers grains, this increased the fat content from 8.9% to 11.7% of dry matter in the dried grains. Phosphorus and sulfur contents likewise increased while protein changed very little. Such variations point to the importance of obtaining analytical data on the specific product being received from a supplier and the importance of suppliers providing uniform, standardized products.

Ruminally undegradable protein (RUP) and ruminally degradable protein (RDP) fractions of the diet are important considerations in formulating diets for dairy cattle, especially for high-producing dairy cows. Corn

DGS is a good source of RUP, usually ranging between 47% and 64% of the crude protein as RUP for higher-quality DGS, with wet DGS usually 5% to 8% lower in RUP than dried DGS (Firkins et al., 1984; Kleinschmit et al., 2007a). However, if RUP values for DGS are quite high (e.g., >80% of crude protein), it may be advisable to check for heat-damaged, undigestible protein. As in other corn products, lysine is the first limiting amino acid in corn DGS, although DGS is a good source of methionine. Limited data (Kleinschmit et al. 2006; 2007a,b) indicate that higher-quality DGS products may contain more available lysine than do lower-quality products. In fact, a recent survey of dried DGS available from a large number of ethanol plants in the Midwest (University of Minnesota, 2008) indicated higher concentrations of lysine (3.05% of crude protein) versus 2.24% of crude protein listed in the latest NRC dairy report (2001). While some may wish to think that a golden yellow color is a good indication of quality for DGS, research data from Belyea, Rausch, and Tumbleson (2004) indicated that color is sometimes (e.g., Powers et al., 1995) but often not (Kleinschmit et al., 2007a) an accurate indicator of protein quality.

New-generation DGS contain more energy than older "book" values. Research by Birkelo, Brouk, and Schingoethe (2004) indicated that wet corn DGS contained approximately 2.25 Mcal/kg of NEL, 10% to 15% more energy than published in even the recent NRC report (2001) for dried DGS. This likely reflects a higher energy value for newer-generation distillers grains and does not necessarily reflect higher energy in wet than in dried DGS; that is a separate comparison that has not been made. At least a part of this high energy content in DGS is due to the fat, while some is also attributed to the highly digestible fiber in DGS.

Distillers grains contain large amounts of neutral detergent fiber (NDF) but low amounts of lignin. While most DGS contain 38% to 40% NDF, it is not unusual for some sources of DGS to contain less than that. Such readily digestible fiber sources can partially replace forages as well as concentrates in diets of dairy cattle; however, for lactating cows, it is recommended that DGS replace concentrate ingredients in the diet and not forage ingredients. Because of the small particle size, DGS contain little effective fiber, only 3.4% to 19.8% physically effective NDF (Kleinschmit et al., 2007a) which is not sufficient to prevent milk fat depression (Cyriac et al., 2005). Nonforage fiber sources such as DGS can supply energy needed for lactation or growth without the ruminal acid load caused by rapidly fermented starchy compounds (Ham et al., 1994).

There is less information available about the nutrient content of DGS produced from other crops such as wheat, barley, triticale, or sorghum. However, data available indicate that the composition usually reflects the nutrient content of the grain after removal of starch via fermentation to ethanol. Thus, the concentrations of protein, fat, fiber, and other nutrients in the DGS from various grain sources usually reflect proportionate increased concentrations of those components relative to the starting grain after removal of the starch (Lodge et al., 1997; Mustafa, McKinnon, and Christensen, 2000). For instance, wheat and barley DGS are usually higher in protein but lower in fat and energy than corn DGS, while sorghum DGS are higher or lower in protein than corn DGS, depending on the source used.

Response of Lactating Cows to Distillers Grains

More than two dozen research trials with more than 100 treatment comparisons have been conducted since 1982 in which corn distillers grains, either wet or dried, were fed to lactating cows. Table 2 is an abbreviated summary of the meta-analysis conducted by Kalscheur (2005) with most of these data and is similar to the recent results of Hollmann, Beede, and Allen (2007) that summarized much of the same data. Other studies conducted since the summary by Kalscheur (2005) are also discussed, especially if results differ from the previous summary. Amounts of DGS fed

Table 3.2. Dry matter intake (DMI), milk yield, milk fat, and protein content when fed diets containing wet or dried corn DGS

Inclusion level	DMI	Milk	Fat	Protein
(% of dry matter)	(kg/d)		(%)	
0	22.1^{b}	33.0^{ab}	3.39	2.95^{a}
4 – 10	23.7^{a}	33.4^{a}	3.43	2.96^{a}
10 – 20	23.4^{ab}	33.2^{ab}	3.41	2.94^{a}
20 – 30	22.8^{ab}	33.5^{a}	3.33	2.97^{a}
> 30	20.9^{c}	32.2^{b}	3.47	2.82^{b}
SEM	0.8	1.4	0.08	0.06

Source: Adapted from Kalscheur, 2005.
^{a,b,c}Values within a column followed by a different superscript differ ($P < 0.05$).

ranged from 4.2% of total diet dry matter (Broderick, Ricker, and Driver, 1990) to 41.6% of dry matter (Van Horn et al., 1985). The lactational response to feeding various amounts of DGS, as well as the response to wet versus dried DGS, is covered later in this chapter.

Production was the same or higher when fed DGS as when fed control diets in virtually all experiments except possibly when fed very large amounts (i.e., 30% or more of diet dry matter) as wet DGS (Kalscheur, 2005). Part of the additional production due to DGS may have been attributable to a slightly higher fat content in DGS diets because fat content of diets was not always balanced across diets in all experiments. However, in experiments such as by Pamp et al. (2006) that compared DGS to soybean protein as the protein supplement, production was similar or higher, even when DGS and soybean-based diets were formulated to be equal in RUP and fat. Production was similar when fed whiskey DGS or fuel ethanol DGS (Powers et al., 1995). In both cases, production was higher than when fed the soybean meal control diet. However, when cows were fed a DGS product that was darker and possibly heat damaged, milk production was lower than when fed lighter, golden-colored DGS but was still similar to production when fed soybean meal. When Kleinschmit et al. (2006) used a standard, good-quality DGS to evaluate the response to two specially processed DGS products intended to have even better quality, milk production was higher for all three DGS products than for the soybean-meal-based control diet, with only small differences in response due to the improved DGS quality.

Many research trials are of relatively short duration, such as four- or five-week periods in Latin-square-style experiments. Dairy producers are likely to be more concerned about long-term responses and whether the shorter-term research experiments accurately reflect the response expected when feeding DGS continuously for long periods of time. Therefore, an experiment was conducted in which cows were fed wet DGS as 15% of diet dry matter for the entire lactation, during the dry period, and into the second lactation. After the first year, there were no differences in production (31.7 and 33.6 kg/d for control and wet DGS), while percentage fat (3.75% and 4.07%), percentage protein (3.29% and 3.41%), and feed efficiency (1.30 and 1.57 kg FCM/kg DMI) were greater for cows fed wet DGS (Mpapho et al., 2006). Reproductive efficiency and cow health were similar for both dietary groups; however, the response in feed intake and milk production tended to be more consistent when fed DGS, possibly reflecting fewer digestive problems. Response during the dry period and first 70 days of the next lactation was similar for control and wet DGS fed cows (Mpapho et al., 2007).

Production responses to DGS are usually similar with all forages (Kalscheur, 2005), although Kleinschmit et al. (2007b) observed slightly greater production when 15% DDGS was fed in high alfalfa versus high corn silage diets, likely reflecting an improved amino acid status with the "blend" of alfalfa-DGS proteins versus a diet containing predominantly corn-based proteins. The summary by Hollmann, Beede, and Allen (2007) likewise showed a greater response to DGS with alfalfa-based than with corn-silage-based diets. While there may be differences in protein quality of various sources of present-day DGS (Kleinschmit et al., 2007a), differences in yields of milk and milk protein might be slight, unless a product is greatly heat-damaged.

Production is usually similar or higher when DGS replace some of the starch in diets of dairy cattle. The starch content of diets is decreased from the typical 23% to 26% starch to less than 20% starch when fed DGS. Ranathunga et al. (2008) demonstrated that replacing incremental amounts of starch in diets from 28% starch in a diet that did not contain DGS to only 17.5% starch in a diet containing 21% DGS had no effect on milk production or composition but tended to improve feed efficiency. All diets contained 49% forage and were balanced for fat content (4.7% of dry matter) in that study such that the response measured was a response to DGS fiber versus corn starch.

Fewer data are available regarding the production response to DGS obtained from other grains. Research (Beliveau, McKinnon, and Racz, 2007) indicated that the energy value of wheat-based DGS was at least equal to that of barley grain for feedlot cattle, and triticale DGS supported similar milk production to that of corn DGS (Greter et al., 2007). Diets containing barley DGS supported similar milk production to that of soybean-meal-based diets (Weiss et al., 1989). When fed sorghum DGS, production (31.9 kg/d) was slightly less ($P < 0.13$) than when fed corn DGS (33.2 kg/d) (Al-Suwaiegh et al., 2002). This result agreed with data that indicates that sorghum DGS are slightly less digestible than corn DGS (Al-Suwaiegh et al., 2002).

Milk Composition When Fed Distillers Grains with Solubles

The composition of milk is usually not affected by feeding DGS unless routinely recommended ration formulation guidelines, such as feeding sufficient amounts of forage fiber, are not followed. Field reports of milk fat depression when diets contained more than 10% of ration dry matter as wet DGS are not supported by research results. Research showed no decreases in milk fat content when diets contained wet or dried DGS at any level, even as high as 40% of dry matter intake (see Table 2). In fact, the milk fat content was usually numerically highest for diets containing DGS. Incidentally, most of those studies were conducted during early to mid lactation; thus, the data in Table 2 are typical for cows during these stages of lactation. In studies that included cows fed DGS during the entire lactation (Mpapho et al., 2006), milk fat tests averaged 4.07% for Holsteins and Brown Swiss, while Kleinschmit et al. (2006) and Pamp et al. (2006) observed fat tests of 3.54% to 3.60% for mid-lactation Holsteins and Kleinschmit et al. (2007b) observed an average of 3.72% fat for late-lactation Holsteins.

Milk fat content was lower with DGS only when diets contained less than 50% forage (Kalscheur, 2005), which provided 22% forage NDF. That result hints at why field observations of milk fat depression may have occurred. Because DGS contain an abundance of NDF, one may be tempted to decrease the amounts of forage fed when formulations indicate more than sufficient amounts of NDF. However, the small particle size of DGS means that its "effective fiber" is not as great as that of the forage fiber it replaced. Research at Wisconsin (Leonardi, Bertics, and Armentano, 2005) and at South Dakota State University (Cyriac et al., 2005; Hippen et al., 2007) support observations from the meta-analysis. Cyriac et al. observed a linear decrease in milk fat concentration while milk production remained unchanged when cows were fed 0%, 7%, 14%, and 21% of dry matter as dried DGS in place of corn silage, even though dietary NDF content remained unchanged at 32% of dry matter. The control diet contained 40% corn silage, 15% alfalfa hay, and 45% concentrate mix. Thus, the key to maintaining milk fat is to feed sufficient amounts of effective forage fiber.

The fatty acid content of milk fat when cows are fed DGS is not expected to be affected greatly, but this has been evaluated in a few studies. Because the fat in DGS, especially corn DGS, is quite unsaturated, with typically more than 60% linoleic acid, it is logical to expect a modest increase in concentrations of unsaturated fatty acids in the milk produced, as observed by Schingoethe, Brouk, and Birkelo (1999). Leonardi, Bertics, and Armentano (2005) and Anderson et al. (2006) also reported modest increases in the healthful fatty acid *cis-9*, *trans-11* conjugated linoleic acid (CLA) and its precursor, vaccenic acid (*trans-11* C18:1). But they observed little change in fatty acids such as *trans-10, cis-12* CLA that are often associated with milk fat depression (Baumgard et al., 2002).

Milk protein content is seldom affected by feeding DGS unless protein is limiting in the diet. Then, the lysine limitation in DGS may cause a slight decrease in milk protein content (Nichols et al., 1998; Kleinschmit et al., 2007b). This effect may be more noticeable in diets that contain more than 30% DGS (Kalscheur, 2005), reflecting the high RUP and lysine limitation in DGS. The meta-analysis (Kalscheur, 2005) indicated slightly higher milk protein percentages when fed blends of alfalfa and corn silage with DGS than with either forage alone, but milk protein yields were the same for all forage combinations. Kleinschmit et al. (2007b) observed no differences in milk protein content or yield when feeding 15% dried DGS in diets in which the forage varied from all alfalfa to all corn silage. However, amino acid balance was improved with the alfalfa diet, indicating a more desirable blend of amino acids in the diet versus a high corn-based-product diet with corn silage, DGS, and corn, which was limiting in lysine.

Feeding distillers products likely does not affect milk flavor or processing of the various products produced from the milk. The author is not aware of any research evaluating the effects of feeding DGS on milk quality; however, there is no reason to expect problems.

Wet versus Dried Distillers Grains with Solubles

The response to wet or dried DGS is usually considered to be equal. However, very few trials actually compared wet versus dried DGS; most trials simply compared DGS to a control diet. When Al-Suwaiegh et al. (2002) compared wet versus dried corn or sorghum DGS for lactating cows, they observed similar production for both wet and dried DGS but 6% more milk ($P < 0.13$) with corn versus sorghum DGS. Anderson et al. (2006) observed greater production ($P < 0.02$) when fed either wet or dried DGS (42.5 kg/d) than when fed the control (corn-soybean meal) diet (39.8 kg/d), a tendency ($P = 0.13$) for greater production when fed wet DGS (43.0 kg/d) instead of dried DGS (41.7 kg/d), and a tendency ($P = 0.12$) for greater production when fed 20% of the ration dry matter as DGS (43.0 kg/d) versus 10% (41.7 kg/d), either wet or dried. Fat content of the control diet (2.3% of dry matter) was slightly lower than the 3.2% and 3.8% fat for the 10% and 20% DGS diets, respectively, but would have accounted for minimal proportions of the differences in production responses.

The main considerations regarding the use of wet versus dried DGS are handling and costs. Dried products can be stored for extended periods of time and can be shipped greater distances more economically and conveniently than wet DGS. Feeding wet DGS avoids the costs of drying the product, but wet DGS will not remain fresh and palatable for extended periods of time; five to seven days is the norm. Some silage additives can extend the storage time of wet DGS by a few days (Spangler et al., 2005). Researchers at South Dakota State University have successfully stored wet DGS for more than six months in silo bags when the wet DGS were stored alone or blended with soyhulls (Kalscheur et al., 2002), with corn silage (Kalscheur et al., 2003), and with beet pulp (Kalscheur et al., 2004). Some field reports indicate successful preservation of wet DGS for more than a year in silo bags.

How Much Distillers Grains with Solubles Can Be Fed?

The review by Kalscheur (2005) (see Table 2 for a summary) indicated that milk production was maintained with increasing amounts of DGS in the diet and actually numerically the highest when fed as much as 30% of diet dry matter as dried DGS. For wet DGS, the highest production was at 20% of diet dry matter. It was only when feeding about 40% DGS, wet or dried, that production declined. This is further illustrated by the recent study of Janicek et al. (2008), which reported a linear increase in milk production when going from 0% to 30% dried DGS in diets. Thus, one can easily feed more than the 5% to 10% DGS that is often fed by many dairy producers.

A practical and appropriate nutrient management approach is to feed 20% of the diet dry matter as wet or dried DGS. Researchers at South Dakota State University (e.g., Nichols et al., 1998; Anderson et al., 2006) and elsewhere have demonstrated in several experiments that dairy cows can easily consume up to 20% of the ration dry matter as distillers grains. With typical feed intakes of lactating cows, this is approximately 4.5 to 5.5 kg of dried DGS or 15 to 17 kg of wet DGS per cow daily. There are no palatability problems, and one can usually formulate nutritionally balanced diets with up to that level of distillers grains in the diet using most combinations of forages and concentrates. For instance, with diets containing 25% of the dry matter as corn silage, 25% as alfalfa hay, and 50% as concentrate mix, the DGS can replace most—if not all—of the protein supplement such as soybean meal and a significant amount of the corn that would normally be in the grain mix. This was illustrated in the experiment by Anderson et al. (2006) in which feeding 20% of the diet dry matter as wet or dried DGS replaced 25% of the corn and 87% of the soybean meal that was fed in the control diet. With diets that contain higher proportions of corn silage, even greater amounts of dried DGS may be feasible; however, the need for some other protein supplement, the protein quality (e.g., lysine limitation), and the phosphorus concentration may become factors to consider. With diets containing higher proportions of alfalfa, less than 20% DGS may be needed to supply the protein required in the diet. Thus, there are no strong advantages to feeding more than 20% distillers grains, but the possibility of feeding excess protein and/or phosphorus may occur. This can be a concern in areas in which nutrient management dictates that minimal amounts of nutrients such as nitrogen and phosphorus be returned to the soil as manure or commercial fertilizers. If feeding more than 20% to 25% of dry matter as wet DGS with other moist feeds such as corn silage also in the diet, gut fill may limit dry matter intake and milk production (Hippen et al., 2003; Kalscheur, 2005). Such diets often contain less than 50% dry matter, conditions which may limit dry matter intake (NRC, 2001).

The economics of ration formulation often indicates that it is most profitable to feed as much DGS as possible. Even with the current high feed prices, formulating diets that contain, for example, 15% DGS in place of ingredients such as soybean meal, corn, cottonseed, and tallow can decrease daily feed costs by $0.90 per cow; feeding 30% DGS daily would save another $0.14 per day. Admittedly, feeding very large amounts of

DGS may mean excessive amounts of nitrogen and phosphorus to dispose of in manure; however, this manure may be a cheaper source of these soil fertility nutrients than commercial sources of fertilizer.

Distillers Grains for Dairy Calves, Heifers, and Dry Cows

Most of the studies of DGS use for growing cattle are with beef cattle; however, DGS can likewise be appropriately used in diets for dairy calves, heifers, and dry cows. Weight gains were similar for calves fed calf starter containing 0%, 28%, and 56% of the dry matter as dried DGS (Thomas et al., 2006a). Rumen papillae development seemed to be optimal with the 28% DGS diet (Thomas et al., 2006b). Distillers grains have also been successfully fed to growing dairy heifers, including blending with other feeds (Kalscheur et al., 2002, 2003). Growth rates are very good when diets are nutritionally balanced, containing appropriate amounts of DGS and other feeds for the age group of animals being considered.

For dry cows, DGS can be fed in appropriate amounts but likely at about 10% of diet dry matter. However, Mpapho et al. (2007) successfully fed 15% of the dry matter as wet DGS throughout the dry period in their long-term feeding experiment.

Distillers Grains for Grazing Cattle

There is virtually no information in the scientific literature about feeding DGS with grazing systems; however, it is safe to assume that it can be done. Research is currently in progress (A.R. Hippen, 2008, unpublished results) in which cows grazing pasture are also fed one of three supplemental total mixed rations—with protein from soybean meal, fish meal, or wet DGS—estimated to supply 50% of the cow's daily dry matter intake.

In general, when formulating diets to supplement pasture, one would formulate the same as under other dietary conditions. Admittedly, one does not always know accurately the amount and composition of the forages consumed, and nutrient content will vary with maturity stage. Thus, some estimates have to be made in that regard. For instance, DGS can likely be included at up to 20% of the total diet dry matter if the forages are low in protein. In many cases, the forages will likely be quite high in protein such that around 15% DGS may satisfy protein needs of the cow. Because fresh forages are quite wet, typically around 20% dry matter, feeding dried DGS rather than wet DGS may be preferred to avoid gut fill limiting total dry matter intake.

Other Distillers Products

Several distillers products in addition to DGS are already available as livestock feeds, and more will be available in the future. For instance, distillers solubles, modified distillers grains, corn bran, corn germ, high-protein distillers grains, and other products may be higher or lower in fiber and phosphorus than are some current products. Some of these products, for which data are available, are discussed next.

Distillers solubles (~20% protein, 20% fat, and 1.4% phosphorus on a dry matter basis) are usually blended with the distillers grains before drying to produce DGS, but the solubles may be fed separately. The solubles, which are also referred to as syrup, are usually condensed to 25% to 30% dry matter before blending with distillers grains or fed as condensed corn distillers solubles (CCDS). Some dairies and feedlots include a small amount of CCDS in diets to decrease dustiness and minimize ingredient separation. When DaCruz, Brouk, and Schingoethe (2005) fed 28% dry matter CCDS at 0%, 5%, and 10% of total ration dry matter to lactating cows, milk production increased 4% with CCDS, although milk fat content was slightly lower while milk protein was unaffected. Sasikala-Appukuttan et al. (2008) fed as much as 20% of the total ration dry matter as CCDS (4% fat from the CCDS) with no apparent adverse affects on dry matter intake or milk composition. Milk yield tended to be higher for cows fed 10% and 20% CCDS than for cows fed the control (corn-soybean meal-based) diet. However, it is not recommended that producers feed as much as 20% CCDS when nutrient management is a concern because diets including that much CCDS contained more than 0.5% phosphorus. When Bharathan et al. (2008) fed 10% of dry matter as CCDS with a small amount of fish oil (0.5% of diet dry matter), concentrations of *cis-9, trans-11* CLA in the milk fat increased. Whitlock et al. (2002) reported that when cows were fed a small amount of fish oil in combination with a source of linoleic acid (extruded soybeans in that experiment), the CLA content of milk fat increased more than when either fish oil or a high linoleic acid fat source were fed separately. In this experiment (Bharathan et al., 2008) with CCDS as the source of linoleic acid and then with fish oil added, *cis-9, trans-11* CLA increased 0.59 g/100g of fatty acids when fed CCDS alone but increased a similar amount (0.62 g/100g of fatty acids) when fed CCDS plus fish oil.

Some ethanol plants offer products termed "modified distillers grains"; however, there are currently no industry guidelines as to what "modified" means. In some cases the distillers grains are partially dried to, for example, 50% dry matter. Sometimes greater or lesser amounts of solubles are added to the distillers grains, or there may be other modifications. These can be very good products to incorporate into dairy cattle diets. However, it is important that the supplier provide accurate composition analysis data, and that the product be consistent from batch to batch.

New distillers products that result from "fractionation" of distillers grains are becoming available. Traditional corn-ethanol production uses a system in which the whole corn kernel is ground, cooked, and fermented. An alternative method separates the kernel into its three major components, namely, bran, germ, and endosperm, prior to fermentation. Some of these products are becoming more available as feeds for livestock.

The bran contains similar amounts of NDF (30%), fat (10%), and phosphorus (0.7%) but less protein (13%) and more nonfiber carbohydrate (45%) than DGS (Janicek et al., 2007). When bran was fed to lactating cows at 10%, 17.5%, and 25% of dry matter in place of portions of corn silage and alfalfa in diets that were already low in forage (40% of dry matter as forage in the 10% bran diet), milk yield tended to increase ($P < 0.07$) with increasing amounts of bran in the diet, and feed efficiency (milk/dry matter intake) increased. However, milk fat content tended to decrease ($P < 0.06$), likely because the diets contained only 15.8% to 9.9% forage NDF even though total NDF in the diets was 31% to 33%.

Corn germ can provide an alternative fat source for dairy cattle diets. The germ from dry grinding of corn contains approximately 20% fat while corn germ obtained from wet milling contains 45% or more fat. The fat in the corn germ from wet milling is typically extracted for use as food-grade corn oil and thus seldom finds use in livestock feeds. Most of the research in this area concerns feeding corn germ from dry grinding.

When Abdelqader et al. (2006) fed the germ from dry grinding at 0%, 7%, 14%, and 21% of ration dry matter, inclusion at 7% and 14% increased milk and fat yields; however, feeding 21% corn germ decreased the concentration and yield of milk fat and tended to decrease dry matter intake. Thus, one can safely feed at least 14% corn germ to lactating cows, but higher amounts may be questionable. However, in their experiment, the problem with feeding as much as 21% corn germ may not have been a problem with the corn germ so much as a problem with total amount of fat in the diet. All diets in that experiment contained 1% additional fat from another source, which caused the 21% corn germ diet to contain more than 8% fat, a situation long known to cause problems with ruminal fat digestion and feed intake (NRC, 2001). When Abdelqader et al. (2008) fed cows diets that were isolipidic at 6% ether extract, 2.5% supplemental lipid as ruminally inert fat (control), 14% corn germ, 30% dried DGS, or 2.5% corn oil, dry matter intake was higher with corn germ (27.2 kg/d) than with the control diet (24.8 kg/d) but similar (26.2 kg/d) for all of the corn fat diets (i.e., corn germ, DGS, and corn oil). Milk production was similar (34.7 kg/d) for all diets. Milk fat content did not decrease with corn germ but did decrease with corn oil and tended to decrease with DGS. Feeding oils such as corn oil often decreases milk fat content whereas feeding the fat as oilseeds or other forms usually does not cause problems (NRC, 2001). Concentrations of *cis-9, trans-11* CLA modestly increased when feeding corn germ and significantly increased when feeding DGS or corn oil. Kelzer et al. (2008) found no differences in total tract digestibility when corn germ or other corn milling products were fed, although ruminal acetate concentrations decreased.

Higher-protein distillers grains can be produced by removing corn germ, by not adding solubles to distillers grains, or by extracting fat. Two products are currently being evaluated and will soon be marketed: high protein distillers grains (HP-DG) from the corn endosperm, which is around 45% crude protein (Hubbard et al., 2008; Kelzer et al., 2008); and de-oiled (low-fat) DGS (dDGS), created after fat is extracted for use in biodiesel, which is around 35% crude protein (Mjoun et al., 2008). One advantage of HP-DG is that it contains similar concentrations of protein as present in many other common protein supplements such as soybean meal. However, the high RUP value and low lysine content of HP-DG may be considerations in some ration situations. Both of these higher-protein DG products have the advantage of containing more protein than traditional DGS but may be lower in energy content because they contain less fat.

In milk production evaluations, two recent Nebraska studies illustrated that HP-DG constitute a good protein feed to include in diets of lactating cows. Hubbard et al. (2008) observed increased milk production when feeding a diet containing 20% HP-DG in place of soy-based protein; milk fat and protein concentrations were not affected by feeding HP-DG. Kelzer et al. (2008) observed similar dry matter intake and milk production when cows were fed isonitrogenous diets containing HP-DG or regular dried DGS as the protein supplement.

Evaluations at South Dakota State University indicated that dDGS also provide a good feed protein for lactating cows. Mjoun et al. (2008) fed 0%, 10%, 20%, and 30% of diet dry matter as dDGS in place of soy-based products. Milk production (34.9 kg/d) was similar for all diets. Likewise, milk composition was not adversely affected by the diets, and milk fat content actually tended ($p < 0.09$) to increase with increasing amounts of dDGS in the diet.

Some higher-fiber distillers products are currently being evaluated in beef cattle studies. While such products may find use in diets for growing heifers and dry cows, they are less likely to be used in diets of lactating cows. This is because dairy producers are usually seeking higher-energy feeds to include in lactation diets, although when forage sources are in short supply or expensive, such higher-fiber distillers products may be considered as alternative ration ingredients for lactating cows.

Concerns and Potential Problems with Distillers Grains in Dairy Production

There are several items often cited by dairy producers and nutrition consultants that should be mentioned here (see chapter 10 for greater detail on these issues).

Inconsistency (variability) of product within plants and between plants is frequently mentioned. This often occurs with new ethanol plants, a situation that can be solved by correcting and standardizing processing procedures. Variation in concentrations of fat, protein, and phosphorus makes it difficult to formulate diets accurately, which can be costly to the dairy producer. For instance, if a producer formulates a diet assuming that the DGS contain 29% protein but then discovers that the DGS actually contain 32% protein, the excess protein fed would be an expensive waste. On the other extreme, if the DGS were assumed to contain, for example, 32% protein but actually contained only 29% protein, milk production might be limited. Variation in fat and/or phosphorus content of DGS often means that variable amounts of solubles were blended with the distiller grains or there was separation in the solubles tank, which may have resulted in more or less of the fat being taken up. These are plant management situations that should be controllable.

High phosphorus or sulfur content in the DGS usually comes through the solubles. A high phosphorus concentration in DGS usually indicates that more-than-normal amounts of solubles were blended with the distillers grains. Sulfur-containing compounds are often used for controlling pH and cleaning equipment during various stages in the ethanol plant operation, and these compounds often end up in the solubles. While high amounts of sulfur in DGS are not usually a problem, if one is feeding more than 30% DGS that may contain higher-than-normal amounts of sulfur, and this is coupled with high sulfur water or other feeds that are also high in sulfur, the diets may approach the recommended dietary maximum of 0.4% sulfur in total ration dry matter (NRC, 2001).

Difficulty with flowability of dried DGS causing bridging in trucks or rail cars has also been a concern voiced by some. Apparently, ethanol processors are making a greater effort to minimize such problems by better controlling the drying and temperature of the DGS.

Because dairy cows are producing a consumable product every day, it is important that the cows not be fed anything that may ultimately contaminate the milk. Mycotoxins, molds, and other potential contaminants are sometimes a problem. Ethanol plants routinely sample and test all loads of grain coming into the plants and reject contaminated loads. This is important because mycotoxins are not destroyed during the ethanol fermentation process or during the production of distillers grains. Thus, contaminated DGS could pose a risk to human health because a metabolite of mycotoxins can transfer to milk (Garcia et al., 2008). Any antibiotics used in ethanol plants are approved products and are ultimately destroyed or inactivated during the processing.

Summary

The major by-product (co-product) of ethanol production, usually made from corn, is distillers grains with solubles (DGS), which can be fed to dairy cattle and other livestock as part of the ration. Distillers grains are a very good protein source, high in ruminally undegradable protein, and are a very good energy source to include in dairy rations. The modest fat concentration and readily digestible fiber contribute to the high energy in DGS.

Research results on animal performance using DGS were usually similar when fed wet or dried products, although some results tended to favor the wet products. Diets fed to dairy cattle can contain DGS as replacements for portions of both concentrates and forages, but they usually replace concentrates. Distillers solubles are often blended with distillers grains to provide DGS, but the solubles can also be fed separately as "thin stillage" or as "condensed corn distillers solubles." Nutritionally balanced diets can be formulated that contain 20% or more of the diet dry matter as DGS. There is usually no nutritional advantage of feeding more than 20% DGS because such diets may contain excess protein and phosphorus, although production performance was very high even with more than 30% dried DGS in the diet, and the economics often indicates advantages of feeding higher amounts of DGS. Milk composition is unchanged at all levels of DGS feeding, but fat content can decrease if inadequate amounts of forage fiber are fed. The fiber in DGS, which often replaces high starch feeds, does not eliminate acidosis but minimizes its problems.

The availability and use of other co-products from DGS processing, such as condensed corn distillers solubles, corn germ, corn bran, and high-protein distillers grains, will increase in the future. Innovations in processing technology will likely result in additional distillers co-products from which to choose for use as livestock feeds.

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Chapter 4

Use of Distillers Co-products in Diets Fed to Swine

Hans H. Stein

Distillers co-products have been used in swine feeding for more than fifty years, but the emergence of the fuel ethanol industry during the last few decades has dramatically increased the total quantities of distillers co-products that are available to the livestock and poultry industries. New technologies have also allowed the industry to convert a greater proportion of the carbohydrates in the grain to ethanol, which in turn has resulted in distillers co-products that have a different composition than the products produced earlier. Different technologies used in the production process allow for upstream or downstream fractionation of the grain or the co-products, which results in a number of different co-products. For the swine industry to use the co-products most efficiently, research must be conducted to measure the nutritional value of these co-products in terms of energy and nutrient digestibility. The next step is to determine the inclusion rates of distillers co-products in diets fed to different categories of pigs that will result in the greatest performance without reducing the quality of the final products. If there are other consequences of including distillers co-products in swine diets, these also need to be documented for each product.

Distillers Co-products Used in Diets Fed to Swine

The co-products produced from the distillation of grain vary in composition according to the sources of grain that were used in the fermentation. In the United States, most distillers co-products are produced from corn, but sorghum is also used in some units (Urriola et al., 2007). Distillers co-products may be produced from fuel ethanol production or from beverage production; the nutritional value is not influenced by the type of plant used (Pahm et al., 2008). Likewise, the region within the United States in which the co-products are produced does not influence the composition or the quality of the co-products (Pahm et al., 2008).

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The most common co-product is distillers dried grains with solubles (DDGS), which by definition is a product that contains all the distillers grains and at least 70% of the condensed solubles produced after fermentation. If no solubles are added, the product is called distillers dried grains (DDG). If the grain is de-hulled and de-germed prior to fermentation, high protein distillers dried grains with solubles are produced (HP-DDGS). This product contains less fat and less fiber but more protein than conventional DDGS. If the solubles are not added back to the distilled grains, high protein distillers dried grains are produced (Widmer, McGinnis, and Stein, 2007). The corn germ that is extracted from corn during de-germing can also be fed to pigs, but this product has a relatively high concentration of non-starch polysaccharides (Widmer, McGinnis, and Stein, 2007). If oil is extracted from the DDGS, de-oiled DDGS are produced (Jacela et al., 2007). De-oiled DDGS contain less ether extract and therefore also less energy than conventional DDGS. If fiber is removed from the DDGS after production, a product called enhanced DDGS is produced (Soares et al., 2008). This product contains approximately 10% less nonstarch polysaccharides than conventional DDGS.

Nutrient and Energy Composition and Digestibility in Distillers Co-products

Concentration and Digestibility of Carbohydrates

Most cereal grains contain between 60% and 70% starch, which is easily digested by pigs and absorbed in the form of glucose. However, production of alcohol from grain requires that the grain is fermented, and most of the starch in the grain is converted into alcohol during this process. All distillers co-products therefore have a low concentration of starch, whereas the concentration of most other nutrients usually is greater than in the original grain (Table 4.1). The concentrations of carbohydrates in distillers co-products are therefore lower than in cereal grains, and most of the carbohydrates are non-starch polysaccharides (fiber). The concentration of the different fiber fractions (neutral detergent fiber, acid detergent fiber, and total dietary fiber) is approximately three times greater in DDGS and DDG than in corn, but HP-DDG and HP-DDGS contain less fiber than DDG and DDGS because the corn is de-hulled before fermentation. The digestibility of fiber in DDGS and in DDG is less than 20% in the small intestine and less than 50% over the entire gastro-in-

Table 4.1. Chemical composition of corn, sorghum, and distillers co-products produced from corn and sorghum (as-fed basis)

	Grain or Co-product								
Item	**Corn**	**Sorghum**	**Corn DDGS**	**Sorghum DDGS**	**Corn DDG**	**Corn HP-DDG**	**De-oiled Corn DDGS**	**Enhanced Corn DDGS**	**Corn Germ**
N	**4**	**1**	**34**	**3**	**1**	**1**	**1**	**2**	**1**
Gross energy, kcal/kg	3,891	3,848	4,776	4,334	-	4,989	-	4,742	4,919
Crude protein, %	8.0	9.8	27.5	31.0	28.8	41.1	31.2	29.1	14.0
Calcium, %	0.01	0.01	0.03	-	-	0.01	0.05	0.27	0.03
Phosphorus, %	0.22	0.24	0.61	0.64	-	0.37	0.76	0.86	1.09
Crude fat, %	3.3	-	10.2	7.7	-	3.7	4.0	10.8	17.6
Crude fiber, %	-	-	-	7.2	-	-	-	-	-
Starch, %	-	-	7.3	-	3.83	11.2	-	-	23.6
Neutral detergent fiber, %	7.3	7.3	25.3	34.7	37.3	16.4	34.6	29.7	20.4
Acid detergent fiber, %	2.4	3.8	9.9	25.3	18.2	8.7	16.1	8.7	5.6
Total dietary fiber, %	-	-	42.1	-	-	-	-	25.2	-
Ash	0.9	-	3.8	3.6	-	3.2	4.64	-	3.3
Indispensable amino acids, %									
Arginine	0.39	0.32	1.16	1.10	1.15	1.54	1.31	1.34	1.08
Histidine	0.23	0.23	0.72	0.71	0.68	1.14	0.82	0.75	0.41
Isoleucine	0.28	0.37	1.01	1.36	1.08	1.75	1.21	1.04	0.45
Leucine	0.95	1.25	3.17	4.17	3.69	5.89	3.64	3.26	1.06
Lysine	0.24	0.20	0.78	0.68	0.81	1.23	0.87	0.93	0.79
Methionine	0.21	0.18	0.55	0.53	0.56	0.83	0.58	0.58	0.25
Phenylalanine	0.38	0.47	1.34	1.68	1.52	2.29	1.69	1.38	0.57

Table 4.1. Continued

	Grain or Co-product								
Item	**Corn**	**Sorghum**	**Corn DDGS**	**Sorghum DDGS**	**Corn DDG**	**Corn HP-DDG**	**De-oiled Corn DDGS**	**Enhanced Corn DDGS**	**Corn Germ**
N	**4**	**1**	**34**	**3**	**1**	**1**	**1**	**2**	**1**
Phenylalanine	0.38	0.47	1.34	1.68	1.52	2.29	1.69	1.38	0.57
Threonine	0.26	0.29	1.06	1.07	1.10	1.52	1.10	1.03	0.51
Tryptophan	0.09	0.07	0.21	0.35	0.22	0.21	0.19	0.19	0.12
Valine	0.38	0.48	1.35	1.65	1.39	2.11	1.54	1.40	0.71
Dispensable amino acids, %									
Alanine	0.58	0.86	1.94	2.90	2.16	3.17	2.13	1.99	0.91
Aspartic acid	0.55	0.60	1.83	2.17	1.86	2.54	1.84	1.80	1.05
Cysteine	0.16	0.18	0.53	0.49	0.54	0.78	0.54	0.52	0.29
Glutamic acid	1.48	1.92	4.37	6.31	5.06	7.11	4.26	4.06	1.83
Glycine	0.31	0.29	1.02	1.03	1.00	1.38	1.18	1.11	0.76
Proline	0.70	0.77	2.09	1.40	2.50	3.68	2.11	1.99	0.92
Serine	0.38	0.37	1.18	2.50	1.45	1.85	1.30	1.25	0.56
Tyrosine	0.27	0.25	1.01	-	-	1.91	1.13	1.04	0.41

Sources: Data from Bohlke, Thaler, and Stein, 2005; Feoli et al., 2007; Jacela et al., 2007; Pedersen, Boersma, and Stein, 2007a,b; Urriola et al., 2007; Widmer, McGinnis, and Stein, 2007; Pahm et al., 2008; and Soares et al., 2008.

testinal tract, and the fiber fraction, therefore, contributes relatively little to the energy value of these products. The digestibilities of fiber in other distillers co-products are thought to be equally low although they have not been measured.

The low digestibility of fiber in distillers co-products results in increased quantities of manure being excreted from pigs fed these products, and the overall dry matter digestibility of diets containing distillers co-products is lower than in corn-based diets (Pedersen, Boersma, and Stein, 2007a). Currently, much effort is being directed toward developing feed additives such as enzymes or yeast products that can improve the digestibility of fiber in distillers co-products. If the digestibility improves, the energy value of these products will also improve.

Digestibility of Amino Acids

The digestibility of most amino acids in DDGS (Table 4.2) is approximately 10 percentage units lower than in corn (Fastinger and Mahan, 2006; Stein et al., 2006; Pahm et al., 2008). The lower digestibility of amino acids in DDGS compared with that in corn may be a result of the greater concentration of fiber in DDGS than in corn, because dietary fiber reduces amino acid digestibility. The variability in digestibility of amino acids among sources of corn DDGS is also greater than among sources of corn, which may be due to differences in production technologies and procedures among plants producing DDGS (Pahm et al., 2008). However, variability in digestibility of amino acids is not related to the region within the United States where the DDGS are produced (Pahm et al., 2008).

The variability in the concentration and digestibility of lysine in DDGS is greater than the variability in digestibility of most other amino acids. The main reason is that some production units overheat the DDGS during drying, which results in Maillard-type destruction of lysine (Pahm et al., 2008). This will result in a reduction in the total concentration of lysine as well as in the digestibility of lysine, but the concentration of crude protein will not be changed. In un-damaged DDGS, the concentration of lysine as a percentage of crude protein is between 3.1% and 3.3%, but in heat-damaged DDGS, this percentage can be as low as 2.10% (Stein, 2007). Therefore, the concentration of lysine should be measured before using DDGS in diets fed to swine, and if the concen-

Table 4.2. Standardized ileal digestibility of amino acids in corn, sorghum, and distillers co-products produced from corn and sorghum

Item	Corn	Sorghum	Corn DDGS	Sorghum DDGS	Corn DDG	Corn HP-DDG	Corn Germ	De-oiled Corn DDGS
N	**2**	**1**	**34**	**1**	**1**	**1**	**1**	**1**
Indispensable amino acids, %								
Arginine	87	70	81	78	83	83	83	823
Histidine	83	65	78	71	84	81	69	75
Isoleucine	81	66	75	73	83	81	57	75
Leucine	87	70	84	76	86	91	68	84
Lysine	72	57	62	62	78	64	58	50
Methionine	85	69	82	75	89	88	68	80
Phenylalanine	84	68	81	76	87	87	64	81
Threonine	74	64	71	68	78	77	53	66
Tryptophan	70	57	70	70	72	81	67	78
Valine	79	64	75	72	81	80	62	74
Dispensable amino acids, %								
Alanine	83	69	78	73	82	86	64	77
Aspartic acid	80	66	69	68	74	76	60	61
Cysteine	82	64	73	66	81	82	64	64
Glutamic acid	80	52	80	76	87	88	72	78
Glycine	84	71	63	67	66	75	76	53
Proline	96	50	74	83	55	73	84	73
Serine	83	72	76	73	82	84	65	73
Tyrosine	82	67	81	-	-	88	59	81

Sources: Data from Bohlke, Thaler, and Stein, 2005; Jacela et al., 2007; Pedersen, Boersma, and Stein, 2007b; Stein, 2007; Urriola et al., 2007; Widmer, McGinnis, and Stein, 2007; and Pahm et al., 2008.

tration of lysine expressed as a percentage of crude protein is less than 2.80%, the DDGS should not be used (Stein, 2007).

Some of the variability in amino acid digestibility, and lysine digestibility in particular, is caused by the addition of solubles to the distilled grain because the solubles contain some residual sugars that are not fermented in the process. The presence of these sugars will increase the likelihood of Maillard reactions occurring when the distilled grain is dried. The digestibility of amino acids in DDG is, therefore, greater than in DDGS, because the solubles are not added to the distilled grain when producing DDG (Pahm et al., 2008).

The digestibility of amino acids in HP-DDG is within the range of values measured for DDGS, but data for only one source are available (Widmer, McGinnis, and Stein, 2007). However, the digestibility of amino acids in corn germ is less than in DDG and DDGS. The reason for this observation may be that the proteins in corn germ are different from other proteins in the grain kernel (Widmer, McGinnis, and Stein, 2007).

Although sorghum has a lower digestibility of amino acids than corn (Pedersen, Boersma, and Stein, 2007b), sorghum DDGS have amino acid digestibilities that are within the range of values observed in corn DDGS (Urriola et al. 2007). However, amino acid digestibility data for only one source of sorghum DDGS have been reported. The digestibility of amino acids was measured in one source of de-oiled corn DDGS and all values were reported to be within the range of values reported for conventional corn DDGS (Jacela et al., 2007).

Digestibility of Phosphorus

Fermentation results in release of a portion of the phytate-bound phosphorus in corn, which in turn results in a greater digestibility of phosphorus in fermented feed ingredients than in corn (Table 4.3). The apparent total tract digestibility of phosphorus is therefore much greater in DDGS and HP-DDG than in corn, whereas the digestibility of phosphorus in corn germ is similar to that of corn (Stein, Pedersen, and Boersma, 2005; Pedersen, Boersma, and Stein, 2007a; Widmer, McGinnis, and Stein, 2007). There are no data on the apparent total tract digestibility of phosphorus in other sources of distillers co-products produced from corn or in DDGS produced from sorghum.

Table 4.3. Concentration and digestibility of phosphorus in corn and distillers co-products produced from corn (as-fed basis)

Item	Corn	DDGS	HP-DDG	Corn Germ
N	2	10	1	1
Total phosphorus, %	0.22	0.61	0.37	1.09
Total phosphorus, % DM	0.25	0.70	0.40	1.18
Apparent total tract digestibility, %	24.1	59.0	59.6	28.6
Digestible phosphorus, %	0.05	0.36	0.22	0.31

Sources: Data from Bohlke, Thaler, and Stein, 2005; Pedersen, Boersma, and Stein, 2007a; and Widmer, McGinnis, and Stein, 2007.

Digestibility of Ether Extract

The apparent total tract digestibility of ether extract in DDGS has been reported in only one experiment that showed that the apparent total tract digestibility of ether extract in DDGS is approximately 70% (Stein, 2005). There is, however, a need for more information in this area, and several current research projects are directed at measuring both apparent and true digestibility of ether extract in DDGS and in other distillers co-products.

Digestibility of Energy

The apparent total tract digestibility of energy in most distillers co-products is lower than in corn because of the greater concentration of fiber in the co-products than in corn (Table 4.4). The fiber in DDGS has a low digestibility in the small intestine, and the fermentation in the large intestine is less than 50% complete, which is the reason for the low digestibility of energy in distillers co-products. In DDGS, the apparent total tract digestibility of energy is 82.9% compared with 90.4% in corn (Pedersen, Boersma, and Stein, 2007a). However, because of the larger oil concentration in DDGS compared to that in corn, the concentration of gross energy is also greater in DDGS than in corn (5,434 vs. 4,496 kcal gross energy/kg dry matter). The concentration of digestible energy in DDGS is, therefore, similar to that in corn (4,088 vs. 4,140 kcal digestible energy/kg dry matter; Stein, Pederson, and Boersma, 2005; Pedersen, Boersma, and Stein, 2007a). The concentration of digestible energy in corn germ (3,979 kcal digestible energy/kg dry matter) is also similar to that in corn, but HP-DDG have a greater concentration of digestible energy (4,763 kcal digestible energy/kg dry matter) than does corn (Widmer, McGinnis, and Stein, 2007). In contrast, de-oiled DDGS have a lower con-

Table 4.4. Concentration of energy in corn and in distillers co-products produced from corn and sorghum

Item	Corn	Corn DDGS	Sorghum DDGS	Corn HP-DDG	Corn Germ	De-oiled Corn DDGS
N	2	10	2	1	1	1
Gross energy, kcal/kg DM	4,458	5,434	4,908	5,399	5,335	4,655
Apparent total tract digestibility, %	90.0	76.8	76.0	88.2	74.6	-
Digestible energy, kcal/kg DM	4,072	4,140	3,459	4,763	3,979	3,093
Metabolizable energy, kcal/kg DM	3,981	3,897	-	4,476	3,866	2,851

Sources: Data from Feoli et al., 2007; Jacela et al., 2007; Pedersen, Boersma, and Stein, 2007a; and Widmer, McGinnis, and Stein, 2007.

centration of digestible energy than does corn (3,093 kcal digestible energy/kg dry matter; Jacela et al., 2007). The concentration of digestible energy in sorghum DDGS was measured in one experiment and reported to be approximately 220 kcal/kg (as-is basis) less than that in corn DDGS (Feoli et al., 2007), which may be the result of a lower concentration of ether extract in sorghum DDGS compared with that in corn DDGS.

Feeding Distillers Co-products to Swine

Inclusion of Distillers Co-products in Diets Fed to Sows

There are no negative effects of feeding diets containing up to 50% DDGS to gestating sows (Wilson et al., 2003), but the effects of feeding other distillers co-products to gestating sows have not been reported. Lactation feed intake, litter weight gain, and sows returning to estrus were not influenced by the inclusion of DDGS in diets (Wilson et al., 2003). However, sows fed DDGS in gestation and lactation for two consecutive parities had greater litter sizes in the second parity than sows fed a control corn-soybean-meal diet. The reason for this is unknown, but it may be a consequence of the increased fiber concentration in diets containing DDGS because litter size is sometimes improved if sows are fed high-fiber diets during gestation (Ewan et al., 1996; Grieshop, Reese, and Fahey, 2001). More research needs to be conducted to verify if the increase in litter size is a common consequence of including DDGS in diets fed to gestating sows.

Results of five experiments in which DDGS were fed to lactating sows have been reported, but there are no data on the inclusion of other distillers co-products. Inclusion rates of DDGS in these experiments were up to 15% (Hill et al., 2008b); 20% (Wilson et al., 2003), or 30% (Song et al., 2007a; Greiner et al., 2008) of the diet. Negative effects of including DDGS in diets fed to lactating sows were not observed in any of these experiments. There was no influence of DDGS on milk composition, apparent nitrogen digestibility, or nitrogen retention. However, sows fed diets containing 20% or 30% DDGS had lower values for blood urea nitrogen than sows fed the control diet (Song et al., 2007b), which indicates that these sows were fed diets with a better amino acid balance compared with sows fed the control diet. One experiment (Greiner et al., 2008) also showed that sows fed diets containing DDGS had improved weight gain in lactation and reduced wean-to-estrus intervals, but these effects were not reported in the other experiments. There is, however, no information on the performance of pigs farrowed by sows fed DDGS, but there are no indications that the growth performance of these pigs is influenced by the inclusion of DDGS in sow diets.

It is concluded that DDGS can be included in diets fed to gestating sows in concentrations of up to 50% and in diets fed to lactating sows in concentrations of up to 30% if diets are formulated based on concentrations of digestible energy, amino acids, and phosphorus. It is possible that the inclusion rate in diets fed to lactating sows can be greater than 30%, but no research has been conducted to verify this hypothesis.

Inclusion of Distillers Co-products in Diets Fed to Weanling Pigs

Effects of including DDGS in diets fed to weanling pigs have been investigated in eight experiments. Up to 30% DDGS can be used without negatively affecting performance if these diets are introduced two to three weeks post-weaning (Gaines et al., 2006; Spencer et al., 2007; Burkey et al., 2008). If DDGS-containing diets are fed to weanling pigs during the initial two weeks post-weaning, up to 25% DDGS may be included (Whitney and Shurson, 2004), and 7.5% DDGS may be included in diets from the day of weaning (Spencer et al., 2007). Improved feed conversion rates from DDGS inclusion have been reported in a few experiments (Gaines et al., 2006; Spencer et al., 2007), but this effect was not observed in other experiments.

Inclusion of sorghum DDGS in diets fed to weanling pigs has been investigated in three experiments, and results from one experiment suggest that it may be possible to include 30% sorghum DDGS in diets fed to weanling pigs without reducing pig performance (Senne et al., 1996). However, later results indicate that inclusion of 30% sorghum DDGS in diets fed to weanling pigs may reduce pig performance (Feoli et al., 2008). It is likely that differences in the quality of sorghum DDGS used in these experiments are responsible for the different observations, but with the limited data that are available for sorghum DDGS, it is recommended that no more than 20% sorghum DDGS be used in diets fed to weanling pigs.

There have been no experiments conducted to investigate the effects of including distillers co-products other than DDGS in diets fed to weanling pigs. It is, therefore, unknown if HP-DDG, corn germ, or other co-products can be used in these diets.

Inclusion of Distillers Co-products in Diets Fed to Growing-Finishing Pigs

Effects of distillers co-products on live pig performance. Results of 25 experiments in which DDGS were included in diets fed to growing-finishing pigs have been reported. No change in performance was observed in most of the experiments, but there are also examples of experiments in which a reduced performance was obtained when corn DDGS were included in the diet.

Up to 30% DDGS can be included in diets fed to growing-finishing pigs without negatively affecting pig performance (Cook, Paton, and Gibson, 2005; DeDecker et al., 2005; Xu et al., 2007a). Lower inclusion rates have also been used without influencing pig performance (Gowans et al., 2007; Jenkin et al., 2007; Linneen et al., 2008). However, data from other experiments in which 10%, 20%, or 30% DDGS were included in diets fed to growing-finishing pigs showed a linear reduction in live pig performance (Fu et al., 2004; Whitney et al., 2006; Linneen et al., 2008; Weimer et al., 2008). In some of these experiments, the reduced growth performance could be an effect of reduced feed intake (Fu et al., 2004; Linneen et al., 2008), but that was not the case in other experiments (Whitney et al., 2006; Weimer et al., 2008). The reduced feed intake of diets containing DDGS may be related to reduced palatability of such diets compared with corn-soybean-meal diets (Hastad et al., 2005). It is also possible that the quality of DDGS that was used may have varied among experiments, which could have influenced the results. If, for example, DDGS with a low digestibility of lysine were used, pig performance would be expected to be reduced because lysine might then limit protein deposition. In addition, diets in some of the experiments in which poor pig performance was observed were formulated in such a way that the total crude protein concentration in the diet increased with the inclusion of DDGS. Increased dietary crude protein may result in poor pig performance, so in such diets, it is not possible to determine if the reduction in pig performance was a result of the DDGS in the diet or the increased crude protein content. However, DDGS-containing diets can be formulated without increasing dietary crude protein concentrations if crystalline lysine is used. Therefore, 0.10% lysine is included for each 10% DDGS in DDGS-containing diets (Stein, 2007). If more than 20% DDGS is used, it may also be necessary to include crystalline tryptophan in the diet (Stein, 2007).

There are eight reports on feeding sorghum DDGS to growing-finishing pigs, with results showing that 30% sorghum DDGS can be included in diets fed to growing-finishing pigs without reducing average daily weight gain, average daily feed intake, or the gain-to-feed ratio (Senne et al., 1996). However, if greater inclusion rates are used, pig performance will be reduced (Senne et al., 1996; Feoli et al., 2008). Based on these observations, it appears that growing-finishing pigs tolerate sorghum DDGS as well as corn DDGS.

Inclusion of corn HP-DDG in diets fed to growing-finishing pigs was reported in one experiment (Widmer et al., 2008). In this experiment, 40%, 30%, and 20% HP-DDG, respectively, were included in diets fed to pigs in the growing (22 to 60 kg), early finishing (60 to 95 kg), and late finishing (95 to 125 kg) stages. At these inclusion rates, HP-DDG replaced all the soybean meal in the corn-based diets, and the overall growth performance was not different for pigs fed the HP-DDG-containing diets compared with pigs fed the corn-soybean-meal control diet. However, in the growing phase, in which 40% HP-DDG was used, reduced feed intake and growth performance was observed for pigs fed the HP-DDG diet, but that was not the case during the later stages of growth or for the overall growing-finishing period (Widmer et al., 2008). It was concluded that HP-DDG may be included in corn-based diets fed to growing-finishing pigs at levels needed to replace all the soybean meal. It is, however, necessary to include relatively large concentrations of crystalline amino acids in diets containing HP-DDG to compensate for the low concentrations of lysine and tryptophan in this ingredient, and diets should always be formulated based on standardized ileal digestible amino acids.

Corn germ was also included in diets fed to growing-finishing pigs in the experiment by Widmer et al. (2008). Diets containing 5% or 10% corn germ, but no other distillers co-products, were used in all three stages of growth. A linear increase in the final weight of the pigs was observed as corn germ was included in the diets, and a tendency for increased daily gain was observed for pigs fed diets containing corn germ. The researchers therefore concluded that growing-finishing pigs will improve performance if they are fed diets containing 10% corn germ (Widmer et al., 2008). It is possible that greater inclusion rates for corn germ can be used, but research to investigate this possibility has yet to be conducted. There have been no reports of experiments in which other distillers co-products were fed to growing-finishing pigs.

Effects of distillers co-products on carcass composition and quality. A reduced dressing percentage of pigs fed DDGS-containing diets has been reported in some of the experiments in which DDGS were fed to growing-finishing pigs (Cook, Paton, and Gibson, 2005; Whitney et al., 2006; Feoli et al., 2007; Gaines et al., 2007 a,b; Hinson et al., 2007; Xu et al., 2007a; Linneen et al., 2008; Weimer et al., 2008). It is possible that this is a consequence of the increased fiber concentration in DDGS-containing diets, because increased concentrations of dietary fiber have been reported to increase the mass of the intestinal tissue and the weight of the digesta (Kass, van Soest, and Pond, 1980). It is also possible that the aforementioned increase in crude protein in DDGS-containing diets may increase the weight of the intestinal tissue, which can also contribute to a reduction in dressing percentage (Ssu, Brumm, and Miller, 2004). However, the dressing percentage of pigs fed DDGS-containing diets is not always reduced, and in approximately 50% of the experiments in which dressing percentage was measured, no difference was observed (Fu et al., 2004;

Xu et al., 2007b; McEwen, 2006, 2008; Drescher et al., 2008; Hill et al., 2008a; Stender and Honeyman, 2008; Widmer et al., 2008). For pigs fed sorghum DDGS, dressing percentages have been reported to be either improved, reduced, or not changed (Senne et al., 1996, 1998; Feoli et al., 2007). It is not known why the dressing percentage for pigs fed DDGS-containing diets is sometimes reduced, whereas this is not the case in other experiments. The quality of the DDGS and the techniques used in diet formulation may contribute to these differences, but research to elucidate these variables is needed.

Backfat thickness, lean meat percentage, and loin depth are not influenced by the inclusion of corn DDGS in the diets, but belly thickness has been reported to decrease in some, but not all, experiments in which corn or sorghum DDGS were included in the diet. However, a reduction in belly firmness (Whitney et al., 2006; Xu et al., 2007a; Widmer et al., 2008) and an increase in the iodine values of carcass fat (Whitney et al., 2006; White et al., 2007; Xu et al., 2008; Hill et al., 2008a) were reported as a result of including corn DDGS in the diets. This increase is probably a consequence of the large quantities of unsaturated lipids that are present in corn DDGS because dietary lipids often are incorporated into carcass fat without hydrogenation. The increased incorporation of unsaturated fatty acids will reduce the firmness of the fat and increase the iodine values. However, inclusion of 1% conjugated linoleic acid in DDGS-containing diets during the final ten days before harvest may reduce iodine values and could be used to avoid the problem with soft fat in pigs fed DDGS (White et al., 2007). Alternatively, if DDGS are removed from the diets during the final three to four weeks prior to harvest, acceptable iodine values are observed in pigs fed diets containing DDGS during the earlier stages of growth (Hill et al., 2008a; Xu et al., 2008).

Pigs fed diets containing HP-DDG may also have softer bellies and increased iodine values compared with pigs fed corn-soybean-meal diets (Widmer et al., 2008). However, pigs fed diets containing corn germ have firmer bellies and reduced iodine values (Widmer et al., 2008). There are no reports of the effects of other distillers co-products on carcass composition and quality. The palatability of pork from pigs fed DDGS, HP-DDG, and corn germ was measured in one experiment (Widmer et al., 2008). Results reported that the overall acceptance of pork from pigs fed diets containing distillers co-products is not different from that of pigs fed corn-soybean-meal diets. It is therefore unlikely that consumers will be able to tell whether or not the pork they are eating comes from a pig that was fed distillers co-products.

Conclusions

The digestibility of nutrients in distillers co-products varies among sources. The variability is of the same magnitude as for other co-products. Heat damage to lysine often occurs, which results in a greater variation in the concentration of total and digestible lysine than for all other nutrients. It is therefore important that the concentration of lysine be measured before distillers co-products are included in diets fed to pigs. For corn DDGS, the average concentration of total lysine is approximately 0.78% and sources of DDGS with below-average concentrations of lysine also have concentrations of digestible lysine that are below average. Such qualities of DDGS should not be used in diets fed to pigs without extra fortification with crystalline lysine.

The inclusion of inorganic sources of phosphorus can be reduced in diets containing DDGS because the digestibility of phosphorus is greater in all fermented distillers co-products than it is in corn, but this is not the case for unfermented co-products. The concentration of starch is low in all distillers co-products and the concentration of fiber is relatively high in most co-products. The concentration of energy in the products is less variable than the digestibility of nutrients, but there is variation among the different co-products according to the procedure used to produce them.

If DDGS of average or above-average quality are used, approximately 30% can be included in diets fed to lactating sows, weanling pigs, and growing-finishing pigs, whereas 50% can be included in diets fed to gestating sows. Inclusion of sorghum DDGS should be limited to 20% in weanling pig diets, but 30% may be included in diets fed to growing-finishing pigs. Corn HP-DDG may be included in diets fed to growing-finishing pigs in quantities sufficient to substitute for all soybean meal, but there are no data on the inclusion of corn HP-DDG in diets fed to sows or weanling pigs. Corn germ can be included in diets fed to growing-finishing pigs in concentrations of at least 10%.

Carcass composition and palatability are not influenced by the inclusion of DDGS, HP-DDG, or corn germ in diets fed to growing-finishing pigs. However, belly firmness is reduced and fat iodine values are increased by the inclusion of DDGS and HP-DDG in these diets. It may therefore be necessary to reduce the inclusion of these products in diets fed during the final three to four weeks prior to slaughter.

All diets containing distillers co-products should be formulated in such a way that the concentration of crude protein is not greater than in traditional corn-soybean-meal diets. This requires the use of crystalline sources of amino acids to balance the amino acid profile of the diets.

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Chapter 5

Use of Distillers Co-products in Diets Fed to Poultry

Kristjan Bregendahl

Co-products from distillation of cereal grains for alcohol production have been available to poultry and livestock producers for many years. Although the co-products were considered better suited for ruminants because of their relatively high fiber content, Morrison (1954) suggested that chick diets could contain up to 7% or 8% distillers grains and that diets for laying hens could contain up to 10% distillers grains without affecting performance. No adverse effects on growth performance of broiler chicken or egg production of laying hens were detected when diets with up to 20% distillers dried grains with solubles (DDGS) from beverage-alcohol production were fed (Matterson, Tlustohowicz, and Singsen, 1966; Waldroup et al., 1981), although the feed utilization of broilers tended to decrease when 25% corn DDGS was included in the diet (Waldroup et al., 1981). In addition to being a source of protein and energy, distillers grains were especially useful as a source of the water-soluble vitamins before chemical synthesis and commercialization of vitamins (Morrison, 1954; Matterson, Tlustohowicz, and Singsen, 1966).

Since the late 1990s, fuel ethanol production from corn grain has greatly increased, through a fermentation process that is slightly different from those of beverage-alcohol production. As a result, over 98% of the fermentation co-products available today are from fuel-ethanol production using corn grain as a substrate (University of Minnesota, 2008a). Of the 13,074 million bushels (5.93 million metric tons) of corn produced in the United States in 2007 (USDA-ERS, 2008), an estimated 3,200 million bushels (81.3 million metric tons) were used for ethanol production (USDA, 2007). The majority of the fuel-ethanol co-products—solubles and wet (or partially dried) distillers grains—are used in ruminant diets, but an estimated

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yearly production of 3.2 million metric tons of corn DDGS are available for use in ruminant and non-ruminant diets (University of Minnesota, 2008a).

In general, fuel ethanol from corn is produced by first grinding the corn grain through a hammer mill. Water is then added to make a slurry, to which carbohydrase enzymes are added and pH is adjusted. The slurry may be jet-cooked at temperatures ranging from 90° to 165°C (194° to 329°F) to remove lactic acid bacteria, followed by cooling and addition of enzymes to further convert the starch into glucose ("liquefaction"). The glucose is then fermented into ethanol (ethyl alcohol) and carbon dioxide using yeast (*Saccharomyces cerevisiae*), and the ethanol is removed from the resulting "beer" through distillation and use of molecular sieves (the latter to remove the water from the distillate). After the ethanol is distilled off from the beer, the whole stillage is centrifuged to separate the wet grains (or wet cake) from the thin stillage. The solubles (or syrup) are produced from the thin stillage through evaporation and condensation. Corn DDGS is finally produced by adding some or all of the solubles to the wet grains followed by drying in a rotary-kiln or a ring drier at temperatures ranging between 127° and 621°C (260° and 1,150°F), depending on the ethanol plant. More detailed information about the ethanol production process is available from the U.S. Grains Council (2008).

Depending on the specific ethanol plant, there can be several variations on the ethanol production process: some remove the oil-rich germ and fiber-rich hulls prior to fermentation to improve ethanol yield, some omit the jet-cooking process, some remove the oil from the thin stillage, and so on. These different processing techniques result in different co-products. For instance, removal of the non-fermentable bran, pericarp fiber, and germ from the corn kernels prior to fermentation results in the co-products high-protein distillers dried grains without solubles (HP-DDG) and corn germ. By definition, corn DDGS (International Feed Number 5-02-843) consist of a dried mixture of at least 75% of the solids in the whole stillage (AAFCO, 2007) and therefore include the wet grains and (most of) the solubles. Corn distillers dried grains (DDG) (International Feed Number 5-02-842), however, include only the wet grains (AAFCO, 2007). Hence, corn DDG do not contain the nutrient-rich solubles fraction, resulting in a markedly different nutrient profile than that of corn DDGS.

DDGS contain all the nutrients in corn grain except most of the starch, which has been fermented to ethanol and carbon dioxide. By removing only the starch, the nutrients in corn grain are concentrated about three times in conventionally processed DDGS, which then typically contain about 27% crude protein, 10% oil, and 0.8% phosphorus (Table 5.1). The HP-DDG, resulting from the pre-fermentation fractionation of the corn grain, contain approximately 40% crude protein, whereas the dehydrated corn germ contains 15% crude protein (Table 5.1). The solubles stemming from the fermentation of fractionated corn grain are combined with the corn hulls and sold for use in ruminant feed. DDGS, HP-DDG, and dehydrated corn germ are suitable feed ingredients for poultry and can be included in diets in the same way as corn grain, soybean meal, canola meal, and so forth as long as the nutrient and energy contents are known and the diet is formulated accordingly. There has been little interest in feeding corn DDG to poultry mainly because of the product's high fiber content, but corn DDG use is possible (Morrison, 1954).

Contents and Bioavailability of Nutrients and Energy for Poultry

Energy

In the United States, the nitrogen-corrected metabolizable-energy (ME_n) system is used to determine feed ingredient energy. This measure represents the gross energy of the feed minus the gross energy of the feces and urine, corrected for nitrogen retained in the body (NRC, 1994). True ME_n (TME_n) is determined by taking into account endogenous (i.e., non-feed) energy losses in the feces. Because of the correction for endogenous energy losses, values for TME_n are usually greater than the corresponding apparent ME_n values, although the values approach each other when birds have free access to feed (NRC, 1994). The energy value of DDGS (corn throughout unless noted) has been evaluated using the precision-fed rooster assay, in which a small amount (25 to 30 g) of DDGS is fed to adult male birds after a twenty-four hour fast, and the resultant excreta is collected over a twenty-four- or forty-eight-hour period; endogenous energy losses are estimated from the gross energy of excreta from birds fasted for twenty-four to forty-eight hours (Sibbald, 1976, 1986).

Table 5.1. Chemical composition of corn grain and co-products from fuel-ethanol production (as-fed basis)

Item	Corn Grain[a]	Corn DDGS[b]	Corn HP-DDG[c]	Corn Germ[c]
	%			
Dry matter	89.0	89.0	91.7	91.1
ME_n[d] (kcal/kg)	3,350	2,770[e]	–	–
TME_n[f] (kcal/kg)	3,470	2,851	2,682	3,881
Crude protein	8.5	26.5	39.6	14.9
Ether extract	3.8	10.1	3.6	15.8
Linoleic acid	2.2	–	–	–
Crude fiber	2.2	7.0	7.5	5.1
Neutral detergent fiber	9.63	32.22[g]	22.20	21.10
Acid detergent fiber	2.83	11.90[g]	11.20	7.50
Calcium	0.02	0.07	0.02	0.02
Phosphorus, total	0.28	0.77	0.44	1.35
Phosphorus, non-phytate	0.08	–	–	–
Phosphorus, available	–	0.48	0.26[h]	0.34[h]
Sodium	0.02	0.20	0.13	0.01
Chloride	0.04	–	–	–
Potassium	0.30	0.85	0.43	1.48
Sulfur	0.08	0.84[i]	0.81	0.19
Arginine, total	0.38	1.09	1.41	1.13
Histidine, total	0.23	0.68	1.08	0.42
Isoleucine, total	0.29	0.96	1.35	0.44
Leucine, total	1.00	3.00	5.09	1.04
Lysine, total	0.26	0.73	1.12	0.79
Methionine, total	0.18	0.50	0.93	0.25
Cystine, total	0.18	0.54	1.32	0.36
Methionine + cystine, total	0.36	1.04	2.25	0.61
Phenylalanine, total	0.38	1.31	2.15	0.60
Threonine, total	0.29	0.96	1.53	0.57
Tryptophan, total	0.06	0.21	0.33	0.19
Valine, total	0.40	1.30	1.93	0.67

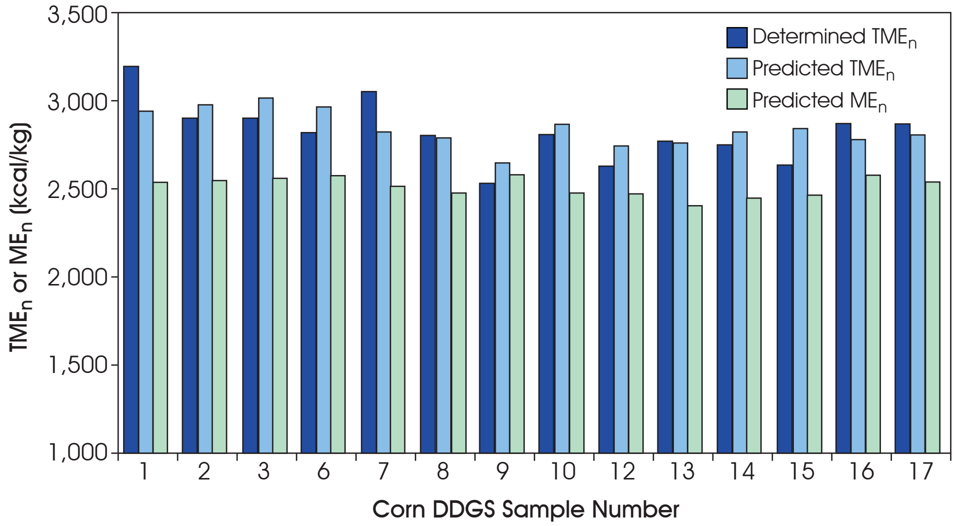
Note: Because of an appreciable variation in nutrient and energy contents (discussed in the text), diet formulation should be performed with nutrient and energy values specific to the particular co-product sample used.

[a] Data from NRC (1994).
[b] Data from Waldroup et al. (2007) except as noted.
[c] Data from Poet Nutrition (2008) except as noted.
[d] Nitrogen-corrected apparent metabolizable energy.
[e] Data from Roberson et al. (2005).
[f] Nitrogen-corrected true metabolizable energy.
[g] Mean of five samples reported by Fastinger, Latshaw, and Mahan (2006).
[h] Calculated using bioavailability values of 58% and 25% for corn HP-DDG and corn germ, respectively (Kim et al., 2008).
[i] Data from Batal and Dale (2003).

Lumpkins, Batal, and Dale (2004) reported the TME_n content of a single DDGS sample to be 2,905 kcal/kg. In a later study, the same group determined the TME_n content of 17 different DDGS samples, representing products from six different ethanol plants (Batal and Dale, 2006). The determined TME_n contents ranged from 2,490 to 3,190 kcal/kg with a mean of 2,820 kcal/kg and an associated coefficient of variation of 6.4%. From a smaller data set with five samples of DDGS from five different ethanol plants, Fastinger, Latshaw, and Mahan (2006) concluded that the TME_n content of DDGS averaged 2,871 kcal/kg, albeit with considerable variation among samples (the largest difference in TME_n among the five samples was 563 kcal/kg). A large variation in TME_n values of DDGS was also reported by Parsons et al. (2006), who determined the mean TME_n value of 20 DDGS samples to be 2,863 kcal/kg with a range spanning 447 kcal/kg. Waldroup et al. (2007) suggested that nutritionists use a TME_n value of 2,851 kcal/kg (Table 5.1) for DDGS, based on a survey of published TME_n values. Roberson et al. (2005) determined the apparent ME_n of a single DDGS sample with laying hens to be 2,770 kcal/kg. This value was about 4% lower than the TME_n value determined for the same DDGS sample using cockerels, similar to the relationship between apparent and true ME_n in corn grain (Table 5.1). Roberson (2003) observed that an ME value of 2,870 kcal/kg was too high for DDGS when used in turkey diets and instead used an ME value of 2,805 kcal/kg in a subsequent experiment. This latter apparent ME_n value is 3% less than the TME_n value recommended by Waldroup et al. (2007) (Table 5.1).

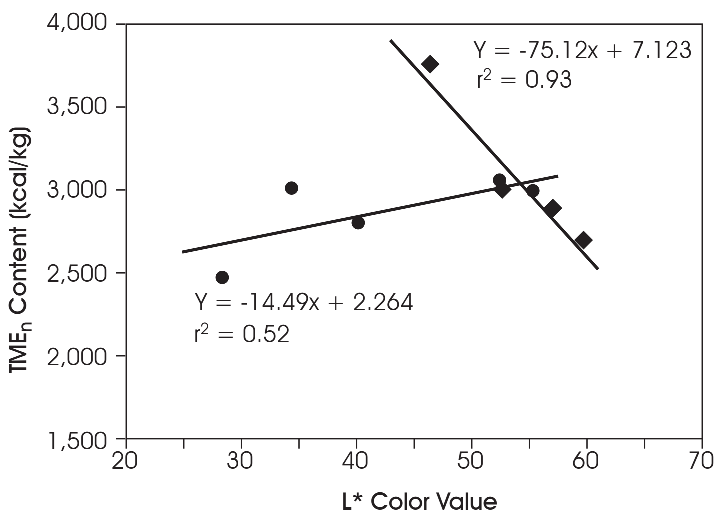
Fastinger, Latshaw, and Mahan (2006) reported both gross energy and TME_n contents (averaging 4,900 and 2,871 kcal/kg, respectively) of five samples of DDGS. These values suggest that the TME_n of DDGS is close to 60% of its gross energy content, similar to the relationship between gross energy and TME_n in other protein-rich ingredients, such as soybean meal (Leske et al., 1991). However, the relationship was decidedly lower (51%) for one sample of DDGS (Fastinger, Latshaw, and Mahan, 2006), so predicting TME_n of DDGS from its gross energy content cannot be recommended, even though gross energy determination is simple, fast, and inexpensive. Rather, the TME_n content can be predicted with better, although not stellar, accuracy from the chemical composition of DDGS. Batal and Dale (2006) correlated the TME_n content of DDGS with its analyzed contents of protein, oil, fiber, and ash, yet the highest coefficient of determination (r^2) was only 0.45. The National Research Council (NRC, 1994) lists ME_n prediction equations for various feed ingredients, including DDGS, based on chemical composition. When the ME_n content of DDGS is calculated by entering the proximate analyses reported by Batal and Dale into the NRC-suggested equation (Figure 5.1), it is evident that the NRC equation underestimates the ME_n content of DDGS when comparing the corresponding TME_n determined by Batal and Dale, even taking into consideration that ME_n values of DDGS are about 4% to 5% lower than their corresponding TME_n values (Roberson et al., 2005). The TME_n values calculated using the prediction equation reported by Batal and Dale correspond well with the determined TME_n values and better than the ME_n values calculated using the NRC equation (Figure 5.1). The TME_n prediction equation by Batal and Dale was based on the determined TME_n values. Thus, the TME_n prediction equation by Batal and Dale should be verified with an independent set of DDGS samples before it is widely used (Black, 1995).

In the study by Batal and Dale, the best single predictor of TME_n content in DDGS was oil content ($r^2 = 0.29$). Because the solubles contain over three times as much oil as do the wet grains, the rate of solubles addition during the DDGS manufacturing process is directly related ($r^2 = 0.88$) to the DDGS TME_n content (Noll, Brannon, and Parsons, 2007; Noll, Parsons, and Dozier, 2007). The oil content of corn DDGS has been reported to vary from 2.5% to 16% in DDGS samples (Batal and Dale, 2006; Parsons et al., 2006; University of Minnesota, 2008b), with substantial potential for variation in TME_n content. Two 2007 studies by Noll and co-authors (Noll, Brannon, and Parsons, 2007; Noll, Parsons, and Dozier, 2007) reported a strong inverse correlation (correlation coefficient, r, = –0.98) between the degree of lightness (L* values) of DDGS and the rate of solubles addition, suggesting that darker DDGS have a greater content of TME_n. However, Fastinger, Latshaw, and Mahan (2006) reported a moderate linear relationship ($r^2 = 0.52$) between the degree of lightness and the TME_n content of DDGS (Figure 5.2). The TME_n and L* values reported in the Noll studies were from DDGS obtained from a single ethanol plant in which the solubles addition rate was experimentally varied, whereas the values by Fastinger, Latshaw, and Mahan were from commercial DDGS samples from different ethanol plants. Moreover, the variation among samples within each study appears to be much smaller in the Noll studies, which may have contributed to the dif-



Modified from Batal and Dale, 2006. Predicted TME_n = 2,732.7 + 36.4 × crude fat – 76.3 × crude fiber + 14.5 × crude protein – 26.2 × ash (Batal and Dale, 2006); predicted ME_n = 39.15 × dry matter – 39.15 × ash – 9.72 × crude protein – 63.81 × crude fiber (NRC, 1994); the chemical composition of the 14 individual corn DDGS samples used in the prediction equations was reported by Batal and Dale (2006).

Figure 5.1. Apparent and true nitrogen-corrected metabolizable energy (ME_n) values of corn distillers dried grains with solubles



Data adapted from Fastinger, Latshaw, and Mahan (2006), ●; and Noll, Parsons, and Dozier (2007), ◆. Greater L* values indicate a lighter color, with values of 0 being completely black and 100 being completely white.

Figure 5.2. Relationship between degree of lightness (L* color value) and true nitrogen-corrected metabolizable energy (TME_n) content of corn distillers dried grains with solubles

ferent results. Nevertheless, the different relationships between L* and TME_n values reported in the Noll studies and by Fastinger, Latshaw, and Mahan suggest that color is not a reliable indicator of energy content in DDGS.

In a recent study, Kim et al. (2008) determined the TME_n contents of conventionally processed DDGS, HP-DDG, and corn germ. The TME_n content of HP-DDG and corn germ was 2,694 and 4,137 kcal/kg, respectively. However, the TME_n value for DDGS determined in the same experiment was 3,266 kcal/kg—outside the range of TME_n values reported for DDGS by Batal and Dale and by Fastinger, Latshaw, and Mahan. Nevertheless, the TME_n of DDGS determined by Kim et al. was within the range reported by Noll and co-authors (2007) after adjusting the rate of solubles addition to the DDGS. The research by Kim et al. showed that the HP-DDG contained about 17% less TME_n than the DDGS used in that study, likely because of a combination of less oil and more protein. Dehydrated corn germ, however, contained about 22% more TME_n than the DDGS, again attributable to the differences in oil and protein contents between the two co-products. Using growing broiler chickens, Thacker and Widyaratne (2007) determined the gross and metabolizable energy contents of a single sample of wheat DDGS from fuel-ethanol production to be 4,724 and 2,387 kcal/kg, respectively.

Amino acids

Corn grain contains 7% to 8% protein, and, because the protein in corn grain is not fermented by yeast, the protein content of DDGS is about three times greater, typically around 27% (Table 5.1). However, the protein content of DDGS has been reported to vary between 23% and 32% (Spiehs, Whitney, and Shurson, 2002; Evonik Degussa, 2005; Batal and Dale, 2006; Fastinger, Latshaw, and Mahan, 2006). This wide range is likely because of differences in the protein content of the corn grain used to produce DDGS and because of differences in residual starch content (diluting the concentrations of protein and other nutrients) caused by differences in fermentation efficiency. Although some DDGS suppliers go to great lengths to minimize variation in nutrient contents (Stein et al., 2006), the amino acid content in DDGS in general can vary substantially. For instance, the content of the first-limiting amino acid for poultry, methionine, has been reported to range from 0.42% to 0.65% (Spiehs, Whitney, and Shurson, 2002; Evonik Degussa, 2005; Fastinger, Latshaw, and Mahan, 2006). Nevertheless, the amino acid content of DDGS is among the main reasons for including this co-product in poultry diets.

The true digestibility of amino acids in DDGS has been reported to vary substantially among ethanol plants (Batal and Dale, 2006; Fastinger, Latshaw, and Mahan, 2006) and it could potentially vary from batch to batch within the same ethanol plant. The main culprit for the variation is the drying process (Fontaine et al., 2007). Different drying techniques (e.g., rotary kiln drying, ring drying), drying temperatures, and drying times can cause inconsistent drying (e.g., "hot spots") or overdrying. Precooking the corn grain to remove unwanted microbial contamination may also be responsible for some of the heat damage. These processes are also the reasons why the amino acid digestibility is lower in DDGS than in corn grain (Table 5.2). In particular, the digestibility of lysine varies substantially because of its susceptibility to heat damage during the drying process (Stein et al., 2006; Fontaine et al., 2007). The epsilon amino group on lysine reacts with reducing sugars in a Maillard reaction. Because poultry do not possess the enzymes to break the bond between lysine and the sugar residue, the Maillard-reaction product either is not absorbed (and therefore excreted into the feces) or is absorbed and—because it is not available for protein synthesis—excreted through the urine. Batal and Dale (2006) measured the true digestibility of lysine in eight DDGS samples using the cecectomized rooster assay; lysine digestibilities ranged from 46% to 78%, with a mean digestibility of 70%. It is noteworthy that the analyzed content of total lysine also varied considerably, from 0.39% total lysine in the DDGS with the lowest digestibility to 0.86% total lysine in the DDGS with the highest digestibility. The low total lysine content in DDGS samples with low lysine digestibility is likely due to partial heat destruction of lysine (Cromwell, Herkelman, and Stahly, 1993; Fontaine et al., 2007; Martinez-Amezcua et al., 2007). While the digestibility varied for all amino acids, the variation in lysine digestibility among DDGS samples was the greatest, suggesting varying degrees of heat damage through differences in drying temperatures and time among ethanol plants. The true amino acid digestibility also varied among the five different DDGS samples tested in a study by Fastinger, Latshaw, and Mahan (2006). The true lysine digestibility varied from 65% to 82%, appearing to be correlated with total lysine content in the DDGS. As before, the lysine digestibility was the most variable, although

Table 5.2. True (or standardized) amino acid digestibilities of corn grain and corn co-products from fuel-ethanol production

Amino acid	Corn Grain[a]	Corn DDGS[b]	Corn HP-DDG[c]	Corn Germ[c]
	%			
Arginine	89	85	91	97
Histidine	94	85	86	86
Isoleucine	88	82	86	91
Leucine	93	89	94	93
Lysine	81	69	73	91
Methionine	91	87	90	91
Cystine	85	77	92	97
Phenylalanine	91	88	91	92
Threonine	84	75	83	90
Tryptophan	–	84	90	–
Valine	88	81	87	91

[a] Data from NRC (1994).
[b] Data from Waldroup et al. (2007).
[c] Data from Kim et al. (2008).

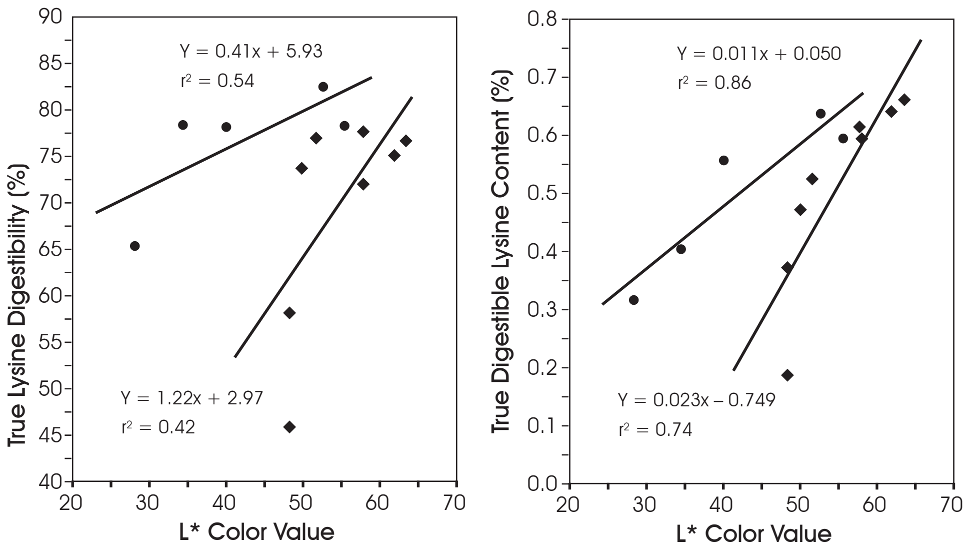
the true cystine digestibility varied substantially as well, also observed by Batal and Dale (2006). Based on a review of the literature, Waldroup et al. (2007) reported weighted averages of amino acid digestibilities for DDGS (Table 5.2); amino acid digestibility values for DDGS are also compiled and reported by Evonik Degussa (2005) and Ajinomoto (2006). The DDGS digestibility values reported by the NRC (1994) are mainly from experiments with DDGS originating from beverage-alcohol production and probably should not be used for DDGS from fuel-ethanol production because of differences in the processes, most notably drying.

Digestibility is an estimate of bioavailability, the latter defined as the portion of amino acids in a feed ingredient that can be used for protein synthesis after consumption. Bioavailability is measured by the slope-ratio method in which the relative bioavailability of a single amino acid in one feed ingredient is compared to that in another feed ingredient (Batterham, Murison, and Lewis, 1979). Estimates of lysine bioavailability in DDGS compared with that of crystalline L-lysine·HCl—which is considered 100% bioavailable (Izquierdo, Parsons, and Baker, 1988)—have been measured by Lumpkins and Batal (2005) using body weight gain of broiler chicks as the response criterion. The relative bioavailability of true digestible lysine in

DDGS was 80% in one experiment and 100% in another experiment. The authors argued that the relative bioavailability of true digestible lysine in DDGS should be 80% of that of L-lysine·HCl. Given the determined true lysine digestibility of 75% in DDGS (Lumpkins and Batal, 2005), it follows that the bioavailable lysine content in the DDGS sample was 60% of the total lysine content. Fontaine et al. (2007) measured the contents of reactive lysine, an estimate of the bioavailable lysine content, in 80 DDGS samples and suggested that 10% to 40% of the lysine in DDGS is heat damaged, and that some overheated batches of DDGS lost up to 59% of their lysine, agreeing with the low bioavailable lysine content determined by Lumpkins and Batal.

The degree of drying (i.e., a combination of the drying temperature and heat-exposure time) affect the amino acid digestibility in DDGS because of Maillard reactions. These reactions between amino acids and sugars generate a characteristic dark color, which can be used as a rough guide for the extent of heat damage to amino acids and ensuing lowered amino acid digestibility (Cromwell, Herkelman, and Stahly, 1993; Batal and Dale, 2006; Fastinger, Latshaw, and Mahan, 2006). In general, samples of DDGS with a lighter and more yellow color (i.e., with greater L* and b* values, respectively) tend to have greater amino acid digestibility values and greater contents of true digestible lysine (Figure 5.3). The rate of addition of solubles to DDGS affects the product's color—a greater addition rate was associated with a darker, less yellow color (i.e., lower L* and b* values), which tended to correlate with true amino acid digestibility, in part because the greater addition rate of solubles warranted greater drying temperatures (Noll, Brannon, and Parsons, 2007; Noll, Parsons, and Dozier, 2007). However, contrary to their expectations, Martinez-Amezcua et al. (2007) did not detect a relationship between the rate of addition of solubles and the true digestibility of amino acids in DDGS. While dietary addition of phytase to DDGS-containing diets improves phosphorus bioavailability, there are minimal, if any, improvements in amino acid digestibility due to phytase addition (Martinez-Amezcua, Parsons, and Baker, 2006).

The amino acid digestibilities of the two co-products from corn fractionation—corn germ and HP-DDG—were reported by Kim et al. (2008), showing that the true amino acid digestibility of corn germ was generally similar to that of HP-DDG, although the true digestibility of some essential



Data adapted from Batal and Dale (2006), ●; and Fastinger, Latshaw, and Mahan (2006), ◆. Greater L* values indicate a lighter color with values of 0 being completely black and 100 being completely white.

Figure 5.3. Relationship between the degree of lightness (L* color value) and lysine digestibility in corn distillers dried grains with solubles

amino acids (i.e., arginine, isoleucine, lysine, and threonine) was greater in corn germ. The true amino acid digestibility of HP-DDG was generally greater than that of unfractionated, conventionally produced DDGS, but, specifically, the true lysine digestibility was not different between the two products. Martinez-Amezcua et al. (2007) produced four different types of corn DDGS co-products, containing from 24% to 41% protein, through corn-grain fractionation and compared their amino acid digestibilities to that of unfractionated, conventionally produced DDGS. The true amino acid digestibilities were not different among the co-products, except for lysine. The true lysine digestibility of unfractionated, conventionally produced DDGS was 66%, lower than three of the four fractionation co-products (with true lysine digestibilities ranging from 77% to 83%). The true lysine digestibility of one fractionation co-product, "dry de-germ de-fiber," was similar to that of unfractionated, conventionally produced DDGS. Thus, the fractionation process can greatly influence the amino acid composition and bioavailability, and care should be taken to use nutrient values and digestibility values obtained using the specific fractionation co-product.

Phosphorus

Corn grain contains about 0.3% phosphorus, but most is contained in phytate and therefore cannot be used by poultry because the birds lack the enzyme phytase to free the phytate phosphorus. In contrast, DDGS contain about 0.7% to 0.8% phosphorus (Table 5.1), most of which is bioavailable. As with other nutrients, the phosphorus content in DDGS varies, with reports ranging widely, from 0.59% to 0.95% (Spiehs, Whitney, and Shurson, 2002; Batal and Dale, 2003; Martinez Amezcua, Parsons, and Noll, 2004; Stein et al., 2006). The large range in phosphorus content stems in part from variation in phosphorus content in corn grain and starch residue in the DDGS, but the rate of addition of solubles to the wet grains prior to drying affects the phosphorus content as well, because the solubles contain more than three times as much phosphorus as do the wet grains (Martinez-Amezcua et al., 2007; Noll, Brannon, and Parsons, 2007; Noll, Parsons, and Dozier, 2007). As with amino acid digestibility, the total phosphorus content of DDGS can be predicted to some extent by looking at the color. The two 2007 Noll studies showed that a greater solubles addition rate to DDGS was associated with a darker color (lower L* color values) and a greater phosphorus content (r^2 = 0.96 and 0.98, respectively).

While the phosphorus in corn grain is only about 30% bioavailable (Lumpkins and Batal, 2005), the bioavailability of phosphorus in DDGS is much greater, likely because of heat destruction of phytate during drying (Martinez Amezcua, Parsons, and Noll, 2004; Martinez Amezcua and Parsons, 2007). Martinez Amezcua, Parsons, and Noll (2004) investigated the phosphorus bioavailability relative to that of phosphorus in dipotassium hydrogen phosphoric acid (K_2HPO_4), considered 100% bioavailable, in DDGS samples collected from commercial feed mills, and they determined the two "good quality" samples to have a relative bioavailability of 69% and 75%. Lumpkins and Batal (2005) conducted two experiments comparing the phosphorus bioavailability in DDGS with that of K_2HPO_4. In the first experiment, the phosphorus bioavailability of DDGS was 68%, whereas it was 54% in the second experiment. It is unclear if both experiments used the same sample. Martinez Amezcua, Parsons, and Noll (2004) determined differences in phosphorus bioavailability, ranging from 75% to 102%, among DDGS samples with varying degrees of lysine digestibility. The phosphorus bioavailability appeared to be inversely correlated with lysine digestibility, and the researchers suggested that the degree of heat damage (which reduces lysine digestibility) increases phosphorus bioavailability. This hypothesis was further examined in a subsequent study in which heat damage of DDGS was controlled by autoclaving or oven drying at different temperatures and lengths (Martinez Amezcua and Parsons, 2007). Increased heating of the DDGS increased phosphorus bioavailability from 69% in the control DDGS to as much as 91% in the DDGS sample that was oven-dried at 55°C for three days and then oven-dried at 121°C for sixty minutes. As expected, the lysine digestibility decreased with increasing heat treatment. Based on a review of the literature, Waldroup et al. (2007) suggested a phosphorus bioavailability of 62% (reflected in Table 5.1), set somewhat low to protect against a potential phosphorus deficiency if DDGS provides a substantial amount of dietary phosphorus. The inclusion of citric acid in DDGS-containing diets improved phosphorus bioavailability in a study by Martinez-Amezcua, Parsons, and Baker (2006), as did the addition of a commercially available phytase enzyme. However, the authors noted that the efficacy of the phytase enzyme in improving phosphorus bioavailability depends on the phytate-phosphorus content of the DDGS, which is likely to be affected by processing (heat treatment).

The phosphorus content of co-products from corn fractionated prior to fermentation depends critically on the fractionation method used (Martinez-Amezcua et al., 2007; Kim et al., 2008) and, presumably, so does the bioavailability. The phosphorus content of HP-DDG is lower than that of DDGS, whereas that of corn germ is greater (Table 5.1). However, the relative phosphorus bioavailability of HP-DDG does not appear to be different from that of DDGS, but the bioavailability of phosphorus in dehydrated corn germ is only 25% relative to the bioavailability of phosphorus in K_2HPO_4 (Kim et al., 2008).

Other Minerals

The contents of calcium, potassium, sulfur, and sodium in corn grain are fairly low (Table 5.1). As would be expected, the calcium and potassium contents in DDGS are about three times greater than those in corn grain, but the contents of sulfur and sodium are appreciably greater than what could be expected from the inherent mineral content in corn grain (Table 5.1). The sources of the "extra" sulfur in DDGS include the sulfur in yeast, well water, and sulfuric acid (H_2SO_4) added during the ethanol-production process. Sulfuric acid is added at several stages in the process to adjust the pH to different optimum levels of the carbohydrases and the yeast. Depending on well-water quality and the need for pH adjustments, the sulfur content of DDGS can vary substantially, from 0.3% to well over 1% (Spiehs, Whitney, and Shurson, 2002; Batal and Dale, 2003; University of Minnesota, 2008b). A sulfur level of 0.4% of the complete diet can be toxic to cattle (NRC, 1980), causing polioencephalomalacia; therefore, the sulfur content in DDG or DDGS may limit the inclusion rate of these feed ingredients in cattle feed. In contrast, broiler chickens can tolerate dietary sulfur levels of up to about 0.5%, and laying hens can tolerate even greater levels (Leeson and Summers, 2005), so there do not appear to be any issues with feeding high-sulfur DDGS to poultry. However, sulfur may interfere with calcium and trace mineral absorption in the small intestines and thus bone and eggshell strength (Leeson and Summers, 2001, 2005).

As with sulfur, the content of sodium in DDGS is greater than expected and variable, ranging from about 0.09% to 0.52% (Spiehs, Whitney, and Shurson, 2002; Batal and Dale, 2003; University of Minnesota, 2008b). The sources of the greater-than-expected sodium in DDGS are unknown (Batal and Dale, 2003) but may stem at least in part from differences in water quality at the ethanol plants. While poultry can tolerate high levels of sodium in the diet (Klasing and Austic, 2003), these levels should be monitored and adjusted (e.g., through changes in the salt inclusion rate) when large amounts of high-sodium DDGS are fed to poultry. High dietary sodium levels cause increased water consumption, which may increase the incidences of wet litter and dirty eggs (Leeson et al., 1995; Klasing and Austic, 2003).

Carotenoid Pigments

Corn grain contains carotenoid pigments of which the xanthophylls—zeaxanthin and lutein—are of special interest. When consumed by poultry, xanthophylls are absorbed and deposited in the skin, adipose tissue, and egg yolks, changing their color to the more desirable yellow or red (Ouart et al., 1988; Leeson and Caston, 2004). Consumption of lutein-enriched yolks can help prevent macular degeneration, an age-related chronic eye disease (Leeson and Caston, 2004). Corn grain contains about 20 ppm of xanthophylls (NRC, 1994; Leeson and Summers, 2005), and it is expected the content is concentrated three times in DDGS through removal of starch in the fermentation process. However, the actual xanthophyll content may be lower because of heat destruction during drying. Roberson et al. (2005) analyzed two DDGS samples and observed 30 ppm of xanthophylls in one of the samples, but only 3 ppm in another dark-colored sample considered heat damaged.

Feeding Distillers Dried Grains with Solubles to Poultry

Egg Production (Laying Hens)

Lumpkins, Batal, and Dale (2005) fed diets containing either 0% or 15% corn DDGS to white leghorn-type laying hens from twenty-two weeks of age (corresponding to about four weeks before peak egg production) to forty-three weeks of age. The DDGS inclusion did not affect egg production, egg weight, feed consumption, or feed utilization. Some of the hens in the experiment were also fed a low-density diet in which energy, amino acids, and the nutrient-to-energy ratios were lowered to increase the likelihood that issues with feeding 15% DDGS, if any, could be detected. Compared to the control diet, the low-density 15% DDGS diet resulted in slightly lower egg production and poorer feed utilization. The diets were formulated on a total-amino-acid basis with equal contents of lysine and methionine, suggesting that the 15% DDGS diets were deficient in one or more amino acids due to the lower digestibility of amino acids in DDGS as discussed previously. Roberson et al. (2005) fed DDGS to laying hens at 0%, 5%, 10%, and 15% of the diet. The diets were fed to white leghorn-type hens from forty-eight weeks of age over a period of eight weeks, during which there were inconsistent effects of DDGS on egg production, with a decrease during two of the experiment's eight weeks. Egg weight was not affected, but egg mass (defined as percent egg production × grams of egg weight) decreased in the same weeks that egg production decreased. In Experiment 2—conducted with the same hens from fifty-eight to sixty-seven weeks of age and using a different, darker-colored DDGS sample—egg production and egg mass were not affected, although egg weights decreased linearly during one of the weeks. Neither feed consumption nor feed utilization was affected in either experiment. Roberson et al. concluded that DDGS could be fed to laying hens at levels as high as 15%, whereas Lumpkins, Batal, and Dale recommended a DDGS inclusion level of no more than 10% to 12%. However, the experimental diets in both experiments were formulated using total amino acids, not digestible amino acids, the importance of which was discussed previously. Roberts et al. (2007b) fed diets containing 0% or 10% DDGS to white leghorn-type laying hens from twenty-three to fifty-eight weeks of age and observed no effects on any egg production or egg quality parameters. The diets used in this study were formulated on a digestible-amino-acid basis and to contain similar amounts of apparent ME_n.

Since the published reports by Lumpkins, Batal, and Dale (2005) and Roberson et al. (2005), the laying hen industry in the U.S. Midwest has routinely used diets containing between 5% and 20% DDGS (averaging about 9%), but these inclusion rates have mainly been limited by economics, as the commercial diets are formulated on a least-cost basis in which the relative prices of all ingredients are considered. Feed prices and availability change daily, so the 15% to 20% maximum DDGS inclusion rate does not necessarily reflect an inclusion rate that limits egg production or egg quality. Ignoring the cost of the feed ingredients, Pineda et al. (2008) conducted an experiment to investigate whether egg production and egg quality would be affected by very high inclusion levels of DDGS. In their experiment, graded levels between 0% and 69% DDGS were fed to white leghorn-type laying hens fifty-three weeks of age for eight weeks after a four-week transition period, during which the dietary DDGS contents were gradually changed in steps of about 12 percentage points per week. Egg production decreased linearly during the eight-week experimental period, countered by an increase in egg weight. As a result, egg mass was unaffected by the dietary DDGS inclusion. Feed consumption increased with increasing dietary DDGS content, but feed utilization was unaffected. Egg quality—measured as Haugh units, egg composition, and specific gravity—was not affected by the DDGS inclusion. The experiment by Pineda et al. demonstrated that laying hens can be fed diets with high amounts of DDGS with no adverse effects on egg production and egg quality as long as the energy and nutrient contents of all feed ingredients (including DDGS) are considered and the diets are formulated on a digestible-amino-acid basis. The diets used by Pineda et al. may not have been practical in that they contained high levels of (expensive) supplemental vegetable oil to compensate for the relatively low energy content in DDGS. As a result, the flowability of the DDGS-containing diets was lower than would probably be acceptable on a commercial farm with automatic feeders. More practical inclusion levels were used in an experiment reported by Scheideler, Masa'dah, and Roberson (2008), in which white leghorn-type hens twenty-four weeks of age were fed diets containing graded levels of DDGS of between 0% and 25% for twenty-two weeks. Egg production, feed consumption, and body weight gain were not affected by the dietary DDGS inclusion. Egg weights, however, were lower when the diets contained 20% and 25% DDGS, which the authors attributed to a dietary amino acid deficiency.

Haugh units, a measure of egg interior quality, are not affected by dietary DDGS inclusion and neither is the shell quality, as indicated by the shell breaking-strength or specific gravity of the eggs (Lumpkins, Batal, and Dale, 2005; Roberson et al., 2005; Pineda et al., 2008). That said, consumption of sulfur from sulfur-rich DDGS may interfere with absorption of dietary calcium from the small intestines (Leeson and Summers, 2001, 2005), thereby reducing eggshell quality. Yolk color, however, is affected by the inclusion of the xanthophyll-rich DDGS, such that L* and a* color scores (indicating darker and redder yolks, respectively) increase with increasing dietary DDGS content (Roberson et al., 2005; Roberts et al., 2007b; Pineda et al., 2008).

Effects of feeding corn DDGS to pullets have yet to be published. However, in the laying-hen industry in the U.S. Midwest, DDGS is incorporated into pullet diets at the same levels as routinely fed to laying hens (i.e., up to about 15%, depending on availability and relative price). Because body-weight-for-age of pullets is an important criterion for developing high-quality laying hens (Leeson and Summers, 2005), research with broiler chickens can be used as a rough guide for using DDGS in pullet diets. Similarly, the effects of feeding DDGS to breeding broiler or turkey hens have not been published. However, research with laying hens can be used as a rough guide for using DDGS in broiler and turkey breeder diets.

Meat Production (Broiler Chickens and Turkeys)

Lumpkins, Batal, and Dale (2004) fed 0% or 15% DDGS to Cobb-500 straight-run broiler chickens from one to eighteen days of age and found no adverse effects on body-weight gain or feed utilization. However, when the diets were formulated to contain lower energy and protein contents to increase the likelihood of detecting differences in growth performance due to DDGS, feed utilization was adversely affected in broilers fed the 15% DDGS diet. This effect was evident during the first two weeks of age, but there were no effects of DDGS at eighteen days of age. In a subsequent experiment, Lumpkins, Batal, and Dale fed 0%, 6%, 12%, and 18% DDGS to one-day-old Cobb-500 chicks until an age of forty-two days. In this experiment, body-weight gain and feed utilization were unaffected by feeding up to 12% DDGS, but gain and feed utilization were lowered when broilers were fed the 18% DDGS diet, which the authors attributed to an amino acid deficiency (likely lysine) in the starter diet. Based on their study, Lumpkins, Batal, and Dale recommended that no more than 12% DDGS be included in the starter diets but that grower and finisher diets could contain 12% to 15% DDGS. However, all diets in the experiments by Lumpkins, Batal, and Dale were balanced on a total-amino-acid basis. Given the relatively low amino acid digestibilities of DDGS, it is possible that the reduced growth performance at high DDGS inclusion levels was caused by an amino acid deficiency (e.g., lysine or arginine).

Wang et al. (2007c) balanced broiler diets on a digestible-amino-acid basis using a standardized nutrient matrix for DDGS (shown in Table 5.1) and dietary digestible amino acid levels based on industry averages. In the study, graded levels of DDGS between 0% and 25% were fed to male Cobb-500 chickens from one to forty-nine days of age with no treatment effects on body-weight gain. However, cumulative feed consumption from zero to thirty-five and from zero to forty-nine days of age increased compared with the control diet when the diet contained 25% DDGS. As a result, the cumulative feed utilization was adversely affected during the same age periods. A careful examination of the analyzed (total) amino acid concentrations in the diets suggests that the 25% DDGS diets may have been marginally limiting in arginine with observed arginine-to-lysine ratios between 102% and 104%, depending on the specific diet. The ideal arginine-to-lysine ratio (albeit expressed on a digestible basis) is 105% to 111% (Baker and Han, 1994; Mack et al., 1999; Baker, 2003), somewhat greater than the arginine-to-lysine ratios calculated from data presented by Wang et al. (2007c).

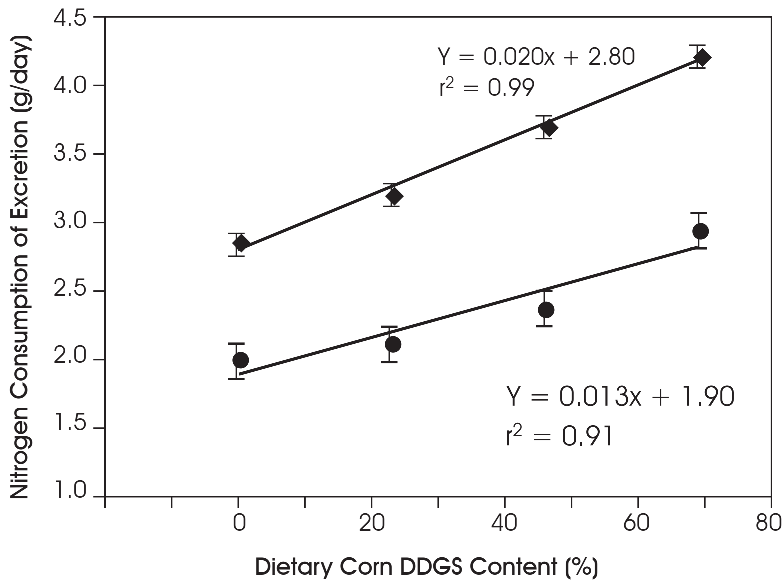
Young broiler chicks are sensitive to feed ingredient quality because their digestive systems are not fully developed until about fourteen days of age (Batal and Parsons, 2002a,b). Because of the high fiber content and low amino acid digestibility of DDGS, feeding diets containing 25% to 30% DDGS during the two first weeks after hatch is not recommended. Indeed, Wang et al. (2007b) observed a trend toward decreased body weight during the initial two weeks after hatch in broilers fed diets containing 30% DDGS compared to 0% or 15% DDGS, and the broilers' body weights continued to lag behind those of control-fed broilers throughout the forty-two-day study. Feed utilization was significantly lower throughout the study for broilers fed the 30% DDGS diet compared to broilers fed 0% or 15% DDGS. When DDGS was omitted from starter diets (one to fourteen days of age), but introduced in grower diets (fourteen to thirty-five days of age) at 15% and subsequently kept constant or further increased in the finisher diets fed for the last seven days before slaughter (i.e., 0%-15%-15% or 0%-15%-30% DDGS), body weight, feed consumption, and feed utilization at forty-two days of age were similar to those of broilers fed no DDGS. However, when 30% DDGS content was included in the diets, either from one day of age or introduced in grower or finisher diets, growth performance was depressed. Similarly, in a third study, Wang et al. (2007a) fed diets containing 0%, 15%, or 30% DDGS to Cobb-500 broiler chicks throughout the growing period from one to forty-two days of age and observed no effect of feeding 15% DDGS, but depressed growth performance was observed when the diet containing 30% DDGS was fed. In both studies, an arginine deficiency may be the culprit, as the arginine-to-lysine ratios, calculated from the reported dietary total amino acid values, were between 82% and 93% in the diets containing 30% DDGS (Wang et al., 2007a,b). Poor pellet quality will result in poorer growth performance and interact with dietary protein quality such that diets with poor pellet quality must contain a greater amount of balanced (or ideal) protein to achieve the same growth performance as diets with good pellet quality (Greenwood, Clark, and Beyer, 2004; Lemme et al., 2006). The diets in the studies by Wang et al. (2007a,b) were pelleted, and pellet quality decreased with increasing DDGS content. Therefore, it is possible that the poorer performance of broilers fed the 30% DDGS diet was, at least in part, due to pellet quality.

In some (Whitney et al., 2006; Linneen et al., 2008)—but not all (Widmer et al., 2008)—studies with pigs, dietary inclusion of DDGS decreased the dressing percentage, presumably because of the empty entrails and water retention within the digesta attributed to an increased dietary fiber content (Linneen et al., 2008). Although similar effects of DDGS on dressing percentage would be expected in poultry for the same reasons as in pigs, dressing percentage was not affected in broilers fed diets containing up to 30% DDGS (Lumpkins, Batal, and Dale, 2004; Wang et al., 2007a,b). In a study by Wang et al. (2007c), however, dressing percentage appeared to decrease linearly with increased DDGS content. Compared to the control diet, the dressing percentage was lower when broilers were fed diets containing 15% and 25% DDGS, but not in diets containing 5%, 10%, and 20% DDGS. Despite decreased growth performance in broilers fed 18% DDGS (Lumpkins, Batal, and Dale, 2004), breast-meat yield and other cuts were unaffected by the dietary treatments whether they were measured on a gram-per-bird basis or a percentage-of-carcass-weight basis. Similarly, Wang et al. (2007a,b) observed no effects on carcass quality when broilers were fed up to 15% DDGS. However, when fed 30% DDGS, broilers had lower breast-meat yield (Wang et al., 2007a,b), likely attributable to an arginine deficiency (Corzo, Moran, and Hoehler, 2003) as previously described.

Roberson (2003) conducted an experiment with turkey hens fed DDGS-containing diets from 56 to 105 days of age, at which time the hens were sent to a commercial processing plant. The diets contained up to 27% DDGS and were formulated on a digestible-amino-acid basis. Body-weight gain decreased linearly with increasing DDGS content, attributed to a deficiency in digestible lysine, likely caused by a lower-than-expected digestibility value. In a second experiment, DDGS was included at up to 10% of the diet with no effects on body-weight gain or feed conversion of the turkeys. Carcass quality was not investigated in the experiment by Roberson, but Noll et al. (2002) reported no adverse effects on breast-meat yield of feeding DDGS to turkey toms as long as needed amino acid levels were met.

Environmental Aspects of Feeding Distillers Dried Grains with Solubles to Poultry

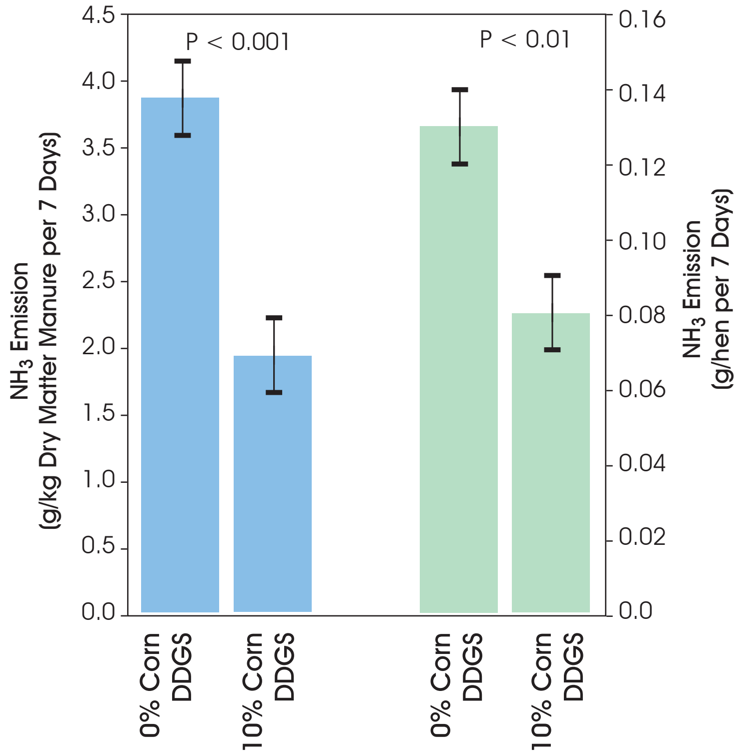
In part because of the relatively low amino acid digestibility in DDGS and in part because of an amino acid profile different from that of soybean meal, protein levels in DDGS-containing diets are expected to be greater than if the diet is formulated with corn grain and soybean meal only. Depending on the magnitude of the dietary DDGS inclusion rate, both nitrogen consumption and excretion from the birds are expected to increase (Roberts et al., 2007b; Pineda et al., 2008) (Figure 5.4). Although increased ammonia (NH_3) emission from the manure is associated with increased nitrogen excretion (Summers, 1993; Kerr and Easter, 1995; Keshavarz and Austic, 2004), dietary DDGS appear



Data adapted from Pineda et al. (2008). Dots represent means ± pooled SEM of six observations.

Figure 5.4. Nitrogen consumption (◆) and excretion (●) by laying hens fed diets containing up to 69% corn distillers dried grains with solubles

to have an attenuating effect on ammonia emissions (Roberts et al., 2007a) (Figure 5.5). Fiber is not digested by the birds, and some of it is instead fermented by microbes in the large intestines, producing short-chain fatty acids, which in turn lower the manure pH. The lowered pH results in a shift in the NH_3 equilibrium toward the less-volatile ammonium ion ($NH_3 + H^+ \leftrightarrow NH_4^+$). Therefore, poultry fed DDGS may excrete more nitrogen, but because of the resultant lower manure pH, the nitrogen does not evaporate off. This effect of dietary fiber on manure acidification and NH_3 emission was first demonstrated in pigs by Canh et al. (1998a,b) and later in laying hens by Roberts et al. (2007a) using DDGS-containing diets. Hence, at first glance, it appears that an increase in dietary crude protein content of DDGS-containing diets may have adverse effects on air quality and the environment because of increased nitrogen excretion. However, the nitrogen appears to remain in the manure, which, when applied correctly on fields, does not adversely affect the environment and may increase the fertilizer and therefore the economic value of the manure.



Data adapted from Roberts et al. (2007a). Bars represent means ± pooled SEM of 32 observations.

Figure 5.5. Ammonia emissions from laying hens fed diets containing 0% or 10% corn distillers dried grains with solubles

Formulating Diets with Distillers Dried Grains with Solubles for Poultry

Traditionally, corn grain and soybean meal have supplied the majority of amino acids in midwestern poultry diets. Corn protein is relatively high in methionine and low in lysine, whereas the opposite is true in soybean protein, illustrated by the differences in their methionine-to-lysine ratios (Table 5.3). Hence, corn grain and soybean meal complement each other very well in meeting the amino acid needs of poultry. The amino acid ratios in corn grain and DDGS are similar (Table 5.3). Therefore, the amino acids in corn grain and DDGS do not complement each other. This discrepancy in amino acid profile ("protein quality") between distillers co-products and other protein supplements has been recognized for a long time (Morrison, 1954) and so, despite the relatively high protein

Table 5.3. Amino acid profiles of corn grain, corn co-products from fuel-ethanol production, and soybean meal (lysine = 100%)

Amino acid	Corn Grain[a]	Corn DDGS[b]	Corn HP-DDG[c]	Corn Germ[c]	Soybean Meal[a]
	%				
Lysine	100	100	100	100	100
Arginine	146	149	126	143	118
Histidine	88	93	96	53	43
Isoleucine	112	132	121	56	72
Leucine	385	411	454	132	126
Methionine	69	68	83	32	23
Cystine	69	74	118	46	24
Methionine + cystine	138	142	201	77	47
Phenylalanine	146	179	192	76	79
Threonine	112	132	137	72	63
Tryptophan	23	29	29	24	25
Valine	154	178	172	85	75

[a]Calculated from NRC (1994).
[b]Calculated from Waldroup et al. (2007).
[c]Calculated from Poet Nutrition (2008).

content, DDGS cannot be viewed as a replacement for soybean meal or other protein supplements in poultry diets.

It is evident from the studies reported in this chapter that DDGS from fuel-ethanol production can make up a substantial portion of diets for broiler chickens, turkeys, and laying hens, provided the diet supplies all the nutrients in the right amounts and proportions. When DDGS-containing diets failed to meet egg production, growth performance, or carcass quality expectations, it could almost always be attributed to an amino acid deficiency, illustrating the important differences in amino acid profiles between DDGS and soybean meal and the differences in amino acid digestibility. Special care should be taken by nutritionists to monitor the dietary contents of all amino acids, for instance, through the ideal amino acid ratio. Ideal amino acid ratios have been published for broilers (Baker and Han, 1994; Mack et al., 1999; Baker, 2003; Rostagno, 2005), turkeys (Firman and Boling, 1998), and laying hens (Coon and Zhang, 1999; Rostagno, 2005; Bregendahl et al., 2008) or they can be calculated from tables of nutrient requirements and recommendations (e.g., NRC, 1994; Centraal Veevoederbureau, 1996; Leeson and Summers, 2005).

Furthermore, because of the relatively low amino acid digestibilities in DDGS, it is especially important to formulate poultry diets on a true digestible-amino-acid basis when uncluding DDGS in diets. If the DDGS-containing diet is formulated on a total-amino-acid basis, only a relatively small amount (5% to 10%) can be included in poultry diets without affecting production. To illustrate the importance of formulating diets on a true digestible basis, three different sets of laying hen diets were formulated (Table 5.4) using either a crude protein minimum of 17% (with a total methionine+cystine minimum), on a total-amino-acid basis (with no crude protein minimum), or on a true digestible-amino-acid basis (with no crude protein minimum). Diets were also formulated with or without 15% DDGS to illustrate the effects of the low amino acid digestibility in DDGS. The dietary lysine content was set to 0.80% total lysine in the diet formulated on total amino acids and to 0.72% true digestible lysine in the diet formulated on a true digestible-amino-acid basis; the requirements for all other amino acids were determined using the ideal amino acid profile reported by Bregendahl et al. (2008). The nutrient contents listed by the NRC (1994) were used for all ingredients, except for DDGS, which used nutrient contents reported by Poet Nutrition (2007) and an available phosphorus content conservatively set at 54% of total phosphorus (Lumpkins and Batal, 2005). The true amino acid digestibility values reported by Ajinomoto (2006) were used for all ingredients. Although the diets were not formulated to be "least-cost diets," the diet costs were calculated using feed ingredient prices from the December 10, 2007, edition of *Feedstuffs* magazine (Minneapolis prices). If it is accepted that the best estimate of the hens' amino acid needs are the true digestible amino acid requirement, then is it evident from Table 5.4 that a diet formulated to contain 17% crude protein from corn, soybean meal, and meat and bone meal will be marginally deficient in methionine+cystine and threonine when amino acid digestibilities are considered. These deficiencies were exacerbated when DDGS was included in the diet. Formulating on total amino acids also resulted in marginal deficiencies when digestibility was considered, yet there may have been some benefits of a concomitant lowered diet cost (although this benefit is likely to be offset by a reduction in performance due to the amino acid deficiencies). The only scenario in which there were no deficiencies was when the diets were formulated on true digestible amino acids, demonstrating the benefits of formulating diets this way. Similar conclusions were reached by Pineda et al. (2008) after an experiment in

Table 5.4. Examples of laying hen diets formulated based on crude protein, total amino acids, or true digestible amino acids with or without corn distillers dried grains with solubles (DDGS)

Item	Minimum Recommended Content	Formulated Using Crude Protein Minimum Corn DDGS		Formulated Using Total Aminoa Acids Corn DDGS		Formulated Using True Digestible Amino Acids Corn DDGS	
		0%	15%	0%	15%	0%	15%
Ingredient							
Corn DDGS	–	–	15.00	–	15.00	–	15.00
Corn grain	–	63.25	54.65	64.70	53.87	63.53	52.26
Soybean meal	–	18.27	11.78	17.00	12.50	18.00	14.00
Meat and bone meal	–	5.50	5.10	5.50	5.00	5.50	4.75
Vegetable oil	–	1.86	2.29	1.64	2.40	1.82	2.65
DL-Methionine	–	0.19	0.14	0.21	0.13	0.20	0.14
L-Lysine·HCl	–	–	–	–	0.03	–	0.06
L-Threonine	–	–	–	0.02	0.02	0.02	0.01
Calcium carbonate	–	10.18	10.29	10.18	10.30	10.18	10.38
Sodium chloride	–	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix	–	0.25	0.25	0.25	0.25	0.25	0.25
Vitamin premix	–	0.25	0.25	0.25	0.25	0.25	0.25
Total	–	100.00	100.00	100.00	100.00	100.00	100.00
Calculated chemical composition							
ME_n, kcal/kg	2,850	2,850	2,850	2,850	2,850	2,850	2,850
Crude protein	–	17.00	17.00	16.55	17.27	16.92	17.74
Ether extract	–	4.96	6.46	4.79	6.54	4.93	6.71
Linoleic acid	2.00	2.40	3.27	2.31	3.31	2.38	3.40
Calcium	4.45	4.45	4.45	4.45	4.45	4.45	4.45
Phosphorus, available	0.44	0.44	0.44	0.44	0.44	0.44	0.44

Table 5.4. Continued

Item	Minimum Recommended Content	Formulated Using Crude Protein Minimum Corn DDGS 0%	Formulated Using Crude Protein Minimum Corn DDGS 15%	Formulated Using Total Aminoa Acids Corn DDGS 0%	Formulated Using Total Aminoa Acids Corn DDGS 15%	Formulated Using True Digestible Amino Acids Corn DDGS 0%	Formulated Using True Digestible Amino Acids Corn DDGS 15%
Total amino acids[a]							
Arginine	0.86	1.06	0.98	1.02	1.00	1.05	1.04
Histidine	–	0.43	0.45	0.42	0.45	0.43	0.46
Isoleucine	0.63	0.66	**0.62**	0.63	0.63	0.65	0.65
Lysine	0.80	0.85	**0.76**	0.81	0.80	0.84	0.86
Methionine	0.38	0.46	0.43	0.48	0.42	0.47	0.44
Methionine+cystine	0.75	0.75	0.75	0.75	0.75	0.75	0.77
Threonine	0.62	0.62	**0.61**	0.62	0.64	0.64	0.65
Tryptophan	0.18	0.19	**0.17**	0.18	0.18	0.19	0.19
Valine	0.74	0.79	0.79	0.77	0.80	0.78	0.82
True digestible amino acids[a]							
Arginine	0.77	0.97	0.91	0.93	0.91	0.96	0.95
Histidine	–	0.38	0.38	0.37	0.38	0.38	0.39
Isoleucine	0.57	0.59	**0.56**	0.57	**0.56**	0.59	0.59
Lysine	0.72	0.75	**0.66**	0.72	**0.66**	0.74	0.72
Methionine	0.34	0.44	0.39	0.45	0.39	0.45	0.41
Methionine+cystine	0.68	**0.67**	**0.66**	0.68	**0.66**	0.68	0.68
Threonine	0.55	**0.54**	0.55	**0.54**	0.55	0.55	0.56
Tryptophan	0.16	0.16	**0.15**	**0.15**	**0.15**	0.16	0.16
Valine	0.67	0.70	0.70	0.68	0.70	0.70	0.72
Diet cost, $/907 kg	–	175	165	173	167	175	171

[a]Amino acid values in bold font are below recommended contents.

which no effects on egg production or egg quality were detected between hens fed a control diet or a diet containing 69% DDGS. Correspondingly, Rostagno and Pupa (1995) and Hoehler et al. (2005) demonstrated the superiority of formulating broiler diets on a digestible-amino-acid basis rather than a total-amino-acid basis.

Different cereal grains (e.g., corn, wheat, sorghum, barley, and rye) can be used as a substrate for fuel-ethanol production, and the differences in chemical composition of the cereal grains are reflected in the DDGS. However, taking these differences into account, there do not seem to be major differences among DDGS originating from different grains with regard to diet formulation strategies, nutrient utilization, or growth and performance (Nyachoti et al., 2005; Thacker and Widyaratne, 2007).

Potential Practical Limitations for Use of Distillers Dried Grains with Solubles in Poultry Diets

When economic restraints are removed and only the feed ingredients' content of energy and nutrients and their desired concentrations restrain diet formulation, as much as 70% DDGS can be included in a laying-hen diet (Pineda et al., 2008). However, while there may be no nutritional or production effects of such high dietary DDGS levels, other factors may limit the dietary inclusion rate of DDGS. For instance, the relatively low energy content of DDGS warrants a greater inclusion of supplemental oil or fat, which may increase the diet cost as well as decrease the flowability of the diet, thereby causing problems associated with bridging (Waldroup et al., 1981; Pineda et al., 2008). The bulk density of DDGS averages 570 g/L (35.7 lb/ft^3), although with some variation among samples from different ethanol plants (U.S. Grains Council, 2008). In comparison, the bulk density of ground corn grain is approximately 580 g/L (36.2 lb/ft^3), and that of soybean meal is around 630 g/L (39.4 lb/ft^3) (Jurgens and Bregendahl, 2007), meaning that the density of DDGS-containing diets tends to decrease with increasing DDGS content (Wang et al., 2007a,b,c). The lower bulk density of DDGS-containing diets means that less feed (on a weight basis) can be transported in each truck from the feed mill to the poultry barn and that gut-fill may limit feed consumption by the birds. As a result, the upper practical limit for DDGS inclusion in mash or meal diets is likely somewhere around 20% to 25% of the diet, with greater levels requiring pelleting, flow agents, or antioxidants. Pelleting of DDGS-containing diets is possible, but there may be difficulties if the diet contains more than 5% to 7% DDGS (Behnke, 2007). The pelleting difficulties stem in part from an increase in the dietary oil content (some of which comes from the DDGS) and in part because DDGS lack starch, which otherwise helps bind the pellets together (Behnke, 2007). However, pelleting issues with high DDGS inclusion are manageable, as shown by Wang et al. (2007a,b,c), who conducted broiler feeding trials with pelleted diets containing up to 30% DDGS. Although pellet durability was not specifically tested in these studies, Wang et al. (2007a,b) reported that the pellet quality of the diet containing 15% DDGS was similar to that of the control diet, but the diet containing 30% DDGS pelleted poorly and contained numerous fines despite the addition of a pellet binder.

Almost all commercial poultry diets are formulated on a least-cost basis, and the choice of ingredients and their inclusion levels are usually reevaluated on a weekly basis. Large fluctuations in price and availability of DDGS may therefore result in similarly large fluctuations in the dietary content of DDGS. Potentially, a diet can contain 0% DDGS one week and, say, 20% the next. Such rapid and large shifts in ingredients may cause temporary decreases in the birds' feed consumption and therefore persistent decreases in growth rate and feed utilization due to changes in pellet quality, smell, taste, or physical appearance of the feed. To test if fluctuations in the dietary DDGS content would affect growth performance and carcass quality of broilers, Wang et al. (2007a) conducted an experiment in which broilers were fed diets containing 0%, 15%, or 30% DDGS. The dietary content of DDGS fluctuated on a weekly basis between 0% and 15% or between 0% and 30% DDGS, and growth performance was compared to broilers fed 0%, 15%, or 30% DDGS throughout the six-week experiment. There were no adverse effects of feeding diets containing 15% DDGS, and it did not matter if the DDGS levels fluctuated weekly or were constant, or if the diets contained 0% or 15% DDGS during the first or last week of the experiment. However, broilers fed fluctuating levels of either 0% or 30% DDGS gained less body weight and had lower breast-meat yield than birds fed 0% DDGS if the feed during the last week before slaughter contained 30% DDGS. If the dietary DDGS content fluctuated such that the last week's feed contained 0% DDGS, body-weight gain and breast-meat yield was similar to that of broilers fed 0% DDGS throughout the experiment. Potential reasons for the reduced performance of broilers fed 30% DDGS include an arginine deficiency, perhaps combined with poor pellet quality as discussed previously. Nevertheless, it appears that broiler chickens are able to adapt to large and rapid changes in dietary DDGS content. A similar adaptability to weekly changes in dietary DDGS was observed in laying hens by Pineda et al. (2008), who increased the DDGS contents by about 12 percentage points on a weekly basis starting from 10% DDGS and ending with 69% DDGS with no adverse effects on egg production.

Conclusion

Corn DDGS and other distillers co-products are valuable sources of energy and nutrients in poultry diets. However, in part because of variation in energy and nutrient contents among and within co-products, care should be taken in formulating the diets. Preferably, the co-products should be from a single source to minimize variation, and chemical analyses should be performed to verify the nutrient composition and to estimate nutrient availability. When the diets are formulated on a digestible-amino-acid basis, the co-products can be included at 15% of the diet or higher for broilers, turkeys, and laying hens, although poultry feeders are advised to start at lower inclusion levels in young birds and gradually increase the inclusion level as the birds mature.

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Chapter 6

The Value of Distillers Dried Grains in Large International Markets

John A. Fox

As of January 2008, U.S. ethanol production capacity stood at 7.9 billion gallons per year, with additional capacity of 5.5 billion gallons under construction (Renewable Fuels Association, 2008). Annual production of 13.4 billion gallons would use approximately 5 billion bushels of corn, or about 36% of the record 13-billion-bushel 2007 crop. The Energy Independence and Security Act of 2007 increased the U.S. renewable fuel standard to a targeted 36 billion gallons by 2022, of which 15 billion gallons can be derived from conventional sources such as corn.

In 2007, the U.S. ethanol industry produced around 14.6 mmt of distillers grains, of which 36% was marketed in wet form and 64% (around 9.3 mmt) as distillers dried grains with solubles (DDGS). Wet or dry distillers grains are a by-product of drymill ethanol production—as distinct from wet milling for which the by-product is corn gluten. Because the recent and likely future expansion in ethanol production capacity is primarily a result of new drymill facilities, production of DDGS is expected to increase in proportion to ethanol production. DDGS production is expected to reach 36 mmt by 2010 (U.S. Grains Council, 2007), and 40 mmt by 2011 (Tokgoz et al., 2007). Under more aggressive assumptions about industry expansion, Tokgoz et al. estimated that production could be as high as 88 mmt by 2016. At a yield of 18 pounds of DDGS per bushel, 40 mmt is the amount of DDGS attainable from 5 billion bushels of corn.

Currently, most of the DDGS produced in the United States is absorbed by the domestic livestock feed market. Exports have increased in re-

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cent years, and, as production continues to increase over the coming years, the ability to exploit international markets will be important in maintaining prices and returns to the ethanol sector. After reviewing the domestic market for DDGS, this chapter examines the recent history and future potential for DDGS exports to six different countries/regions: the European Union, Canada, Mexico, Japan, Taiwan, and South Korea. Chapter 7 provides a similar analysis for the rest of the world.

The U.S. Market for Distillers Dried Grains with Solubles

The United States is currently the world's largest producer of ethanol. The next largest producer, Brazil, produces ethanol primarily from sugarcane, leaving the United States far and away the largest producer of DDGS. As noted, U.S. production of distillers grains was approximately 14.6 mmt in 2007. Exports totaled 2.36 mmt, leaving over 85% of production on the domestic market. Livestock accounted for the bulk of domestic consumption, with the distribution across species at approximately 42% for dairy cattle, 42% for beef cattle, 11% for swine, and 5% for poultry.

Clemens and Babcock (2008) reviewed results from several feeding trials on the use of distillers grains in livestock rations and examined how U.S. consumption of DDGS might change as production increases. While estimates of appropriate inclusion rates vary, Clemens and Babcock's summary suggests practical levels of approximately 30% to 50% for beef cattle and cattle on feed, 20% to 25% for dairy cattle, 20% for hogs, and 15% for poultry. In practice, inclusion rates for DDGS fall well short of these levels. A 2006 National Agricultural Statistics Service survey (USDA-NASS, 2007) of Midwest livestock operations found average inclusion rates of 23% for DDGS in feedlot rations and rations for beef cattle. Furthermore, only 36% of responding feedlots and only 13% of responding beef cattle operations reported feeding any type of ethanol co-product, with lack of availability cited as the primary reason for not feeding those products.

However, the same survey found that an additional 34% of feedlot operations and 30% of beef cattle operations were considering using co-products, suggesting substantial potential for the domestic livestock sector to absorb increasing quantities of DDGS. Clemens and Babcock describe a number of technological and management efforts to address nutritional issues with DDGS related to sulphur, phosphorus, and fat content. Those efforts hold the potential to enhance significantly the adoption and inclusion rates of DDGS in animal feed rations.

Even with higher domestic adoption and inclusion rates, it is questionable whether the domestic market can absorb all of the anticipated increase in DDGS production. Dhuyvetter, Kastens, and Boland (2005) used U.S. livestock inventories and production levels to estimate maximum domestic consumption of DDGS. Using inclusion rates that, for some species, were considerably lower than currently accepted levels, they estimated a maximum domestic market uptake of 51.5 mmt—approximately four times as much as was consumed domestically in 2007 and an amount well in excess of current production. The analysis, however, assumed 100% adoption of DDGS in all livestock rations, a scenario that is unlikely to be realized.

Using currently recommended inclusion rates, and adoption rates based on producer intentions reported in the USDA-NASS (2007) survey, Table 6.1 suggests a domestic consumption capacity of 38.8 mmt. Compared to Dhuyvetter, Kastens, and Boland's estimates, potential consumption levels on a per animal basis are substantially higher in this analysis for dairy cows, cattle on feed, and market swine. Nevertheless, given the assumed adoption rates, the aggregate potential of 38.8 mmt suggests that the domestic market alone may not absorb all of the anticipated increase in DDGS production, particularly under the more aggressive expansion scenario considered by Tokgoz et al. Furthermore, the assumed inclusion rate of 35% for cattle-on-feed in this analysis may be optimistic given the widespread use of steam-flaking of grain and the apparent animal performance issues that arise with DDGS inclusion rates over 15% in steam-flaked diets (Clemens and Babcock, 2008).

The foregoing analysis suggests that the ability to market DDGS in international markets may be crucial to maintaining sufficient demand and avoiding stockpiles. Fortunately for the ethanol industry, export markets have been developing rapidly for DDGS in recent years as a result of both high grain prices and aggressive market development efforts of the U.S. Grains Council.

Table 6.1. U.S. potential consumption of distillers dried grains with solubles

Livestock class	Inventory (1,000 hd)[a]	Daily Intake (lbs)	Days on Feed[b]	DDGS Inclusion[c]	DDGS Adoption[d]	DDGS (tons/year)[e]
Beef cows	32,600	24	90	35%	43%	5,298,804
Dairy cows	9,220	42	365	20%	60%	8,480,556
Other cattle	40,580	15	135	20%	43%	3,533,504
Cattle on feed	14,300	22	365	35%	70%	14,066,553
Breeding swine	6,070	8	310	20%	47%	707,519
Market swine	39,005	5	365	20%	47%	3,345,654
Breeding sheep	4,510	4	90	10%	40%	32,472
Lambs	4,120	4	90	10%	40%	25,956
Broilers	8,900,000	0.2	56	10%	40%	1,993,600
Layers	344,000	0.2	365	15%	40%	753,360
Turkeys	272,000	0.7	151	10%	40%	575,008
Total						**38,812,985**

Sources:

[a] Jan. 1, 2008, U.S. inventory except broilers, turkeys, and lambs, which represent 2007 U.S. production. Data from USDA-NASS, 2007.

[b] Days fed are as used by Dhuyvetter, Kastens, and Boland, 2005.

[c] Inclusion rates taken from U.S. Grains Council, 2007.

[d] Adoption rates based on USDA-NASS (2007) survey, and assumed 40% for sheep and poultry.

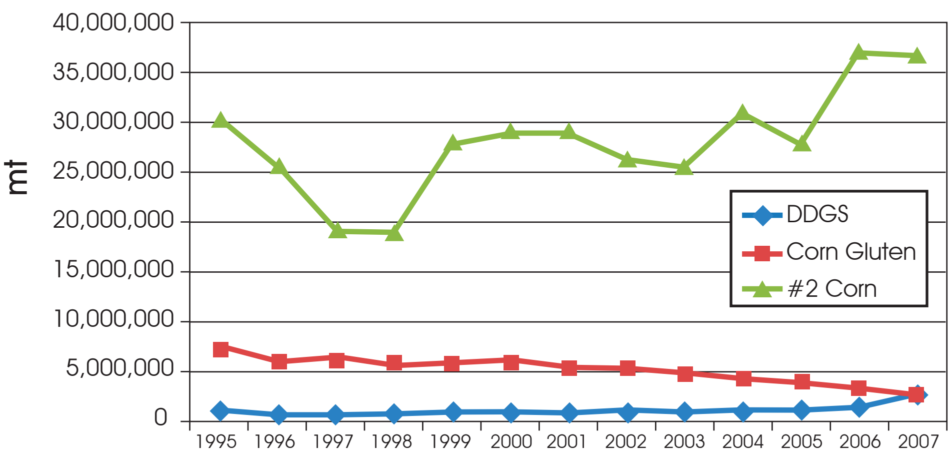
[e] Adapted from Tables 2 and 3 of Dhuyvetter, Kastens, and Boland, 2005.

U.S. Feed Grain Exports

With a relative abundance of arable land, the United States has long been and remains the world's dominant exporter of feed grains. During the 2006-07 and 2007-08 crop marketing years (Sept. 1–Aug. 31), U.S. corn exports of 53.9 and 62.2 mmt accounted for 58% and 63%, respectively, of total world exports. As of June 10, 2008, projected exports for the 2008-09 crop year were 50.8 mmt, accounting for 55% of world trade (USDA, 2008). For the same period, the market share of the second-largest exporter, Argentina, ranged from 15% to 17%.

Figure 6.1 shows the recent history of U.S. exports of #2 corn (the dominant grade), corn gluten (combining corn gluten meal and corn gluten feed), and DDGS. Exports of #2 corn ranged from less than 20 mmt in 1997 to over 36 mmt in 2007. Relative to corn, exports of corn gluten and DDGS are small. Exports of corn gluten fell from over 7 mmt in 1995 to 2.5 mmt in 2007 while exports of DDGS, after remaining stagnant at around 0.6 mm between 1995 and 2004, have grown rapidly over the past three years and almost doubled, from 1.3 mmt to 2.4 mmt, between 2006 and 2007.

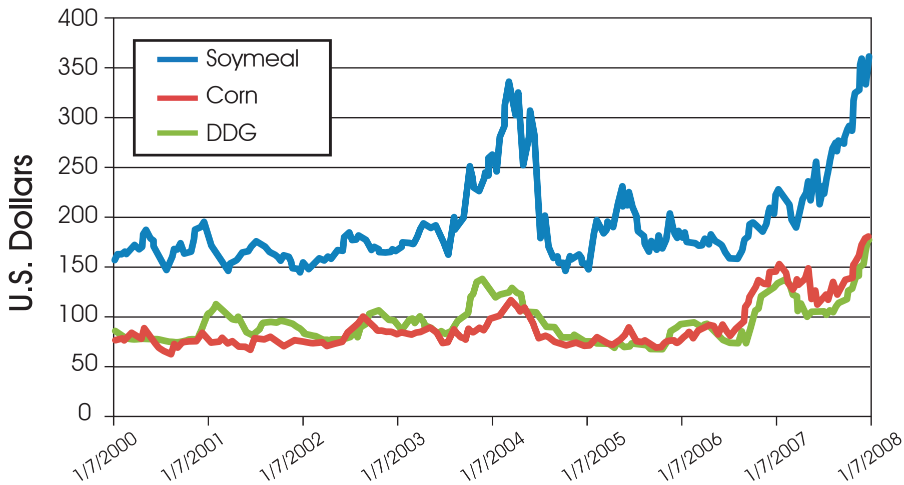
Because DDGS readily substitutes for corn as an energy source in livestock feed rations, and because prices for DDGS have tracked and



Source: USDA-FAS, U.S. Trade Exports - HS 10-Digit Codes database.

Figure 6.1. U.S. feed exports

appear likely to continue to track corn prices[1] (see Figure 6.2), it seems reasonable to assume that the most likely potential export markets for DDGS will be countries that currently import U.S. corn. According to the USDA (2008), the world's leading corn importers for the 2007-08 crop year, with estimated market shares in parentheses, are Japan (17.2%), the European Union–27 (13.7%), Mexico (10.2%), South Korea (9.3%), Taiwan (5.9%), Egypt (4.4%), and Canada (2.6%).



Source: USDA.

Figure 6.2. Nearby Chicago Board of Trade corn, soymeal, and Chicago distillers dried grains weekly prices

Focusing on U.S. (as opposed to world) corn exports, the pattern of buyers is somewhat similar, with the important exception that, as a result of restrictions on imports of genetically modified crops, the European Union now imports very little corn from the United States. Table 6.2 shows the market shares for six of the seven top corn-importing countries/regions (Egypt is covered in chapter 7) for the periods 1995–97 and 2005–07. Between these two periods, the European Union has, for all practical purposes, been eliminated as an export market for U.S. corn, while Mexico has grown in importance. Between 1995 and 2007, the six countries/regions listed in Table 6.2 accounted for between 44% and 60% of U.S. corn

[1]Tokgoz et al. (2007) conclude that "U.S. and world ruminant demand is strong enough to cause the prices of DG to track corn prices" (p. 17).

Table 6.2. U.S. exports of #2 corn—shares for selected markets

	Share of U.S. Exports (%)					
Country/Region	**1995**	**1996**	**1997**	**2005**	**2006**	**2007**
Taiwan	19.8	21.8	27.6	15.4	9.6	9.8
S. Korea	8	8.1	8.8	1.4	4.5	3.5
Japan	6.3	7.2	8.9	10.5	10.8	5.9
Mexico	5.8	17.4	9.3	20.1	19.8	21.1
EU - 27	3.6	4.3	1.9	0	0	0
Canada	1.1	0.7	1.9	3.2	2.5	3.2
Combined share	**44.6**	**59.5**	**58.4**	**50.6**	**47.2**	**43.5**
U.S. exports(mmt)	**30.35**	**25.42**	**19.17**	**27.76**	**37.04**	**36.65**

Source: USDA-FAS U.S. Trade Exports (http://www.fas.usda.gov/ustrade/USTExHS10.asp).

exports and thus likely represent the bulk of the potential export markets for U.S. DDGS.

U.S. Exports of Distillers Dried Grains with Solubles

As noted earlier, U.S. exports of DDGS have increased dramatically over the past four years—from 0.8 mmt in 2004 to 2.4 mmt in 2007 (Table 6.3). That growth appears to be continuing in 2008. A comparison of exports during the first four months of 2008 versus the same period in 2007 shows an increase of 132%, projecting 2008 exports at over 5.4 mmt (equivalent to 37% of total distillers grains production in 2007).

Table 6.3 shows rapid growth in exports to Canada, with exports tripling between 2005 and 2007. During the same period, exports to Mexico increased more than five times, making Mexico the largest export market in 2007 with a share of approximately 30%. While data for January–April 2008 indicate further growth in exports to Mexico (up 65% compared to 2007), dramatically higher exports to Canada suggest that Canada is about to surpass Mexico in 2008 as the number-one market for U.S. DDGS. Taiwan, Japan, and South Korea are essentially new entrants in the market since 2004, and exports to all three are continuing to grow in 2008. Exports to the European Union meanwhile are 82% lower in 2008 compared to 2007. Combined, the six countries/regions shown in Table 6.3 account for well over half the market for U.S. exports of DDGS. And while ag-

Table 6.3. U.S. exports of distillers dried grains with solubles

	Quantity (mt)					
Country/Region	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**[a]
Canada	30,898	83,984	105,929	123,022	317,580	1,659,743
Japan	15	0	2,824	45,248	83,586	149,327
S. Korea	70	625	4,843	24,587	102,529	249,728
Mexico	45,721	66,894	128,271	367,386	708,216	1,169,901
Taiwan	0	7,431	42,249	92,824	134,404	169,371
EU-27	622,200	568,188	571,850	316,288	264,547	47,997
Sum as % of total DDGS exports	94.2%	92.3%	80.1%	77.3%	68.3%	62.9%
Rest-of-World	43,056	60,584	213,245	284,298	745,921	2,032,258
Total DDGS	**741,960**	**787,706**	**1,069,211**	**1,253,653**	**2,356,783**	**5,478,326**

Source: USDA-FAS (http://www.fas.usda.gov/ustrade/USTExHS10.asp) 10-digit harmonized system code for DDGS is 2303300000.

[a]Projection based on a comparison of Jan.–April 2008 vs. Jan.–April 2007 exports.

gregate exports to these countries have continued to grow, their combined share of U.S. DDGS exports has declined from 94% in 2003 to 68% in 2007. Most of that decline is due to the shrinking E.U. market, but it is important to note the rapid growth in exports to smaller market countries represented by "Rest-of-World" in Table 6.3.

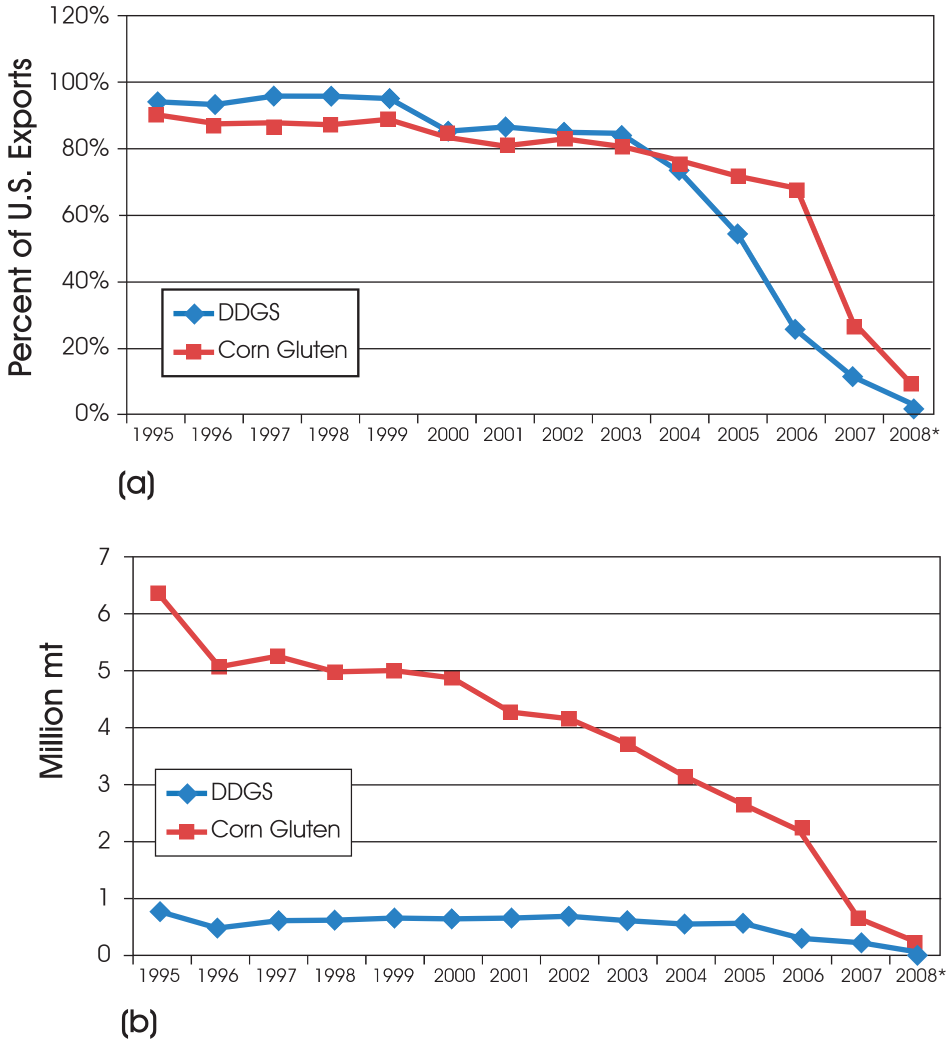
The European Union

During the 1990s the European Union was a reasonably important market for U.S. corn, accounting for 4.3% of U.S. corn exports in 1996 (Table 2) with most of that going to Spain and Portugal. For DDGS and corn gluten, however, the European Union was the dominant export market, taking over 90% of DDGS exports every year between 1995 and 2000, and over 80% of corn gluten exports during the same period (Figure 6.3a). However, as a result of new E.U. labeling requirements introduced in 1997[2] and a 1998 de facto moratorium on the approval of new genetically modified (GM) varieties, Europe has effectively been eliminated as an export market for U.S. corn. Exports of #2 corn fell from over 1 million mt in 1996 to less than 75,000 mt in 1998, a reduction of 93%, and since then corn exports to the European Union have been negligible.

Because E.U. labeling laws did not initially apply to by-products, the European Union continued to be an important market for corn gluten and DDGS. Until 2005, the European Union remained the largest export market for DDGS, with exports of over 571,000 mt that year accounting for 53% of total U.S. shipments. Within the European Union, the largest individual markets were Ireland (36%), the United Kingdom (20%), and Spain (19%). In fact, for the decade between 1995 and 2004, Ireland was consistently the largest individual-country export market for U.S. DDGS, with exports as high as 297,000 mt (33% of total U.S. exports) in 2002. With the introduction of new labeling and traceability requirements for animal feed in 2004,[3] exports to the European Union declined rapidly. Be-

[2]Regulation (EC) No. 258/1997, "Regulation on Novel Foods and Novel Food Ingredients."

[3]Regulation (EC) No. 1830/2003, "concerning the traceability and labeling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC," went into effect in April 2004.



Source: USDA-FAS, U.S. Trade Exports.

Figure 6.3. U.S. exports of distillers dried grains with solubles and corn gluten to the European Union

tween 2005 and 2007, shipments fell from 572,000 mt to 265,000 mt, and they are projected at only 48,000 mt for 2008. The pattern for corn gluten exports has been similar (Figure 6.3b), falling from over 2.2 mmt in 2006 to a projected 425,000 mt in 2008, a reduction of 80%.

The primary reason for the loss of the E.U. export market is the fact that GM varieties of corn approved and grown in the United States and other countries have not been approved by the European Union. This problem of "asynchronous approval" is in large part due to the length of the approval process in the European Union, in which approval typically takes about two-and-a-half years compared to fifteen months in the United States (European Commission, 2007). While regulations adopted in 2003[4] provided the framework for a new E.U.-wide GM approval process, that process has encountered problems. Under the new process, applications for approval of new GM crops are first reviewed by the European Food Safety Authority (EFSA), which subsequently conducts a risk assessment and provides an opinion to the European Commission. The Commission then submits a draft of its proposed decision to the Council of Ministers of the member states for a vote. Member countries are divided on the issue of GM approvals, with, typically, representatives from France and Austria voting against approval and representatives from the United Kingdom and some others voting for approval. To date, none of the draft recommendations submitted to the Council of Ministers has received a supporting qualified majority vote, and none has been rejected by a qualified majority vote. What normally happens in these situations is that the matter is sent back to the Commission, which then acts to approve the application in accordance with its original recommendation.

Complicating the picture further is the ability of individual E.U. member states to invoke a "safeguard clause" under which they continue to ban GM feeds or foods that have been approved by the Commission (Pew Trusts, 2005). Member state bans, which have been invoked by Austria, France, Germany, Greece, and other countries, throw into question the ability of the European Union to implement an effective approval process.

In addition to the problems created by delays in the approval process, two additional factors create a significant disincentive for U.S. exports of corn or corn by-products to Europe: (*a*) the fact that the U.S. grain system does not facilitate segregation and that comingling of GM and non-GM varieties is commonplace, and (*b*) the fact that the European Union applies a zero-tolerance for non-approved genetically modified organisms

[4]Regulation (EC) No. 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed.

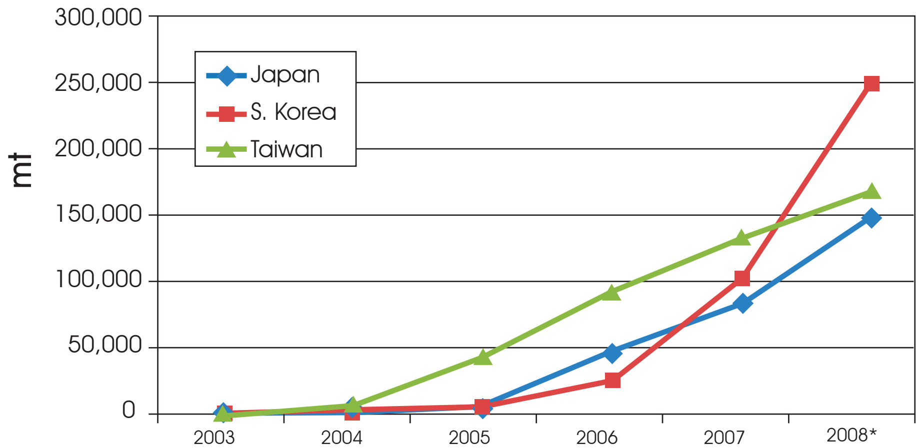
(GMOs). The zero tolerance policy essentially means that if any traces of a non-approved GMO are found in a shipment, the full shipment can be rejected. Such an incident occurred in April 2007 when traces of an E.U. non-approved GM variety, *Herculex RW (59122)*, were found in a shipment of DDGS unloaded at Dublin port (see Greenpeace, 2007). Herculex has been approved in the United States since 2005 and was first grown commercially in 2006. It was submitted for E.U. approval in January 2005 but was not finally approved by the E.U. Commission until October 2007. Even if the U.S. grain system did facilitate segregation, the zero-tolerance standard would probably still be impossible to meet. Seed purity laws cannot even guarantee 100% non-GM seed, and testing procedures have margins of error that can lead to false-positive test results.

As of July 2008, the Web site GMO Compass (www.gmo-compass.org) listed 54 varieties of maize for which E.U. approval had been sought under the new GM approval regulations. The list includes 25 varieties, many already approved for cultivation in North America, at the "application submitted" stage for which an EFSA risk assessment has not yet been completed. While EFSA typically recommends approval of GM applications,[5] given the length of the approval process and the continuous development of new GM varieties, it appears unlikely that the E.U. market will be open to significant U.S. export shipments of corn, corn gluten, or DDGS in the near term.

Japan, Taiwan, and South Korea

Japan, Taiwan, and South Korea are heavily reliant on imported feed for their livestock and poultry sectors. From 2005 to 2007, their combined corn imports accounted for between 20% and 27% of U.S. exports. The three countries have only recently begun to import DDGS, but since 2004, exports have grown rapidly to all three markets (Table 6.3, Figure 6.4). None of the three has domestic ethanol production capacity, so, apart from some by-products from the brewing and distilling industries, there are no competing domestic supplies of DDGS.

[5]Since 2005, the Commission has authorized the import of 16 GMOs. As of May 2008, EFSA has never given a negative GMO recommendation (Ellinghuysen.com, 2008).



Source: USDA-FAS, U.S. Trade Exports.

Figure 6.4. U.S. exports of distillers dried grains with solubles to Japan, South Korea, and Taiwan

Japan imported 83,000 mt of DDGS in 2007 and is on pace to increase imports by 78% in 2008. Japan has no import duties on DDGS and the product is currently being used in the dairy, poultry, and swine sectors. Livestock numbers in most categories in Japan are steady or in moderate decline. Dairy cow numbers have shown the greatest recent decline, from 964,000 in 2003 to 875,000 in 2008. At the same time, compound feed use for cattle has increased slightly, with total feed use for poultry, swine, and cattle estimated at 23.5 mmt in 2006, over 40% of which goes to poultry (Informa Economics, 2007b). Using livestock inventories, the potential market for DDGS in Japan is estimated at around 2.7 mmt (Table 6.4), or about 11.5% of total feed use.

Taiwan imported over 134,000 mt of DDGS from the United States in 2007, an increase of 45% over 2006. During the first four months of 2008, imports were 26% higher than the corresponding period in 2007, representing the slowest rate of market growth among these three countries. According to Informa Economics (2007b), all sectors of the Taiwanese livestock and poultry industries are using DDGS, with adoption by about 60% of dairy farmers. The hog and poultry sectors, however, are far larger than the beef or dairy sectors, and the hog sector in particular represents the greatest opportunity for DDGS. Tariffs rates on DDGS are low, at approximately 3% (Informa,

Table 6.4. Livestock inventories and potential exports for distillers dried grains with solubles

Livestock Class[a]	Mexico[c]	Canada	E.U.	Japan	South Korea	Taiwan[c]
Calf crop	8,000	5,270	30,470	1,405	860	140
Beef cows	11,800	5,000	12,020	635	762	110
Dairy cows	2,200	1,005	24,344	871	266	51
Breeding swine	955	1,546	15,411	915	1,012	808
Slaughter swine	14,840	21,200	250,745	16,385	13,800	9,370
Broilers	1,145,725	456,392	3,466,078	621,820	220,863	245,882
Turkeys	1,170	12,677	143,546	n/a	n/a	312
Potential DDGS exports (short tons/yr)[b]	3,140,232	3,793,647[d]	51,382,334	2,678,063	1,794,534	1,030,609
Projected imports 2008 (short tons)	1,286,891	1,825,718	52,797	164,260	274,701	186,308
Unexploited potential	59%	52%	100%	94%	85%	82%

Source: USDA PSD Online.

[a]Inventory values for 2007 in 1,000-head units. Production data for broilers and turkeys converted assuming broilers have an average weight of 5.1 lb, and turkeys, 28.2 lb.

[b]Estimated using same rates for intake, DDGS inclusion, and adoption used in Table 1. Resulting assumed average intakes are (lb/hd) calves, 174 (treated as "other cattle"); beef cows, 325; dairy cows, 1,840; breeding swine, 233; slaughter swine, 172; broilers, 0.45; and turkeys, 4.23.

[c]To adjust for less-intensive production practices, Mexican adoption rates are adjusted downward by 50% relative to other countries.

[d]Allowing for 530,000 short tons domestic production from corn and wheat.

[e]Estimates for cattle numbers based on Informa, 2007a.

2007a), and in response to a request from the Taiwan Feed Industry Association, it appears likely that the import tariff on DDGS will be eliminated.

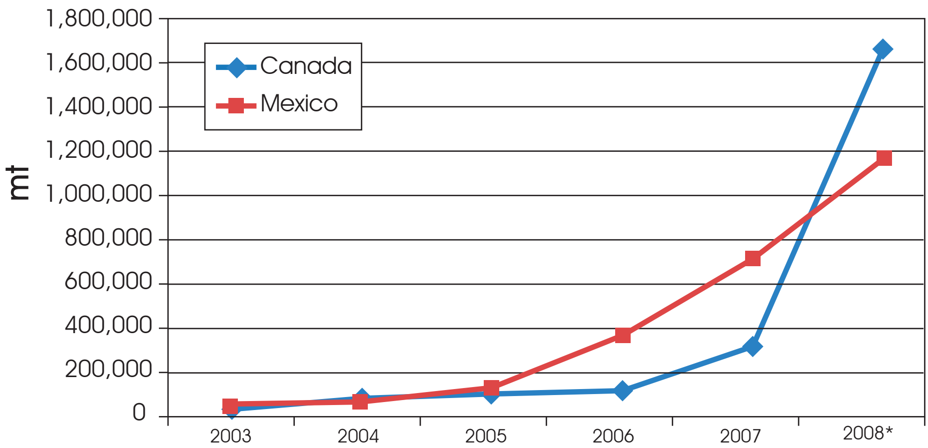
Exports to South Korea grew four-fold between 2006 and 2007 and are on pace to more than double in 2008, indicating that South Korea is set to overtake Taiwan as the largest export market on the Pacific Rim. Interest in DDGS appears to be growing, particularly from the dairy sector, which originated several inquiries to U.S. suppliers during 2007 (B. Johnson, Kansas State University, personal communication, March 2008). The beef sector in Korea has been expanding in recent years, partly a consequence of restrictions on beef imports from the United States because of the discovery of mad cow disease in the United States in 2003. From 2003 to 2008, beef cow numbers increased from 532,000 to 800,000.

Combined, Japan, Taiwan, and Korea accounted for exports of 320,000 mt in 2007, up from 162,000 mt in 2006. Given their livestock inventories, there appears to be substantial potential for exports to increase, with total export potential for the three countries estimated at 5.4 mmt (Table 6.4).[6] To date, most DDGS exports to these countries have been via container shipment, taking advantage of what had previously been the availability of empty containers moving back from the United States to the Pacific Rim. While container shipment has been economical in comparison to recent record high rates for bulk shipment, it has presented some logistical problems. For example, in Japan most of the container traffic goes to major ports that do not routinely handle animal feed or have feed mill facilities, and prices are substantially higher for shipping containers to smaller ports that are closer to feed mills (Informa, 2007a).

Canada and Mexico

In 2006, Mexico surpassed the European Union to become the largest export market for U.S. DDGS, at 367,000 mt. Exports doubled to 708,000 mt in 2007 and are on pace to increase by 65% in 2008 (Figure 6.5). The Mexican livestock and poultry sectors are growing. Between 2003 and 2008, the calf crop increased by 14%, hog slaughter by 9%, and broiler

[6]Informa Economics (2007b) conducted a similar study and estimated market potential for the three countries to be 5.0 mmt.



Source: USDA-FAS, U.S. Trade Exports.

Figure 6.5. U.S. exports of distillers dried grains with solubles to Canada and Mexico

production by 19%. Dairy cow numbers have been steady at around 2.2 million head while beef cow numbers have grown steadily over recent years to reach 11.8 million head in 2007.

Compared to the United States and other countries covered in this chapter, livestock production in Mexico is less reliant on compound feed use. For example, 30% of swine production occurs on what might best be described as subsistence operations, and dairy cow rations typically have a higher percentage of forage compared to operations in the United States and Canada. Total animal feed production is estimated at 25.6 mmt in 2007 (Informa, 2007b), only marginally higher than Japan's even though Mexico has 20 times as many beef cows and 2.5 times as many dairy cows. Thus, when estimating the potential for DDGS exports to Mexico using livestock inventories, potential adoption rates are adjusted downward by a factor of 50% to allow for the effect of less-intensive production practices. Given that adjustment, the potential market is estimated to be around 3.1 mmt, or about 2.5 times more than the projected level of imports for 2008 (Table 6.4).

In 2007, exports to Canada were 2.5 times greater than in 2006, and during the first four months of 2008 they were 5 times the level of the corresponding period in 2007. If exports continue at that pace throughout 2008, Canada will become the largest export market for DDGS, at around 1.6 mmt (Figure 6.5). Canada's livestock production systems are similar to those of the United States in many ways, with most beef production coming from large commercial feedlots. And like the United States, Canada has a growing domestic ethanol sector produced from both corn and wheat. The sector is small compared to that of the United States but utilized around 40 million bushels of corn and 17 million bushels of wheat in 2007 and produced around 530,000 short tons of DDGS (USDA, GAIN reports). After allowing for domestic DDGS supplies, estimates based on livestock inventories suggest a potential export market of around 3.8 mmt.

Exports to both Canada and Mexico are facilitated by the option to ship by rail and by the absence of tariffs under the North American Free Trade Agreement. The combined potential of exports to the two countries, at around 7 mmt, and the pace of U.S. export growth there suggests that the North American market is likely to be the most important destination for U.S. exports of DDGS.

Summary

With expanding global demand for meat, record prices for feed grains, favorable tariff rates, and the lack of domestic supplies of DDGS in importing countries, U.S. exports of DDGS appear likely to continue to grow. The potential level of exports to any market can be estimated using livestock and poultry inventories or production levels and assuming some level of DDGS inclusion and adoption. Using similar assumptions about inclusion and adoption rates to those used to estimate potential domestic consumption (Table 6.1), the potential market for DDGS in the six countries/regions examined in this chapter is estimated in Table 6.4.

Not surprisingly, given its livestock inventories, the largest potential market is the European Union. But given the current difficulties with GM approvals and labeling requirements for that market, it seems unlikely that the European Union will be a significant export market for U.S. exports of DDGS in the near future. Ignoring the European Union, the other five countries analyzed are estimated to have a combined market potential of over 12 mmt, or about 30% of the anticipated 40 mmt level of DDGS production for 2011.

The analysis suggests that under most scenarios the combined potential of the domestic market (39 mmt) and these export markets (12 mmt) can absorb the anticipated increase in U.S. production of DDGS. Furthermore, those estimates do not account for a large number of rapidly growing "smaller" export markets covered in chapter 7, and the estimates are not based on maximum inclusion and adoption levels. While there remains substantial unexploited potential in export markets, particularly in the Pacific Rim countries, the ability to grow exports is likely dependant on continuing efforts by the U.S. Grains Council to educate foreign buyers about DDGS. It also depends upon the ability to address some technical and marketing issues related to the product. Shurson (2005) identified a number of challenges facing the DDGS market, including product definition and the lack of a quality grading system, variable quality, and poor product flowability leading to difficulties in loading and unloading operations.

If the expansion of the U.S. ethanol sector occurs at a more rapid pace than commonly anticipated, and if, for example, DDGS production reaches 88 mmt by 2016 in the scenario described in Tokgoz et al., the ability of the domestic and currently available export markets to absorb the output of DDGS is questionable. In that scenario it will become critical to regain at least partial access to the E.U. market, perhaps through individual plants adopting certification and traceability programs and using only E.U.-approved corn varieties, and with the European Union adopting a non-zero tolerance level for non-approved GMOs.

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Chapter 7

International Demand for U.S. Distillers Dried Grains with Solubles in Small Markets

Nicholas D. Paulson

The United States produced 6.5 billion gallons of ethanol in 2007. The current annual production capacity of existing ethanol plants is over 7 billion gallons, with more than 6 billion gallons of additional capacity currently under construction or planned (RFA, 2008). The Energy Independence and Security Act of 2007 mandates the use of 36 billion gallons of biofuels each year by 2022, with up to 15 billion gallons of that total coming from corn-based ethanol.

Distillers dried grains with solubles (DDGS) are a by-product created from the dry milling ethanol production process.[1] These DDGS can be used as components of feed rations for livestock and poultry production and have predominantly been used as an energy replacement for corn and/or a protein replacement for soybean meal (Markham, 2005). The rates at which DDGS can be used in feed rations, referred to as inclusion rates, vary across livestock species. Each bushel of corn processed into ethanol can yield approximately 18 pounds of DDGS. An estimated 14.6

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[1]Distillers grains can be marketed in both wet and dry forms. Currently, about 64% of distillers grains sold are in dry form with the remaining 36% being marketed wet (RFA, 2008). Wet distillers grains have a relatively short shelf life and are generally marketed to buyers close to the production plant. Since the focus of this chapter is on export markets, only DDGS will be discussed. The wet milling production process results in different feed by-products—corn gluten feed and meal—which can also be incorporated into livestock feed rations. Since nearly all industry expansion is expected to be in dry mill plants, the production levels of corn gluten feed and meal are projected to stabilize at 10 mmt and 2 mmt, respectively.

million metric tons (mmt) of DDGS were produced in 2007. The U.S. Grains Council (USGC) projects that DDGS production levels will reach 36 mmt by 2010 (USGC, 2007). Other projections estimate that annual DDGS production in the United States will surpass 40 mmt by 2015 (Informa, 2007b) or as early as 2011 (Tokgoz et al., 2007).

The recent rise in corn prices has squeezed profit margins in the ethanol industry, making the successful marketing and sale of DDGS increasingly more important for ethanol producers to ensure profitability. Dhuyvetter, Kastens, and Boland (2005), using inclusion rates from a variety of feeding trial studies, estimate the domestic feeding potential for DDGS in the United States at more than 50 mmt, which would have replaced about one-third of the amount of corn fed in 2005 (156 mmt). While this would be sufficient to exhaust projected production levels, it assumes all livestock producers fully adopt DDGS into their feed rations at maximum inclusion rates without consideration for the DDGS price that would be needed to clear the market. Because the profitability of ethanol production is directly proportional to the price of both ethanol and the by-products created from the process, ethanol producers need to consider the benefits of developing export markets to enhance demand for the DDGS they produce. Given the average nutrient composition of DDGS, their value as a feed component should be slightly higher than corn and slightly lower than soybean meal when used at inclusion rates recommended from recent feeding trials (USGC, 2007). Historically, the price of DDGS has generally tracked along with corn prices (see Figure 6.2 in Chapter 6). The ratio of DDGS to corn prices (expressed in $/short ton) from January 2007 through June 2008 in Northeast Iowa and Illinois are reported in Figure 7.1 (USDA-AMS, 2008). The average price ratio over the period was equal to 0.92 in both Iowa and Illinois but varied from 0.7 to 1.1. Tokgoz et al. (2007) conclude that potential demand from ruminants worldwide should be sufficient to maintain a DDGS value close to that of corn.

Figure 7.2 shows U.S. exports of DDGS from 1996 through 2007 (USDA-FAS, 2008b; USITC, 2008). Exports of DDGS slowly increased from 500,000 metric tons (mt) in 1996 to well over 1 mmt in 2005 and 2006. DDGS exports nearly doubled in 2007 to reach 2.3 mmt or more than 15% of total DDGS production. As of June 2008, DDGS exports were on pace to total 3.8 mmt for 2008 (USGC, 2008b). The European

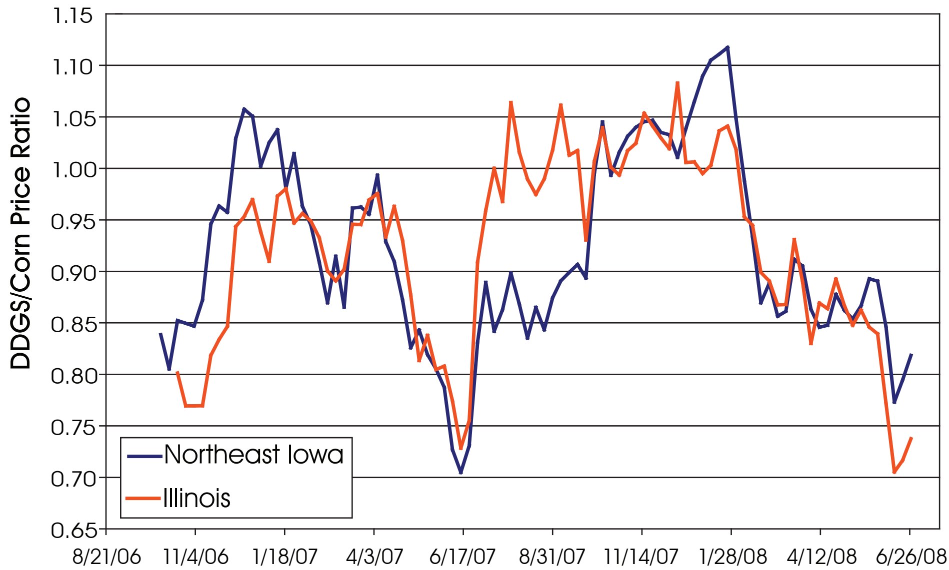

Figure 7.1. Ratio of price of distillers dried grains with solubles to corn price in Northeast Iowa and Illinois, January 2007 through June 2008

Sources: USITC, 2008, and USDA-FAS, 2008b.

Figure 7.2. U.S. exports of distillers dried grains with solubles, 1996-2007

Union, Mexico, and Canada have been among the largest export markets to date (RFA, 2008). However, recent export history shows the export share of these large markets declining. The focus of this chapter is on the value and potential for DDGS demand in the "small" international markets of Central and South America, the Caribbean, Southeast Asia, Africa, and the Former Soviet Union. Export growth has roughly mirrored the expansion of ethanol production and DDGS while the total export share attributed to small markets has increased from a negligible amount prior to 2000 to nearly 25% of total exports in 2007, or 588,000 mt. The export histories and potential DDGS demand for each of the small market regions are presented individually in the sections that follow, with additional discussion devoted to the challenges faced in export market development. Available information on tariff rates applied[2] to corn, soybean meal, and DDGS imports is also provided and indicates that tariff rates on DDGS imports are in many cases lower than those applied to corn and soybean meal imports (WTO, 2008).

Estimating Demand Potential for Distillers Dried Grains with Solubles

Data on DDGS export levels to the countries in each region were compiled from the United States International Trade Commission DataWeb (USITC, 2008) and the Foreign Agricultural Service's U.S. Trade Database (USDA-FAS, 2008b).[3] Estimates of potential DDGS consumption in each small market region were calculated using 2007 animal inventory data (FAOStat, 2008)[4] and inclusion rate assumptions for each livestock species based on (1) maximum recommended rates (USGC, 2007) and (2) typical inclusion rates implemented by U.S. livestock producers based on a recent USDA survey on ethanol co-product use (USDA-NASS, 2007).

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[2]Reported tariff rates are those that have been applied in practice and are often much lower than the bound, or maximum, rates set in each country.

[3]DDGS exports are listed under HTS code 230330 for "brewing or distilling dregs and waste," which may also include other products. DDGS exports to Egypt were listed under HTS code 230310, "residues of starch manufacturing," prior to 2007 (Informa, 2007a).

[4]Potential demand is estimated based on 2007 animal inventory data from the Food and Agriculture Organization (FAO). The FAO provides both stock and production animal

While the results of feeding trial studies and the nutrient composition of DDGS vary, the general conclusion is that DDGS provide a feeding value slightly exceeding that of corn up to maximum inclusion rates, which differ by livestock species (USGC, 2007). The first column of Table 7.1 reports the maximum inclusion rates at which DDGS reportedly provide equivalent or even slightly improved feed performance relative to rations without DDGS included. The second column reports the values of potential DDGS consumption used by Dhuyvetter, Kastens, and Boland (2005) to estimate feeding potential for DDGS in the U.S. livestock industry. The inclusion rates that correspond to the Dhuyvetter, Kastens, and Boland feeding values are similar to the maximum recommended inclusion rates reported in the first column. Actual inclusion rates and the corresponding feed amounts consumed per animal from a recent USDA survey of U.S. livestock producers are also reported in Table 7.1 for beef and dairy cattle and market swine (USDA-NASS, 2007). In all three cases, actual inclusion rates being implemented by surveyed livestock producers are well below the maximum rates suggested from feeding trial data, indicating that the assumption of maximum inclusion rates may overstate potential demand even if DDGS inclusion in feed rations were to be fully adopted by U.S. livestock producers.[5]

Data on the amounts of corn and soybean meal fed domestically, net imports, and import levels from the United States in each region were also collected from the USDA-FAS Production, Supply and Distribution Database. This study assumes that net importers of feed products, especially those who depend on U.S. corn and soybean meal, will be most likely to demand DDGS imports as a partial feed replacement if the product is priced competitively with corn and soybean meal. The levels of corn and soybean meal imports from the United States are compared with domestic feed levels to illustrate the relative dependence on U.S. feed sources within each

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inventory data for cattle, swine, chickens, and turkeys. Beef and dairy cattle inventory estimates were taken from FAO production data. Other cattle inventories were defined as total cattle stocks less the beef and dairy production inventories. FAO does not distinguish between market and breeding swine, so all inventories were assumed to be market swine.

[5]Demand potential for DDGS in the U.S. beef industry, specifically, may be overestimated using maximum inclusion rates due to the reliance on steam-flaked rather than dry-rolled corn because feeding research suggests higher inclusion rates can be used in diets based on dry-rolled corn (Clemens and Babcock, 2008).

Table 7.1. Summary of inclusion rates of distillers dried grains with solubles and average consumption levels by livestock class

	Maximum Inclusion Rates[a]	Average Consumption (lb/animal/yr)[b]	Observed Inclusion Rate[c]	Average Consumption (lb/animal/yr)[c]	Value(s) Used, Average Consumption max/typical (lb/animal/yr)
Beef cattle	40%	650.0	22%	396	720/360
Dairy cattle	20-30%	1520.8	8%	1002	3125/1042
Other cattle	40%	375	nr	nr	375/187.5
Market swine	20%	171.6	11%	82	149/74.5
Breeding swine	20-50%	374.0	nr	nr	374/187
Broilers	10%	1.1574	nr	nr	1.1574
Turkeys	10%	6.3539	nr	nr	6.3539

Sources: [a]USGC, 2007; [b]Dhuyvetter, Kastens, and Boland, 2005; [c]USDA-NASS, 1007.
Note: nr means not reported in the USDA survey.

region, again assuming that DDGS will experience greater demand potential in areas that are already importing a portion of their feed supply from the United States. Net exporters of corn and soybean meal and importing regions with limited dependence on U.S. feed sources have revealed a shadow value below the price of imported feed sources such as U.S. DDGS, implying limited potential for export market growth and development.

Because DDGS are most commonly used to partially replace corn and/or soybean meal in livestock rations and the composition of livestock rations will vary across regions, domestic feeding rates for corn and soybean meal were also used to derive a third estimate for potential DDGS demand within each region. The estimate for U.S. feed potential of more than 50 mmt given by Dhuyvetter, Kastens, and Boland (2005) would have replaced one-third of all corn fed in the United States in 2005. If DDGS are priced at a level competitive to the value of corn, it is assumed that DDGS could also replace up to one-third of the corn fed in other regions. For DDGS consumption to increase significantly beyond that level, the grains will likely have to be priced below the value of corn. The potential demand for DDGS based on domestic corn feeding is by far the most conservative estimate for all regions considered, with the exception of countries in North Africa, where the potential demand estimate based on typical inclusion rates is the most conservative. This result implies that feed rations in the majority of the small markets considered in this study are less grain intensive than the rations used by U.S. livestock producers. Therefore, potential demand estimates based on inclusion rates experienced in the United States may only apply to these regions if the price of DDGS becomes sufficiently low enough to induce livestock producers in these regions to change the composition of their feed rations to be more grain intensive.

South America

A handful of countries in South America have been importing U.S. DDGS for the past seven years. In 2000, Colombia became the first South American importer of U.S. DDGS by purchasing 40,000 mt. Although export levels declined significantly in 2003, exports to South American countries have increased each year since 2004. From 2006 to 2007, South American imports of U.S. DDGS increased by nearly five times, to just over 60,000 mt, or 2.5% of total U.S. exports. Furthermore, South American imports of DDGS for 2008 are on pace to increase by four times their 2007 levels. Chile and Colombia imported 37,500 and 12,500 mt, respectively, in 2007. The balance of imports, roughly 10,000 mt, went to Peru which imported DDGS for the first time in 2007. The start of DDGS imports into Peru is largely attributed to recent feeding research and educational efforts in the country that were spearheaded by the USGC (USGC, 2008a).

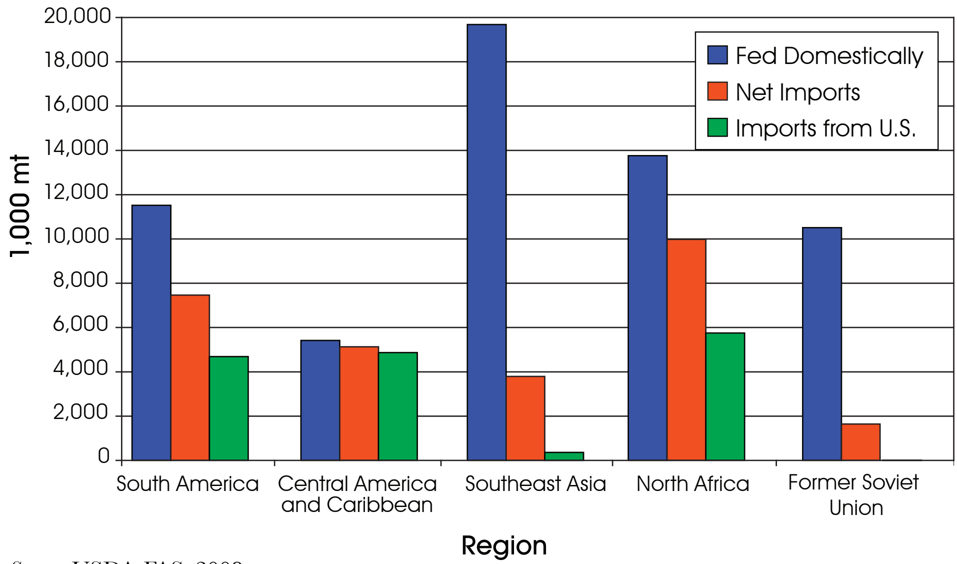
The estimates for feeding potential of DDGS in South America by livestock class are reported in Table 7.2. Given the scale of South America's livestock industry, particularly beef and dairy cattle production, the feeding potential for all South American countries would be estimated to be well over 100 mmt at recommended inclusion rates. However, livestock rations in the South American countries of Argentina, Brazil, Paraguay, and Uruguay differ considerably from the more grain and meal intensive rations used in the United States. Figures 7.3 and 7.4 show that South Americans fed only 54 mmt of corn and 17 mmt of soybean meal in 2007. The U.S. livestock industry, which is significantly smaller in scale compared to that of South America, fed more than 150 and 31 mmt of corn and soybean meal, respectively, in 2007. Moreover, the whole of South America has a positive trade balance for both corn and soybean meal, and the limited import levels from the United States represent a very small fraction of the total used for livestock feed.

Table 7.2. Potential consumption of distillers dried grains with solubles in South America based on 2007 livestock inventories

Livestock Class	2007 Inventories[a] (1000 Head)	Potential Consumption at Max Rates (mt/year)	Potential Consumption at Typical Rates (mt/year)
Beef cows	10,090	3,302,313	1,651,156
Dairy cows	11,740	16,676,080	5,560,472
Other cattle	43,345	7,388,376	3,694,188
Market swine	15,424	1,044,594	522,297
Broilers	1,929,706	1,015,201	1,015,201
Turkeys	28,183	81,396	81,396
Total		29,507,960	12,524,711

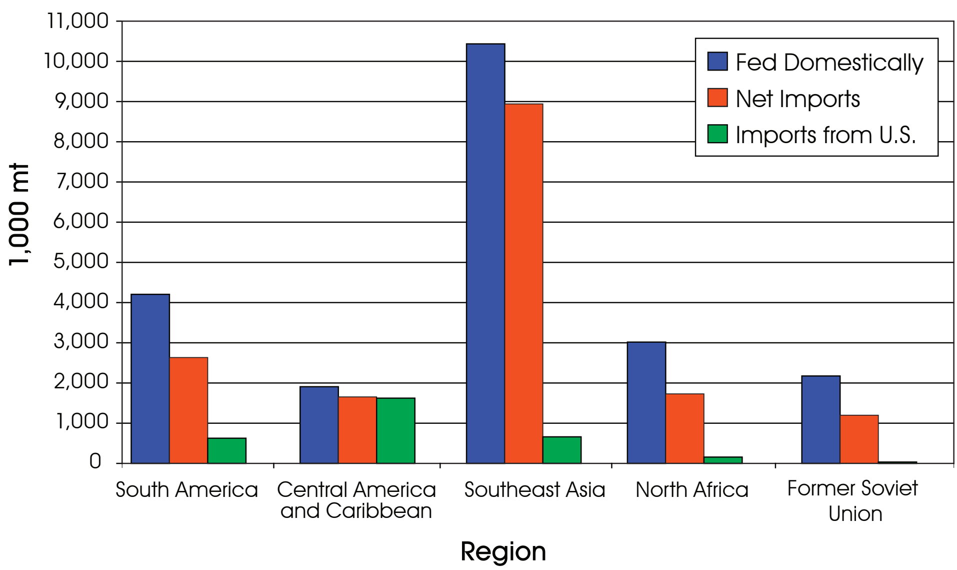
[a]*Source:* USDA-FAS, 2008a.

Note: Excludes Brazil, Argentina, Paraguay, and Uruguay.



Source: USDA-FAS, 2008a.
Note: South America region excludes Argentina, Brazil, Paraguay, and Uruguay.

Figure 7.3. Domestic feed use, net imports, and imports of U.S. corn by region for the 2006/07 marketing year



Source: USDA-FAS, 2008a
Note: South America region excludes Argentina, Brazil, Paraguay, and Uruguay.

Figure 7.4. Domestic feed use, net imports, and imports of U.S. soybean meal by region for the 2006/07 marketing year

The potential DDGS demand estimates for South America reported in Table 7.2 exclude the countries of Argentina, Brazil, Paraguay, and Uruguay because of these countries' differing feeding practices and their status as net corn exporters. Animal inventories outside of these countries are significantly lower and result in potential demand for DDGS of 29.5 mmt at maximum inclusion rates, or 12.5 mmt assuming that the more typical inclusion rates currently being implemented by U.S. producers are also adopted in South America. All of the DDGS importing countries in South America have historically been net importers of corn despite the overall positive trade balance for all countries in South America. These net importing countries are relatively dependent on U.S. corn imports, which represent more than 37% of the total amount of the corn used for feeding purposes from 2000 to 2006. The potential demand estimate for U.S. DDGS based on the domestic feeding rates of corn is even lower at 3.8 mmt per year.

The competitiveness of DDGS as a protein replacement for soybean meal is highly unlikely in South America given the supply of soybean meal generated from the large and continually expanding soybean industries of Argentina and Brazil. DDGS in South American countries will most likely be used as an energy replacement for corn in livestock rations and thus valued similarly to corn in the net importing countries.

Average applied tariff rates on corn and soybean meal imports to South America range from 0% to 15%, with corn imports generally having a higher rate in most South American countries. DDGS tariff rates are equal to those applied on soybean meal in all countries but lower than the applied tariff rates on corn in Argentina, Brazil, Paraguay, and Peru. Free trade agreements between the United States and Colombia and Peru are currently pending. The Colombian agreement would eliminate the 15% tariff currently being applied on corn, soybean meal, and DDGS. Peru has not been applying tariffs on DDGS or soybean meal imports, while a 9% tariff has been applied on U.S. corn imports.

Central America and the Caribbean

Countries in Central America and the Caribbean began importing U.S. DDGS in 2000 when Guatemala, Honduras, and Jamaica imported a combined total of 8,900 mt. In 2007, five countries in Central America imported a total of 31,500 mt, led by Costa Rica with just over 15,000 mt. Cuba imported close to 85,000 mt, and Jamaica imported 9,000 mt, to bring total U.S. DDGS exports to the region to more than 125,000 mt, or 5.1% of total U.S. exports. Imports of U.S. DDGS through February 2008 already exceeded the total for 2007 (USDA-FAS, 2008b). The USGC has initiated educational efforts on feeding in Guatemala and El Salvador, which has helped to bring DDGS to those countries and the surrounding regions (USGC, 2008a).

Potential DDGS consumption in Central America and the Caribbean by livestock class is reported in Table 7.3. The combined potential is estimated to be 10.2 mmt at maximum inclusion rates and 4.3 mmt at typical inclusion rates. The livestock industries in the region have undergone expansion over the past four years, leading to increasing amounts of corn and soybean meal being fed each year. Over 5 mmt of corn and nearly 2 mmt of soybean meal were fed to livestock in Central America and the Caribbean during the 2006/07 marketing year. Based on the amount of corn fed each year, the potential DDGS consumption in this region was estimated to be just over 1.8 mmt but should continue to grow with the amount of corn and soybean meal fed in the region if the livestock industries in these countries continue to expand.

Countries in Central America and the Caribbean typically do not generate any corn or soybean meal exports, resulting in the trade deficit

Table 7.3. Potential consumption of distillers dried grains with solubles in Central America and the Caribbean based on 2007 livestock inventories

Livestock Class	2007 Inventories[a] (1000 Head)	Potential Consumption at Max Rates (mt/year)	Potential Consumption at Typical Rates (mt/year)
Beef cows	3,371	1,103,371	551,686
Dairy cows	4,163	5,913,142	1,971,678
Other cattle	13,902	2,369,633	1,184,817
Market swine	5,928	401,481	200,741
Broilers	850,434	447,406	447,406
Turkeys	355	1,025	1,025
Total		10,236,059	4,357,352

[a]*Source*: USDA-FAS, 2008a.

for both commodities trending upwards at the same rate as domestic feeding, which has increased 7%–12% each year since 2003. U.S. imports have historically represented nearly 90% (80%) of all corn (soybean meal) fed in the region. The coupling of high and volatile commodity prices and relatively high dependence on U.S. feed sources makes Central America and the Caribbean an area of high growth potential for DDGS exports.

The average tariff rates applied on DDGS imports to countries within Central America are all well below those applied on corn imports, helping to promote DDGS. Applied rates for soybean meal imports are generally lower than those applied on DDGS imports. In Belize, the tariff rate applied on corn is 40%, whereas no tariff is applied on DDGS and soybean meal imports. Panama applies a 26% tariff rate on corn imports but only a 15% tariff on DDGS and no tariff on soybean meal. Most other Central American countries apply a 5% rate on DDGS imports and a 2.5% rate on soybean meal imports, while corn imports have tariff rates ranging from 9.3% (Costa Rica) to 17.5% (Guatemala). The Central American Free Trade Agreement between the United States, Central American countries, and the Dominican Republic gives the United States preferential tariff rates on many imported goods, making these goods more competitive with imports from other countries. A free trade agreement between the United States and Panama, currently pending, would remove the current tariff rates being applied to corn and DDGS imports.

Southeast Asia

Countries in Southeast Asia began importing U.S. DDGS on a reasonable scale in 2004 when more than 25,000 mt were imported, mostly by Indonesia and Malaysia. Total exports increased nearly fourfold in 2005 and by more than 50% in both 2006 (193,000 mt) and 2007 (305,000 mt). As of February, export levels for 2008 were on pace to double those of 2007. Indonesia, Thailand, and Vietnam each imported roughly 20% of the total in 2007. The greatest amount of imports, 79,000 mt, went to the Philippines. Malaysia imported 40,000 mt and Singapore also imported a very small amount (150 mt). DDGS exports to Southeast Asia account for 13% of total U.S. exports or more than half of total exports to small markets. USGC education efforts in the Philippines and Malaysia and transportation economies are attributed as the main causes of the excellent export growth realized in Southeast Asia (USGC, 2008a; Informa, 2007a, b).

Table 7.4 reports the DDGS consumption potential for countries in Southeast Asia, which was estimated to be more than 15 mmt at maximum inclusion rates, or 8.4 mmt at typical inclusion rates. Figures 7.3 and 7.4 show domestic feed consumption, net import levels, and imports from the United States for corn and soybean meal, respectively, for Southeast Asia during the 2006/07 marketing year. The amount of corn fed to livestock in the region has been steadily increasing since 2003 and was close to 20,000 mt in 2007. The amount of soybean meal fed to livestock has also been increasing, with nearly 11,000 mt fed in 2007. The region is highly dependent on soybean meal imports, which represent more than 80% of the total amount of soybean meal fed domestically. Southeast Asian countries are also net importers of corn, with 15%–20% of total corn fed domestically coming from other regions. However, U.S. imports of corn and soybean meal have been historically low and, in the case of soybean meal, declining. Based on the amount of corn fed in the region, a more conservative estimate of DDGS consumption potential was found to be 6.5 mmt per year.

While the ratio of U.S. corn imports to domestic feed use for corn has been historically low for countries in Southeast Asia, transportation economies attributed to the use of container freight options have helped stimulate DDGS export growth to this region. Export growth in Southeast Asia

Table 7.4. Potential consumption of distillers dried grains with solubles in Southeast Asia based on 2007 livestock inventories

Livestock Class	2007 Inventories[a] (1000 Head)	Potential Consumption at Max Rates (mt/year)	Potential Consumption at Typical Rates (mt/year)
Beef cows	5,285	1,729,676	864,838
Dairy cows	992	1,408,604	469,685
Other cattle	25,390	4,327,860	2,163,930
Market swine	87,212	5,906,651	2,953,326
Broilers	3,797,627	1,997,897	1,997,897
Turkeys	568	1,640	1,640
Total		15,372,328	8,451,316

[a]*Source:* USDA-FAS, 2008a.

will likely continue, with the most limiting factors being those of competition from other commodities, procuring containers for transportation, and port capacity limitations (USGC, 2007; Informa, 2007a).

Applied tariff rates on corn, soybean meal, and DDGS vary across the countries in the region. Indonesia has applied tariffs of 5% on corn, soybean meal, and DDGS imports. In the Philippines, a tariff rate of 3% is applied on DDGS and soybean meal while the tariff rate for corn imports is much higher at 30.7%. Thailand applies lower tariff rates on DDGS (9%) and soybean meal (6%) relative to corn imports with a 20% tariff rate. Malaysia and Singapore reportedly do not apply tariffs on corn, soybean meal, or DDGS imports.

North Africa

African imports of U.S. DDGS have grown from about 546 mt in 2004 to nearly 66,000 mt in 2007. Imports through 2008 were on pace to more than triple the amount in 2007. Morocco and Egypt account for nearly all of the imports of DDGS into Africa each year, importing a combined 64,000 mt in 2007. The growth in exports to Morocco and Egypt is largely attributed to the USGC's recent efforts to educate livestock producers on the benefits of incorporating DDGS into their feed rations (USGC, 2008a; Informa, 2007b).

Table 7.5 reports the estimates of DDGS feeding potential in North Africa by livestock class. At maximum recommended inclusion rates, more than 8.7 mmt of DDGS could be fed in North Africa, while typical inclusion rates result in a potential demand level of 3.5 mmt. Figures 7.3 and 7.4 show the amounts of corn and soybean meal fed domestically, net imports, and imports from the United States for the 2006/07 marketing year. The amount of corn fed in North Africa has been relatively stable at 13 mmt each year while the amount of soybean meal fed has seen a steady increase over the past decade to reach more than 3 mmt in 2006/07. Corn imports from the United States have represented more than 45% of the total amount of corn fed to livestock in North Africa since the year 2000. However, soybean meal imports from the United States have declined since 2000 and now account for less than 5% of the soybean meal fed to livestock in North Africa. North Africa has historically been a net importer

Table 7.5. Potential consumption of distillers dried grains with solubles in North Africa based on 2007 livestock inventories

Livestock Class	2007 Inventories[a] (1000 Head)	Potential Consumption at Max Rates (mt/year)	Potential Consumption at Typical Rates (mt/year)
Beef cows	3,278	1,072,800	536,400
Dairy cows	4,759	6,759,943	2,254,035
Other cattle	1,641	279,738	139,869
Market swine	80	5,439	2,719
Broilers	1,118,000	588,170	588,170
Turkeys	15,501	44,769	44,769
Total		8,750,858	3,565,962

[a]*Source*: USDA-FAS, 2008a.

of both corn and soybean meal, with imports representing 70% (50%) of the corn (soybean meal) fed domestically each year.

The market for DDGS in North Africa should continue to grow based on the region's dependence on feed imports, which are partially fulfilled by the United States. Based on the amount of corn used for feed in North Africa, DDGS demand potential is estimated to be up to 4.6 mmt per year. This DDGS demand potential estimate is larger than that based on typical inclusion rates and animal inventories for North Africa, which implies that feed rations being implemented in the region are more similar to those in used in the U.S. livestock industry compared to the other regions considered in this study.

Morocco applies average tariff rates of 25%, 17.5%, and 35% on soybean meal, corn, and DDGS, respectively. The fact that applied tariff rates on DDGS are higher than those on corn and soybean imports is somewhat surprising considering Morocco is currently the leading importer of U.S. DDGS in North Africa. Egypt applies a 2% tariff on DDGS imports and a 5% tariff on imported soybean meal; a tariff is not applied to Egypt's corn imports. South Africa[6] does not apply a tariff to corn or DDGS imports, but there is a 6.6% tariff rate applied to soybean meal imports from the United States.

[6]South Africa, while not within the region of North Africa, imported a small amount of U.S. DDGS in both 2005 (50 mt) and 2006 (1,100 mt).

Former Soviet Union

Exports of U.S. DDGS have not yet penetrated any of the countries in the Former Soviet Union (FSU). The estimated feeding potential for DDGS in the FSU by livestock class is reported in Table 7.6. At maximum recommended inclusion rates, the FSU livestock industry could potentially feed more than 30 mmt of DDGS each year, while potential demand at typical inclusion rates was estimated to be much lower at 12.7 mmt.

Corn used for feed in the FSU has increased from less than 6 mmt in 2000 to more than 10 mmt for the 2006/07 marketing year, as shown in Figure 7.3. However, corn imports from the United States to the region have been negligible. FSU countries have shown a steady increase in the domestic feeding of soybean meal since 2003, with more than 2.2 mmt being fed to livestock in the region in 2006/07. Imports of soybean meal from the United States have steadily declined, making up less than 2% of the total soybean meal fed in 2007. Based on the amount of corn fed in the region, a more conservative estimate for DDGS demand potential in FSU countries would be 3.5 mmt, although for any significant amount of U.S. DDGS to be imported, it is likely that DDGS would need to be priced lower than corn given the region's lack of dependence on U.S. corn and soybean meal.

Table 7.6. Potential consumption of distillers dried grains with solubles in the Former Soviet Union based on 2007 livestock inventories

Livestock Class	2007 Inventories[a] (1000 Head)	Potential Consumption at Max Rates (mt/year)	Potential Consumption at Typical Rates (mt/year)
Beef cows	13,879	4,542,316	2,271,158
Dairy cows	14,586	20,719,105	6,908,578
Other cattle	24,806	4,228,291	2,114,145
Market swine	30,210	2,046,065	1,023,032
Broilers	649,534	341,714	341,714
Turkeys	14,515	41,921	41,921
Total		31,919,412	12,700,550

[a]*Source*: USDA-FAS, 2008a.

Applied tariff rate data for the individual countries within the FSU were not reported by the World Trade Organization. A number of the countries, such as the Ukraine, Czech Republic, Poland, and Latvia, are now a part of the European Community. The European Community countries reportedly do not apply tariff rates on soybean meal or DDGS imports, but an E.U.$94/ton duty has been applied on corn imports.

Total Small Market Demand and Other Issues

Table 7.7 summarizes the total potential demand for U.S. DDGS in export markets based on (1) maximum inclusion rates, (2) typical inclusion rates being implemented by U.S. livestock producers (USDA-NASS, 2007), and (3) one-third of the level of corn fed domestically during the 2006/07 marketing year. The table also reports the current level of market penetration realized for U.S. DDGS (the ratio of imports of U.S. DDGS in 2007 to the potential demand estimate). The final column in Table 7.7 reports the average ratio of corn imports from the United States to the amount of corn fed domestically in each region from 2000 to 2006 to illustrate each region's dependence on U.S. feed sources.

Total potential demand across all five small market regions is estimated to be nearly 100 mmt at maximum inclusion rates, 42 mmt at typical inclusion rates, and more than 20 mmt based on domestic corn feeding rates. Given the low likelihood of export development to the FSU discussed previously, total DDGS demand potential excluding countries in the FSU is also reported. It is worth noting that even the most conservative estimate of total potential demand of more than 16 mmt could result in consumption of 40% of the projected 40 mmt of DDGS that will be produced in the United States each year over the next three to seven years (Informa, 2007b; Tokgoz et al., 2007).

Market penetration rates for 2007 vary from 0% in the FSU to nearly 7% in Southeast Asia. The markets that have experienced the greatest penetration rates—Southeast Asia, Central America, and the Caribbean—include countries that are net importers of corn and soybean meal and are at least somewhat dependent on feed sources imported from the United States. Additional export growth in these regions can be expected as livestock producers become more familiar with the feeding value of

Table 7.7. Summary of potential demand of distillers dried grains with solubles (% market penetration) and dependence on U.S. corn imports for domestic feed in small international markets

Region	Potential Consumption at Maximum Inclusion Rates (mt/year)	Potential Consumption at Typical Inclusion Rates (mt/year)	Potential Consumption Based on Corn Fed Domestically (mt/year)	U.S. Corn Imports/Corn Fed Domestically (2000-2006 avg.)
South America[a]	29,507,960 (0.20%)	12,524,711 (0.48%)	3,840,667 (1.56%)	37.2%
Central America and the Caribbean	10,236,059 (1.22%)	4,357,352 (2.87%)	1,806,000 (6.93%)	89.6%
Southeast Asia	15,372,328 (1.99%)	8,451,316 (3.61%)	6,560,333 (4.66%)	2.4%
North Africa	8,750,858 (0.75%)	3,565,962 (1.84%)	4,587,000 (1.43%)	46.5%
Former Soviet Union	31,919,412 -	12,700,550 -	3,503,000 -	<1%
Total	95,786,617 (0.58%)	41,599,890 (1.34%)	20,297,000 (2.74%)	-
Total[b]	63,867,205 (0.87%)	28,899,341 (1.93%)	16,794,000 (3.31%)	-

[a]The South America region excludes Argentina, Brazil, Paraguay, and Uruguay.
[b]Excluding the Former Soviet Union.

DDGS and as increasing commodity prices make DDGS a more competitive and attractive alternative to the more traditional feed sources (corn and soybean meal).

In South America, export markets for U.S. DDGS have been developed in Chile, Colombia, Peru, and, to a more limited extent, Ecuador, where trade deficits prevail for corn at the national level. Export markets for DDGS in the FSU have not yet developed and seem unlikely to develop in the future, given the region's status as a net corn exporter, unless DDGS are priced well below the value of corn and/or large transportation economies develop. Considering that many of the FSU countries are now a part of the European Community, restrictions on food and feeds based on biotechnology regulations are also likely to hinder export market development in the region.

Because DDGS are a relatively new product, there are a number of issues and challenges that must be considered in attempting to develop more markets for DDGS both domestically and internationally. These include product recognition, variation in product quality, a lack of standardized grading and test procedures, transportation methods and costs, and the technical education needed for potential buyers (Shurson, 2005). Since transportation issues are discussed in chapter 9 of this book, they will not be discussed in detail in this chapter. However, the economies of container freight and the resulting implications for the markets in Southeast Asia are worth noting.

DDGS have enjoyed transportation economies in a variety of Asian markets by taking advantage of the recent cost differential between container and bulk freight rates. DDGS, as well as other commodities, have taken advantage of containers carrying imported goods from Asia, which were previously being shipped back empty to their ports of origin. However, demand for containers has increased faster than expansion in capacity, putting limitations on the amount of additional DDGS that can be exported in containers to Asian markets (Informa, 2007b).

Potential buyers need to understand the value of DDGS as a component of their feed ration before widespread adoption of DDGS at higher inclusion rates will take place. The incorporation of DDGS into livestock rations is relatively complex, while international producers often rely on simple methods for ration calculation. The USGC has made significant efforts to educate livestock producers by introducing them to the benefits of incorporating DDGS into their feed rations. These efforts include feeding trial research studies and educational short courses, which have been conducted and offered in a variety of international locations such as Japan, Egypt, the Philippines, Taiwan, China, Guatemala, El Salvador, South Korea, and Chile (USGC, 2008a). Export markets have successfully developed in these countries and continue to grow each year. As producers become more knowledgeable about the value of DDGS, international demand will continue to grow. However, it is crucial to ensure a high-quality product that can be delivered consistently so that international livestock producers have a good first experience with feeding DDGS. Creating quality grades and standardized testing procedures could go a long way in ensuring that import demand for U.S. DDGS will continue to strengthen.

Summary

The rapid increase in ethanol production has led to a proportional increase in the amount of by-products created in the production process. Distillers grains, one of these by-products, have been shown to have significant feeding value as an energy replacement for corn and/or a protein replacement for soybean meal in livestock rations. As ethanol production continues to expand and profit margins continue to tighten, the marketing and sale of these distillers grains will become increasingly important to ensure continued profitability in the industry.

While it has been estimated that all DDGS produced could be consumed domestically by the U.S. livestock industry (Dhuyvetter, Kastens, and Boland, 2005), ethanol producers have become increasingly concerned with export market development to increase the total demand for this by-product. Historically, only a handful of markets have imported a significant amount of U.S. DDGS, including Canada, Mexico, and countries in the European Union. More recently, smaller international markets have been developed and account for an increasingly larger share of total U.S. exports of DDGS each year.

The focus of this chapter has been the potential value and demand for DDGS in some of these "small" international markets, especially those regions that have already begun to import U.S. DDGS. Using data on livestock inventories in each region and inclusion rates from feeding trials and actual feeding practices in the United States, estimates of potential consumption levels of DDGS were derived for each region and compared with actual DDGS import histories. Total potential demand for DDGS was estimated to be more than 95 mmt at maximum inclusion rates, or just over 40 mmt if more typical inclusion rates experienced in the U.S. livestock industry are assumed. Despite impressive export growth over the past two years, actual consumption rates of U.S. DDGS remain well below the total feeding potential (less than 7% market penetration) for all regions considered, implying the potential for significant growth in DDGS exports to these small markets.

Even the most conservative estimates of potential DDGS demand in these small international markets, which were based on domestic feeding rates of corn, total more than 16 mmt per year. Combined with the potential domestic demand for DDGS, which was recently estimated at more than 50 mmt (Dhuyvetter, Kastens, and Boland, 2005), the price of DDGS should easily be supported at or slightly above the level of corn prices into the future as ethanol, and DDGS, production levels continue to increase.

Developing new export markets for DDGS and expanding current ones is challenging because it is a relatively new and seemingly complicated feed source to incorporate into livestock rations. Recent efforts by the USGC have been extremely effective in educating international livestock producers about the feeding benefits of DDGS and should continue to promote rapid growth in existing export markets as well as the development of new export markets in additional countries. Given the demand potential existing both domestically and abroad, DDGS should hold its value as a feed replacement for both energy and protein even as ethanol and DDGS production levels continue to expand to meet mandated biofuel levels. The marketing of DDGS will also be aided by the sharp increase in commodity prices and increasing demand for feed from growing livestock industries, as well as high demand for food use worldwide. The major limitations to continued export growth include the need for more educational efforts; established quality grades and testing standards to ensure a consistent, identifiable, and high-quality product; and logistical concerns related to the interplay between container freight capacity and costly, highly volatile bulk freight rates to guarantee that importers receive shipments in a timely and consistent fashion.

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Chapter 8

Ingredient Value and Cost Calculator for Livestock and Poultry Diets

Garland Dahlke and John D. Lawrence

Editors' note: The Ingredient Value and Cost Calculator for Livestock and Poultry Diets described in this chapter is available at
http://www.matric.iastate.edu/DGCalculator

Livestock producers and feed manufacturers face increased competition for corn from ethanol production and also have more feedstuffs such as distillers grains with solubles available to them. As biofuel producers adopt new methods of extracting value from grain and oilseeds, new feedstuffs are created and remaining co-products are altered. For example, some ethanol producers are extracting, or plan to extract, corn oil through either "front-end" fractionation before fermentation or "back-end" centrifuging after fermentation. Both technologies produce a feedstuff co-product that has different nutritional values and characteristics than conventional distillers grains with solubles. When composition and prices of feedstuffs change, best-cost diets for animal performance also change. Livestock and poultry producers, nutritionists, and feed manufacturers and distributors need to be aware of the evolving nutrient composition of available feedstuffs but should also know how to price them appropriately.

Whether a feedstuff should be used in a diet and whether it increases or decreases the cost of the diet—or more importantly, the cost of producing a unit of animal output—depends on the price of the feedstuff compared to its relative feed value. The relative value of a feedstuff depends on two primary factors: its price and the portfolio of nutrients that it is contributing to the diet compared with what it is replacing.

Nutrients in the diet have physiological requirements, such as minimums, maximums, and their ratio to other nutrients. They also express

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economic principles, and these must be considered. First, nutrients have "value if needed," meaning that additional amounts beyond what an animal requires do not have value and may suppress performance or even be toxic at high levels and thus have a negative value. Second, nutrients also express diminishing marginal returns. A nutrient will have a higher value per unit at low levels in a diet, but it will have less value per unit at higher levels in the diet. Finally, it is important to consider the value of a feedstuff in terms of its opportunity cost, that is, what it is replacing in the diet.

The computer application described in this chapter can be used to determine the economic value of a feedstuff. A feedstuff's economic value is compared to its price to determine if there is an economic advantage in including it in the diet. The economic value also serves as the maximum price a producer or feed manufacture would be willing to pay for the ingredient.

The application begins with the current or representative diet being fed to a particular class of animal. Next, it uses linear programming to solve for the least-cost formulation to achieve the same nutrition as the original diet and thus determines the relative value of including a particular feedstuff. It includes additional characteristics of the feedstuff, such as moisture, shrink, and handling cost, to determine how much a producer would be willing to pay for the feedstuff, or how much a feed manufacturer should charge for it.

The Computer Application

The purpose of this computer application is to help livestock and poultry producers, nutritionists, and feed distributors determine the economic value of a given ingredient. This economic value may be viewed by producers as whether the specified ingredient is a good buy when it is included in a diet, and by distributors as the appropriate price to charge for the ingredient. A brief example of how the representative diet affects the economic value of a feedstuff is given. This is followed by step-by-step instructions for using the computer application.

Pricing is based on value, and value is composed of the quantity of nutrients provided, the rate of utilization in a diet, the handling properties of the feed, and the value of the initial inputs necessary to make the given feed. For example, corn-based distillers grains can be a plentiful source of energy in the form of fat, digestible fiber, protein, energy, sulfur, and phosphorus, depending on the animal species consuming this product. Different processes in the production of corn-based ethanol and co-product extraction can modify the concentrations of the nutrients present and therefore modify the value of the resulting feed. Because distillers grains have more than one nutrient and because some of these nutrients have a window of opportunity, after which they may have a detrimental effect in the diet, an ingredient can only be properly assessed in the context of the diet for which it is to be provided.

Consider the following examples in which distillers dried grains are used in the diet at 5% for broilers, 10% for growing pigs, and 40% for feedlot steers. The three species vary in their ability to utilize distillers dried grains in feeds, and these usage rates are reflected in the respective sample diet formulations presented in Figures 8.1 through 8.3. In the example in Figure 8.1, the 5% utilization rate in the broiler diet is achieved primarily by substituting distillers dried grains for soybean meal and corn. At the pricing structure used in the example, this substitution rate does not favor the use of distillers dried grains in the diet. However, a price reduction of $0.36 per ton for distillers dried grains allows this ingredient to be included in the diet.

An increase in the use rate changes this scenario. As noted, the grower pig diet can utilize distillers dried grains at a rate of 10% of dietary dry matter. As shown in Figure 8.2, at the 10% rate of use, the distillers dried grains replace soybean meal, animal fat, corn, and some minerals and become more valuable in the grower pig diet, with a $12.78-per-ton advantage. Finally, the growing steer is capable of utilizing distillers dried grains at 40% of the overall dietary dry matter. This diet is a little different from that of the pig and broiler since other protein sources can be used to balance the diet. These protein sources, which are generally more cost-effective, change the extent to which we may value the product, but even in this case the higher inclusion rate has a price advantage of up to $16.48 per ton in the use of distillers dried grains (see Figure 8.3).

By evaluating an ingredient in the context of a given diet, we address the nutrient density and nutrient quantity simultaneously. When the diet is then

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Ingredient Value & Cost Calculator for Livestock & Poultry Diets

Iowa Beef Center

Ration Name: **Poultry 5% DDG**

Feedstuff Specifications

Ingredient Library Number	Name	Batch Wt. As-Fed	Scale Wt. As-Fed	Fixed % of Diet DM	Percent of Diet DM	Percent of Diet As-Fed	Utilization Price
17	Distillers dried grains	100.0	100.0	5.0%	5.0%	4.8%	
47	Corn, dry	1396.4	1496.4	69.8%	69.8%	71.1%	
26	Soybean meal 44	373.8	1870.2	18.7%	18.7%	18.4%	
59	Animal fat	93.7	1963.9	4.7%	4.7%	4.1%	
60	Vegetable oil						$235.71
64	Calcium carbonate	27.6	1991.5	1.4%	1.4%	1.3%	
78	Salt	5.2	1996.7	0.3%	0.3%	0.2%	
66	Dicalcium phosphate	3.4	2000.1	0.2%	0.2%	0.2%	
		2000.0		100.0%	100.0%	100.0%	

Diet Specifications

	Current Diet Specifications	Results Specifications
$/Ton	239.35	239.70
TDN %		91.33
NE m Mcal/lb		1.03
NE g Mcal/lb		0.72
ME Mcal/lb	1.50	1.56
Cr.Pro %	15.50	17.40
DIP %		58.62
Lysine %	0.70	0.75
Methionine %		0.27
Threonine %		0.58
Tryptophan %		0.17
NDF %		9.63
NFC %		57.27
Fat %		4.06
Calcium %	0.65	0.66
Phosphorus %	0.39	0.45
Sulfur %		0.20
Sodium%	0.15	0.16

Feed Price Evaluation

Ingredient Library Number	Name	Use Price per unit	Use Price per lb	Purchase Price $ per unit	Purchase Price lb / unit	Storage %	Handling %	Markup %
17	Distillers dried grains	$224.490	$0.112	$200.000	2000.00		2.0%	10.0%

Maximum Purchase Price per Unit	$199.68	
Maximum Use Price per Unit	$224.14	not a good buy currently

Figure 8.1. Summary printout for a broiler diet using distillers dried grains at a 5% inclusion rate

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Iowa Beef Center

Ingredient Value & Cost Calculator for Livestock & Poultry Diets

Ration Name: **Pig 10% DDG**

Feedstuff Specifications

Ingredient Library Number	Name	Batch Wt. As-Fed	Scale Wt. As-Fed	Fixed % of Diet DM	Percent of Diet DM	Percent of Diet As-Fed	Utilization Price
17	Distillers dried grains	200.0	200.0	10.0%	10.0%	9.6%	
47	Corn, dry	1392.8	1592.8	69.6%	69.6%	70.8%	
26	Soybean meal 44	329.4	1922.2	16.5%	16.5%	16.2%	
59	Animal fat	40.0	1962.2	2.0%	2.0%	1.7%	
60	Vegetable oil						$235.71
64	Calcium carbonate	20.0	1982.2	1.0%	1.0%	0.9%	
78	Salt	16.0	1998.2	0.8%	0.8%	0.7%	
66	Dicalcium phosphate	2.0	2000.2	0.1%	0.1%	0.1%	
		2000.0		100.0%	100.0%	100.0%	

Diet Specifications

	Current Diet Specifications	Results Specifications
$/Ton	248.05	235.20
TDN %		89.04
NE m Mcal/lb		1.00
NE g Mcal/lb		0.69
ME Mcal/lb	1.50	1.50
Cr.Pro %	14.00	17.82 high
DIP %		59.20
Lysine %	0.70	0.73
Methionine %		0.28
Threonine %		0.59
Tryptophan %	0.14	0.17 high
NDF %		11.28
NFC %		57.31
Fat %		4.49
Calcium %	0.50	0.50
Phosphorus %	0.45	0.46
Sulfur %		0.23
Sodium%	0.35	0.39

Feed Price Evaluation

Ingredient Library Number	Name	Use Price per unit	Use Price per lb	Purchase Price $ per unit	Purchase Price lb / unit	Storage %	Handling %	Markup %
17	Distillers dried grains	$224.490	$0.112	$200.000	2000.00		2.0%	10.0%

Maximum Purchase Price per Unit $211.45

Maximum Use Price per Unit $237.34 good opportunity to use at current price

Figure 8.2. Summary printout for a pig diet using distillers dried grains at a 10% inclusion rate

11/12/2008

Iowa Beef Center

Ingredient Value & Cost Calculator for Livestock & Poultry Diets

Ration Name: **Beef 40% DG**

Feedstuff Specifications

Ingredient Library Number	Name	Batch Wt. As-Fed	Scale Wt. As-Fed	Fixed % of Diet DM	Percent of Diet DM	Percent of Diet As-Fed	Utilization Price
17	Distillers dried grains	800.0	800.0	40.0%	40.0%	38.7%	
47	Corn, dry	870.0	1670.0	43.5%	43.5%	44.5%	
38	40-20 dry						$205.05
64	Calcium carbonate	8.0	1678.0	0.4%	0.4%	0.4%	
78	Salt	2.0	1680.0	0.1%	0.1%	0.1%	
66	Dicalcium phosphate						
106	Alfalfa, late bloom	320.0	2000.0	16.0%	16.0%	16.4%	
		2000.0		100.0%	100.0%	100.0%	

Diet Specifications

	Current Diet Specifications	Results Specifications
$/Ton	210.00	193.52
TDN %		83.95
NE m Mcal/lb		0.92
NE g Mcal/lb	0.62	0.63
ME Mcal/lb		1.34
Cr.Pro %	13.00	18.75 high
DIP %		57.77
Lysine %		0.52
Methionine %		0.29
Threonine %		0.67
Tryptophan %		0.17
NDF %	15.00	26.72 high
NFC %		41.39
Fat %		6.27
Calcium %	0.45	0.47
Phosphorus %	0.20	0.52 high
Sulfur %		0.39
Sodium%	0.10	0.17 high

Feed Price Evaluation

Ingredient Library Number	Name	Use Price per unit	Use Price per lb	Purchase Price $ per unit	Purchase Price lb / unit	Storage %	Handling %	Markup %
17	Distillers dried grains	$224.490	$0.112	$200.000	2000.00		2.0%	10.0%

Maximum Purchase Price per Unit $214.69
Maximum Use Price per Unit $240.97 good opportunity to use at current price

Figure 8.3. Summary printout for a beef diet using distillers dried grains at a 40% inclusion rate

compared with a nutrient-equivalent diet, we can arrive at an appropriate pricing structure that takes into account current market demands and supplies.

How to Use the Ingredient Value and Cost Calculator

Computer Software Requirements

a. Microsoft Excel must be installed on your computer to run this program.

b. Microsoft Excel security levels must be set to low or medium. If needed, use Excel Help to determine how to set the security level.
   - To access the Excel help menu, select the F1 button while the Excel program is running and search for security level or Trust Center.
   - Enable macros if asked.

See the Definitions section at the end of these instructions for an explanation of the terms used in the Ingredient Value and Cost Calculator.

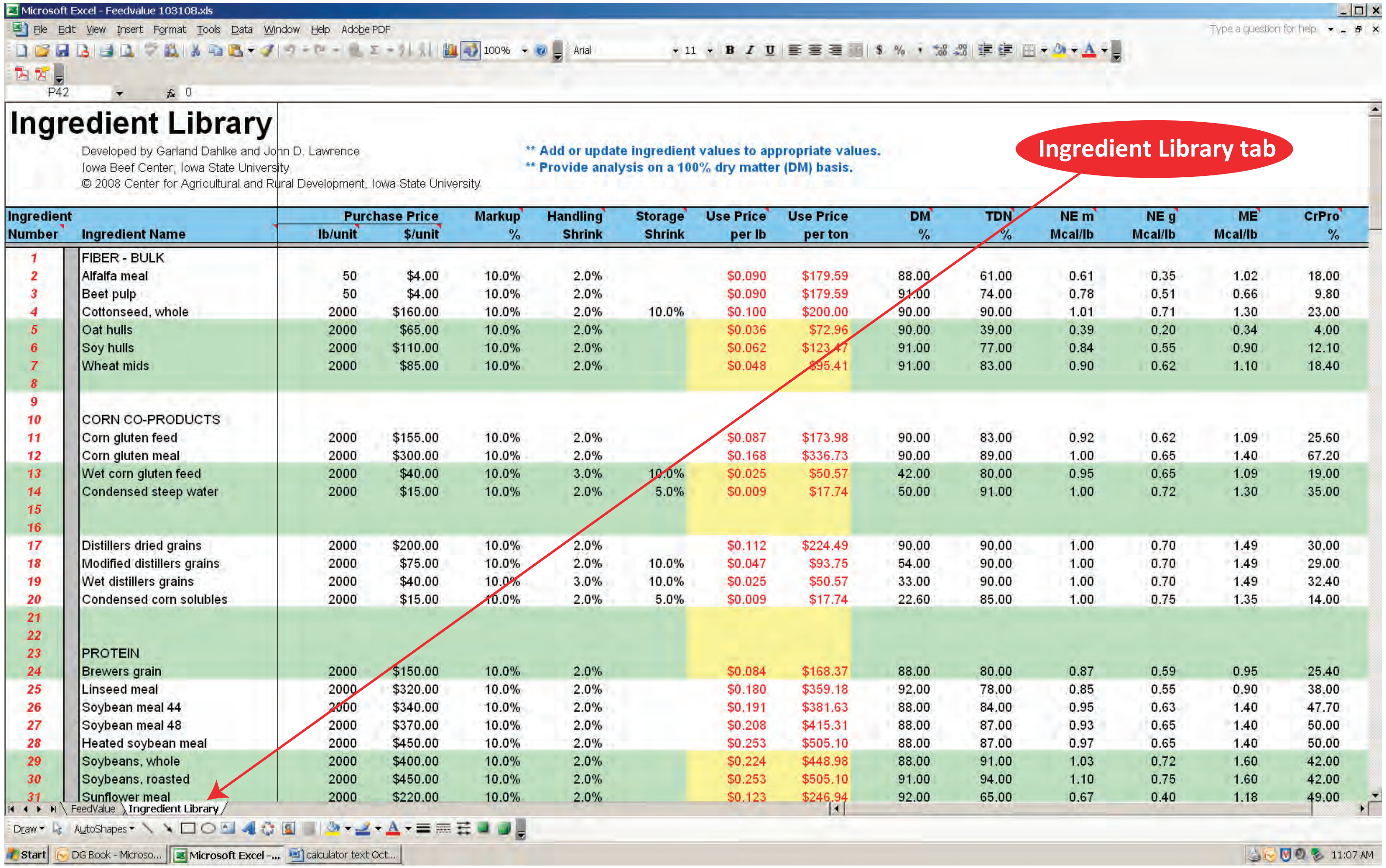
Step 1. Enter ingredient value and cost information into the Ingredient Library.

a. Open the Ingredient Value and Cost Calculator in Microsoft Excel and select the "Ingredient Library" tab at the bottom of the Excel page to open the Ingredient Library worksheet (see Figure 8.4). Modify ingredient values as needed.

   Note: When entering or changing nutrient content, the values entered should be appropriate for the species being fed. This means that available levels of the nutrient should be entered, rather than total levels. For example, inputs such as DIP (degradable intake protein) are specific for ruminants. All ingredient nutrient contents are to be indicated on a 100% dry matter basis.

b. To update values for existing ingredients, simply change the values as needed in each column.

c. To enter a new ingredient, use any open row in the library, enter the ingredient name, number of pounds per unit (for example, 50



Ingredient Number	Ingredient Name	Purchase Price lb/unit	Purchase Price $/unit	Markup %	Handling Shrink	Storage Shrink	Use Price per lb	Use Price per ton	DM %	TDN %	NE m Mcal/lb	NE g Mcal/lb	ME Mcal/lb	CrPro %
1	FIBER - BULK													
2	Alfalfa meal	50	$4.00	10.0%	2.0%		$0.090	$179.59	88.00	61.00	0.61	0.35	1.02	18.00
3	Beet pulp	50	$4.00	10.0%	2.0%		$0.090	$179.59	91.00	74.00	0.78	0.51	0.66	9.80
4	Cottonseed, whole	2000	$160.00	10.0%	2.0%	10.0%	$0.100	$200.00	90.00	90.00	1.01	0.71	1.30	23.00
5	Oat hulls	2000	$65.00	10.0%	2.0%		$0.036	$72.96	90.00	39.00	0.39	0.20	0.34	4.00
6	Soy hulls	2000	$110.00	10.0%	2.0%		$0.062	$123.47	91.00	77.00	0.84	0.55	0.90	12.10
7	Wheat mids	2000	$85.00	10.0%	2.0%		$0.048	$95.41	91.00	83.00	0.90	0.62	1.10	18.40
8														
9														
10	CORN CO-PRODUCTS													
11	Corn gluten feed	2000	$155.00	10.0%	2.0%		$0.087	$173.98	90.00	83.00	0.92	0.62	1.09	25.60
12	Corn gluten meal	2000	$300.00	10.0%	2.0%		$0.168	$336.73	90.00	89.00	1.00	0.65	1.40	67.20
13	Wet corn gluten feed	2000	$40.00	10.0%	3.0%	10.0%	$0.025	$50.57	42.00	80.00	0.95	0.65	1.09	19.00
14	Condensed steep water	2000	$15.00	10.0%	2.0%	5.0%	$0.009	$17.74	50.00	91.00	1.00	0.72	1.30	35.00
15														
16														
17	Distillers dried grains	2000	$200.00	10.0%	2.0%		$0.112	$224.49	90.00	90.00	1.00	0.70	1.49	30.00
18	Modified distillers grains	2000	$75.00	10.0%	2.0%	10.0%	$0.047	$93.75	54.00	90.00	1.00	0.70	1.49	29.00
19	Wet distillers grains	2000	$40.00	10.0%	3.0%	10.0%	$0.025	$50.57	33.00	90.00	1.00	0.70	1.49	32.40
20	Condensed corn solubles	2000	$15.00	10.0%	2.0%	5.0%	$0.009	$17.74	22.60	85.00	1.00	0.75	1.35	14.00
21														
22														
23	PROTEIN													
24	Brewers grain	2000	$150.00	10.0%	2.0%		$0.084	$168.37	88.00	80.00	0.87	0.59	0.95	25.40
25	Linseed meal	2000	$320.00	10.0%	2.0%		$0.180	$359.18	92.00	78.00	0.85	0.55	0.90	38.00
26	Soybean meal 44	2000	$340.00	10.0%	2.0%		$0.191	$381.63	88.00	84.00	0.95	0.63	1.40	47.70
27	Soybean meal 48	2000	$370.00	10.0%	2.0%		$0.208	$415.31	88.00	87.00	0.93	0.65	1.40	50.00
28	Heated soybean meal	2000	$450.00	10.0%	2.0%		$0.253	$505.10	88.00	87.00	0.97	0.65	1.40	50.00
29	Soybeans, whole	2000	$400.00	10.0%	2.0%		$0.224	$448.98	88.00	91.00	1.03	0.72	1.60	42.00
30	Soybeans, roasted	2000	$450.00	10.0%	2.0%		$0.253	$505.10	91.00	94.00	1.10	0.75	1.60	42.00
31	Sunflower meal	2000	$220.00	10.0%	2.0%		$0.123	$246.94	92.00	65.00	0.67	0.40	1.18	49.00

Figure 8.4. Ingredient Library page of the calculator

for a 50-pound bag or 2,000 for a ton), and purchase price. If applicable, enter the percent margin markup and estimates of percent handling and storage shrink. If these values are not applicable, the columns can be left blank. The program will automatically use these values to calculate the use price. For the distributor, the use price is the price per pound that must be charged on the outgoing ingredient to satisfy shrinkage losses and provide the necessary margin to maintain the business. For the producer, the use price is the price per pound that will be paid for the ingredient.

d. When finished, select "Save" from your Excel menu.

Note that the pre-set numbers in the Ingredient Number column are used to identify individual ingredients in the following steps.

Step 2. Enter the feedstuff specifications of the diet to be calculated.

a. Select the "FeedValue" tab at the bottom of the Excel page to open the Calculator page (see Figure 8.5).

b. In the *Feedstuffs Specifications* box, enter an Ingredient Library Number under the column labeled *Number* for each ingredient being considered for use in the diet. The corresponding ingredient name will automatically appear in the column labeled *Name* (see Figure 8.6).

c. Indicate a fixed percentage of dietary dry matter, as desired, to hold the inclusion rate constant for any of the ingredients under the column labeled *Fixed % of Diet DM*. As shown in Figure 8.6, the user has specified 40% distillers dried grains, which will force a 40% inclusion rate when the ration is balanced. The program will calculate percentages for the other ingredients.

Step 3. Enter the diet specifications.

a. In the Diet Specifications box, under the column labeled Current Diet Specifications, indicate the price per ton of the diet currently being fed (or the diet being used for comparison). By indicating this price, a basis can be established for arriving at the price for the new diet you have specified in the Feedstuffs Specifications box (see Figure 8.7).

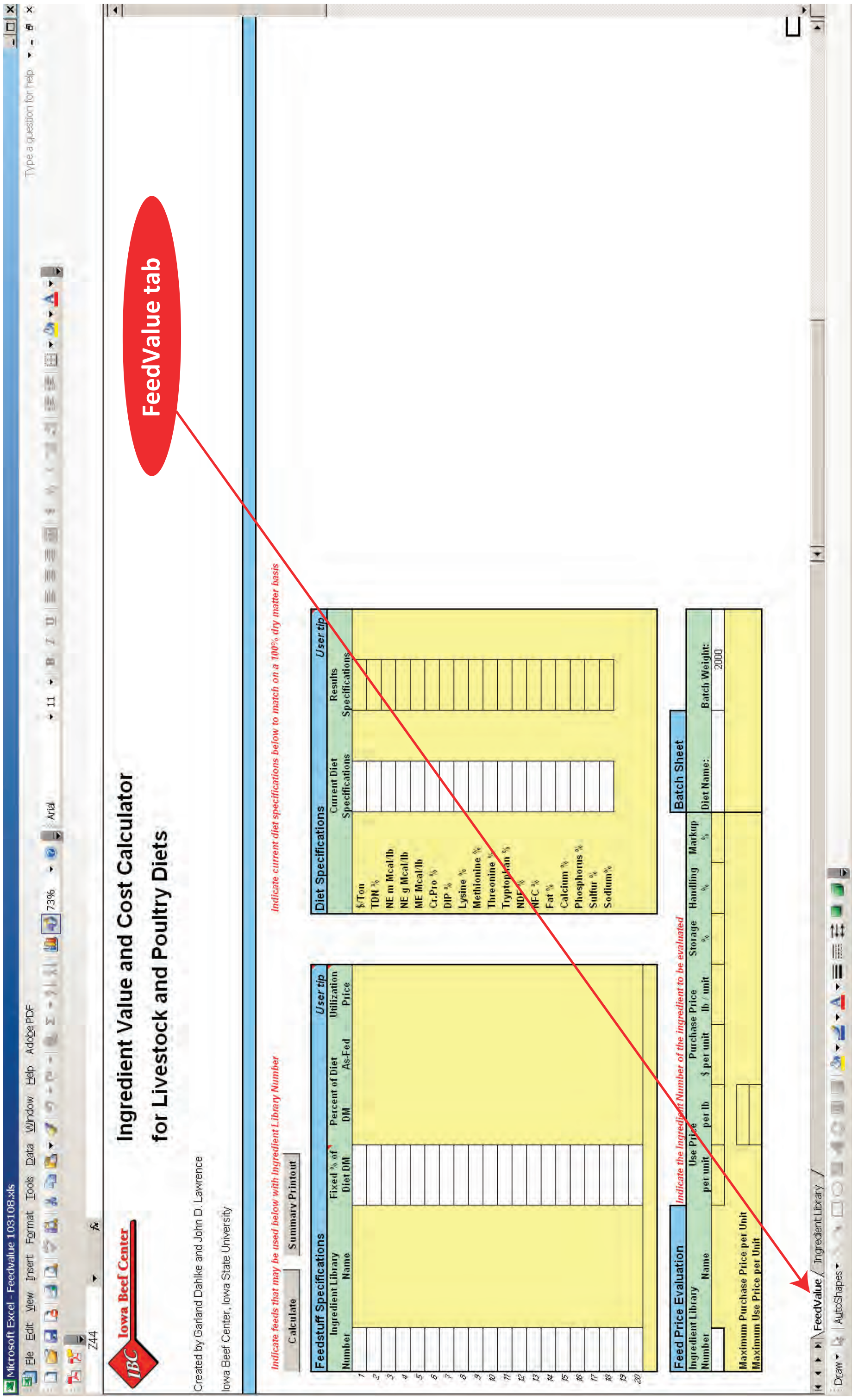


Figure 8.5. FeedValue page of the calculator

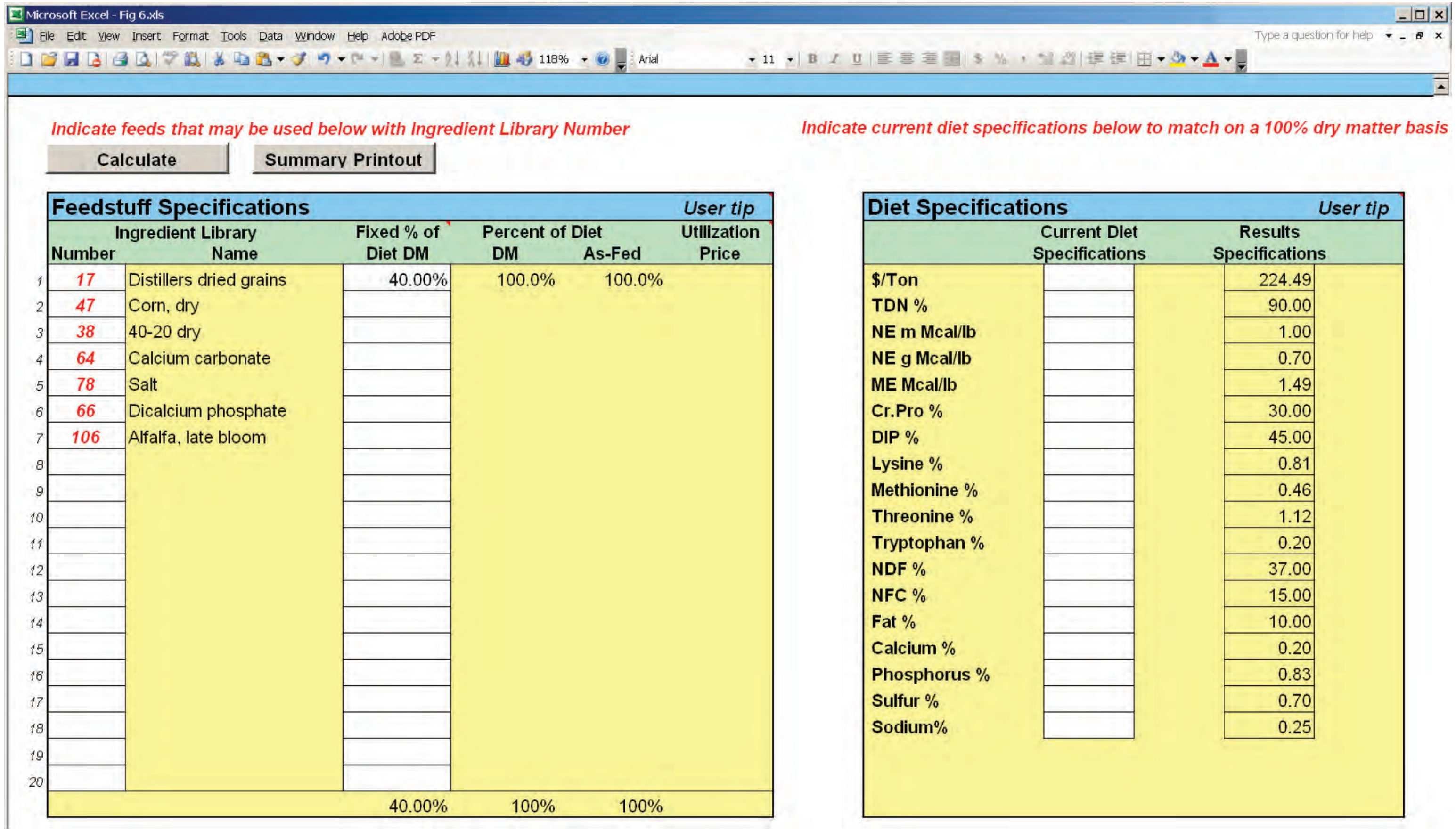
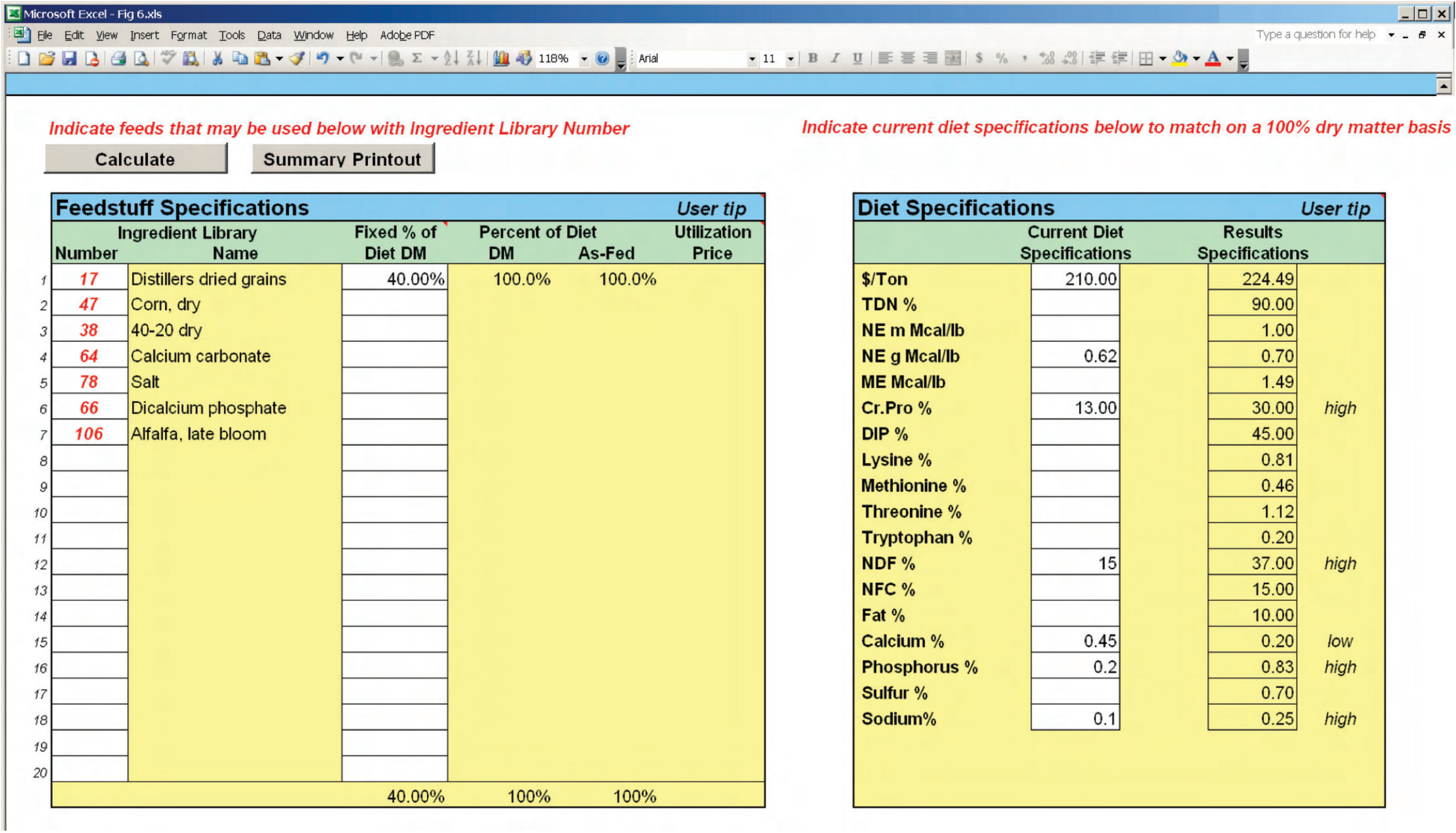


Figure 8.6. Feedstuff specifications for desired ingredients in a ration using 40% distillers dried grains



Feedstuff Specifications *User tip*

	Ingredient Library Number	Ingredient Library Name	Fixed % of Diet DM	Percent of Diet DM	Percent of Diet As-Fed	Utilization Price
1	17	Distillers dried grains	40.00%	100.0%	100.0%	
2	47	Corn, dry				
3	38	40-20 dry				
4	64	Calcium carbonate				
5	78	Salt				
6	66	Dicalcium phosphate				
7	106	Alfalfa, late bloom				
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
			40.00%	100%	100%	

Diet Specifications *User tip*

	Current Diet Specifications	Results Specifications	
$/Ton	210.00	224.49	
TDN %		90.00	
NE m Mcal/lb		1.00	
NE g Mcal/lb	0.62	0.70	
ME Mcal/lb		1.49	
Cr.Pro %	13.00	30.00	high
DIP %		45.00	
Lysine %		0.81	
Methionine %		0.46	
Threonine %		1.12	
Tryptophan %		0.20	
NDF %	15	37.00	high
NFC %		15.00	
Fat %		10.00	
Calcium %	0.45	0.20	low
Phosphorus %	0.2	0.83	high
Sulfur %		0.70	
Sodium%	0.1	0.25	high

Figure 8.7. Diet specifications for current diet priced at $210 per ton

b. Also in the *Diet Specifications* box, enter the nutrient specifications of the diet currently being fed (or the diet being used for comparison). Only the diet specifications that you wish to indicate need to be provided here; the rest can be left blank (see Figure 8.7).

Step 4. Calculate the ingredient value and cost of the new diet.

a. Select the "Calculate" button, located above the *Feedstuff Specifications* box. (If nothing happens, evaluate your macro security or Trust Center settings because they are preventing the program from functioning.)

b. Once the "Calculate" button has been selected, the program will formulate the diet as closely as possible to your specifications in a "least-cost" manner. The results for the example are shown under the column labeled *Results Specifications* (see Figure 8.8).

c. The calculator will also indicate the utilization price of ingredients, or the price to which the ingredient must be reduced before the program will consider using it in the diet formulation. In this example, 40-20 dry must fall below $205.05 (see Figure 8.8).

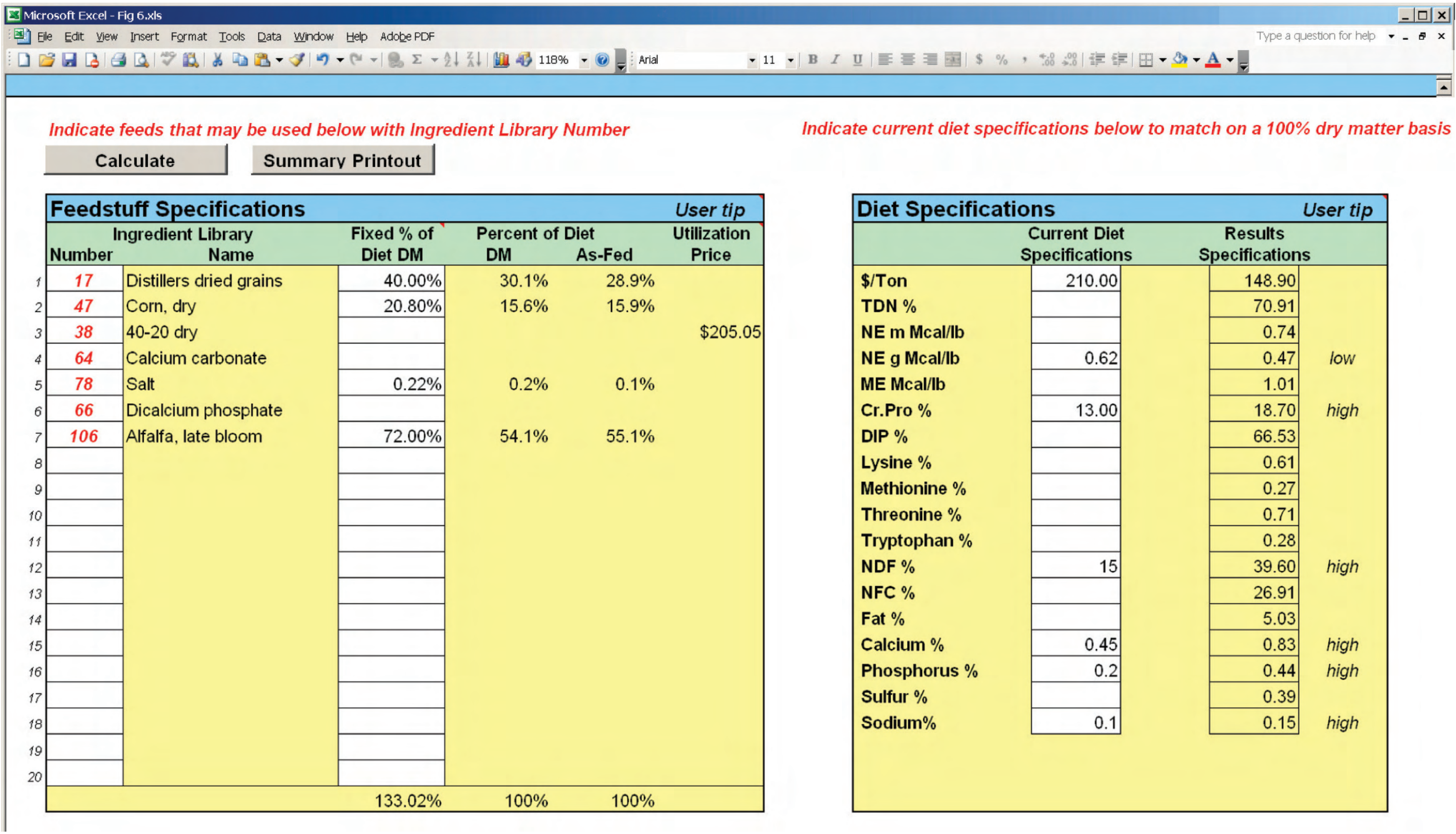
d. If the program cannot find a suitable solution, you may need to specify other ingredients or manually adjust the fixed % of diet dry matter values to arrive at a reasonable cost and nutrient content. In this example, the user adjusts the fixed % of diet dry matter for ingredients rather than specifying new ingredients (see Figure 8.9).

Note that if a nutrient level is not met, a "low" flag will appear next to the results for that nutrient in the *Diet Specifications* box. If the nutrient content exceeds the original specification by more than 15%, a "high" flag will appear next to the results for that nutrient.

Step 5. Evaluate the price of a selected ingredient.

a. Scroll down to the *Ingredient Price Evaluation* box and indicate the ingredient library number of the ingredient you are interested in pricing from the diet balanced in Step 4 (see Figure 8.10).

b. In this example, the selection is distillers dried grains (see Figure 8.10). The *Ingredient Price Evaluation* results are based on the proper-


Microsoft Excel - Fig 6.xls

Indicate feeds that may be used below with Ingredient Library Number

Indicate current diet specifications below to match on a 100% dry matter basis

Calculate

Summary Printout

Feedstuff Specifications *User tip*

	Number	Ingredient Library Name	Fixed % of Diet DM	Percent of Diet DM	Percent of Diet As-Fed	Utilization Price
1	17	Distillers dried grains	40.00%	30.1%	28.9%	
2	47	Corn, dry	20.80%	15.6%	15.9%	
3	38	40-20 dry				$205.05
4	64	Calcium carbonate				
5	78	Salt	0.22%	0.2%	0.1%	
6	66	Dicalcium phosphate				
7	106	Alfalfa, late bloom	72.00%	54.1%	55.1%	
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
			133.02%	100%	100%	

Diet Specifications *User tip*

	Current Diet Specifications	Results Specifications	
$/Ton	210.00	148.90	
TDN %		70.91	
NE m Mcal/lb		0.74	
NE g Mcal/lb	0.62	0.47	*low*
ME Mcal/lb		1.01	
Cr.Pro %	13.00	18.70	*high*
DIP %		66.53	
Lysine %		0.61	
Methionine %		0.27	
Threonine %		0.71	
Tryptophan %		0.28	
NDF %	15	39.60	*high*
NFC %		26.91	
Fat %		5.03	
Calcium %	0.45	0.83	*high*
Phosphorus %	0.2	0.44	*high*
Sulfur %		0.39	
Sodium%	0.1	0.15	*high*

Figure 8.8. Initial calculation based on values entered into the program

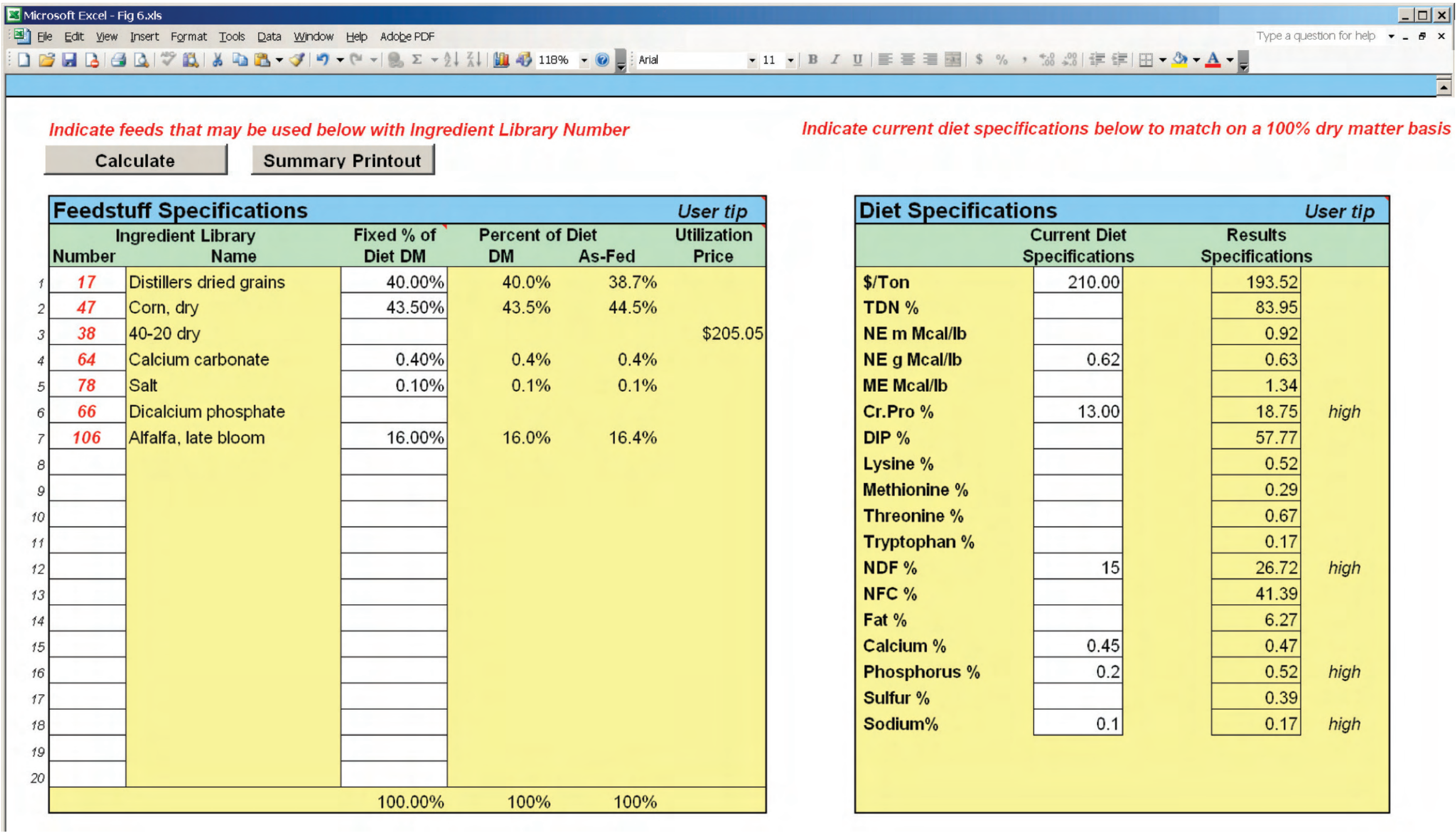


Figure 8.9. Second calculation after manually adjusting feedstuff specifications

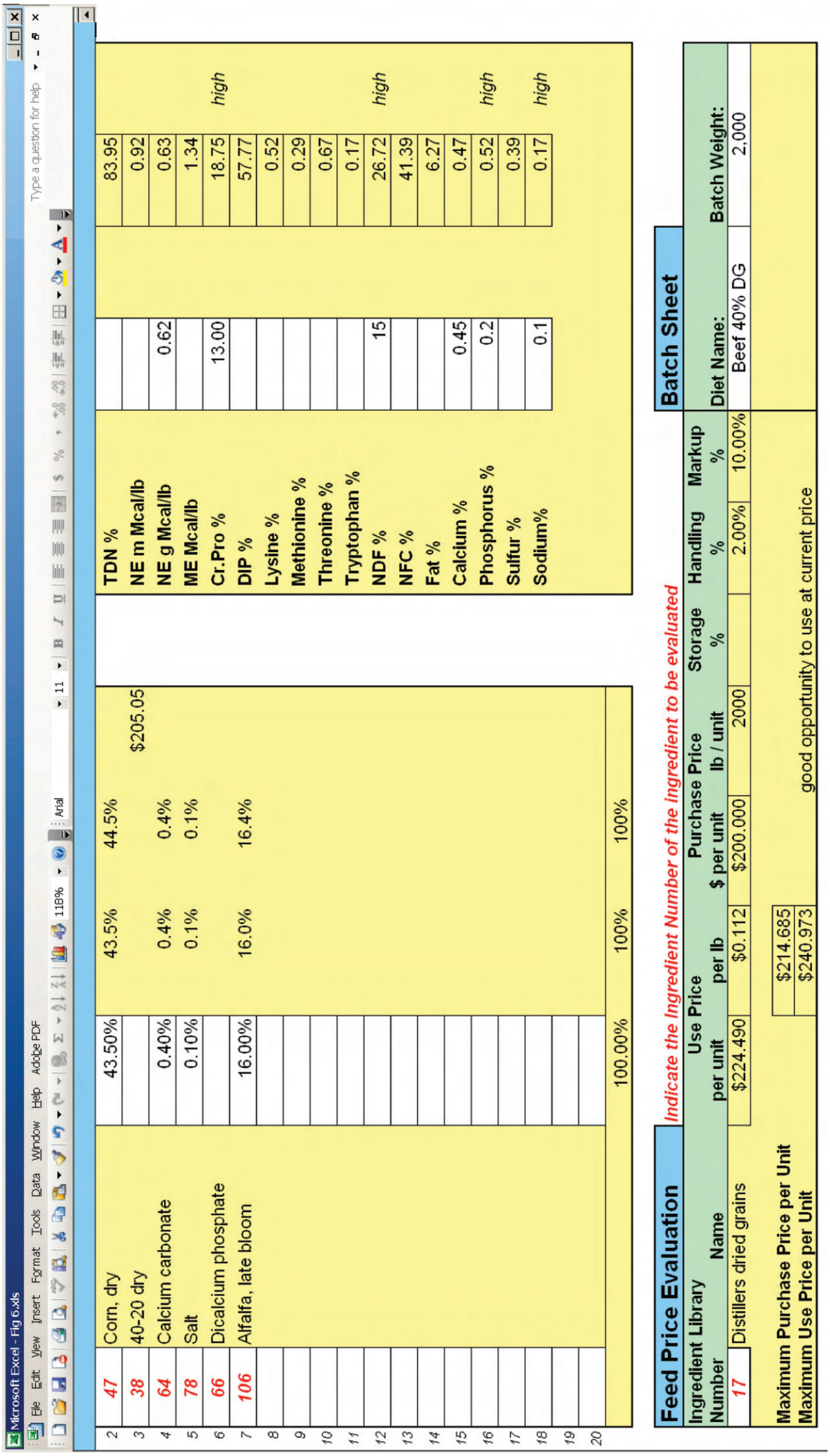


Figure 8.10. Feed price evaluation for distillers dried grains with diet name and batch weight entered

ties and price of distillers dried grains relative to the comparison diet. The calculator holds the prices of all other ingredients constant in this evaluation, and the pricing results of the selected ingredient are given in terms of a maximum purchase price per unit and a maximum use price per unit. A diet name and batch weight can be specified in the *Batch Sheet* box (optional). The batch weight defaults to 2,000 lb.

Step 6. Generate a Summary Printout.

Generate a summary printout by selecting the "Summary Printout" button, located next to the "Calculate" button at the top of the Calculator page. (If the "Summary Printout" button does not work, you will need to re-evaluate your macro security or Trust Center settings because they are preventing the program from functioning.) The summary printout for the example used in Steps 1 through 6 is shown in Figure 8.11. If a batch size was indicated in Step 5, the summary printout will show the weight of each ingredient to be included when the feed is mixed.

Definitions

Batch Weight – The weight of a batch of feed for the diet being calculated (optional). If desired, this weight is entered in the *Batch Sheet* box and will appear on the summary printout. The batch weight defaults to 2,000 lb.

Current Diet Specifications – The nutrient specifications that must be met by the diet being calculated in the *Feedstuffs Specifications* box. Only values for the pertinent nutrients need to be entered.

Diet Name – The name of the diet being calculated (optional). If desired, this name is entered in the *Batch Sheet* box and will appear on the summary printout.

Fixed % of Diet DM – Percentage of each ingredient to be used in the diet on a dry matter basis. The user can enter a percentage for any ingredient; the remainder will be calculated.

High/Low Flag – A "low" flag appears next to the nutrient(s) that is deficient if the desired diet specifications are not met by the diet entered in

11/12/2008

Iowa Beef Center

Ingredient Value & Cost Calculator for Livestock & Poultry Diets

Ration Name: **Beef 40% DG**

Feedstuff Specifications

Ingredient Library Number	Name	Batch Wt. As-Fed	Scale Wt. As-Fed	Fixed % of Diet DM	Percent of Diet DM	Percent of Diet As-Fed	Utilization Price
17	Distillers dried grains	800.0	800.0	40.0%	40.0%	38.7%	
47	Corn, dry	870.0	1670.0	43.5%	43.5%	44.5%	
38	40-20 dry						$205.05
64	Calcium carbonate	8.0	1678.0	0.4%	0.4%	0.4%	
78	Salt	2.0	1680.0	0.1%	0.1%	0.1%	
66	Dicalcium phosphate						
106	Alfalfa, late bloom	320.0	2000.0	16.0%	16.0%	16.4%	
		2000.0		100.0%	100.0%	100.0%	

Diet Specifications

	Current Diet Specifications	Results Specifications
$/Ton	210.00	193.52
TDN %		83.95
NE m Mcal/lb		0.92
NE g Mcal/lb	0.62	0.63
ME Mcal/lb		1.34
Cr.Pro %	13.00	18.75 high
DIP %		57.77
Lysine %		0.52
Methionine %		0.29
Threonine %		0.67
Tryptophan %		0.17
NDF %	15.00	26.72 high
NFC %		41.39
Fat %		6.27
Calcium %	0.45	0.47
Phosphorus %	0.20	0.52 high
Sulfur %		0.39
Sodium%	0.10	0.17 high

Feed Price Evaluation

Ingredient Library Number	Name	Use Price per unit	Use Price per lb	Purchase Price $ per unit	Purchase Price lb / unit	Storage %	Handling %	Markup %
17	Distillers dried grains	$224.490	$0.112	$200.000	2000.00		2.0%	10.0%

Maximum Purchase Price per Unit	$214.69	
Maximum Use Price per Unit	$240.97	good opportunity to use at current price

Figure 8.11. Summary printout for example used in Steps 1 through 6

the *Feedstuff Specifications* box. A "high" flag appears when the resulting diet exceeds a given nutrient specification by more than 15%. The user can decide whether deficiencies or excesses will present a problem.

Ingredient Library Name – The name assigned to each ingredient in the Ingredient Library. The ingredient library name will automatically appear when an ingredient library number is entered into the calculator.

Ingredient Library Number – The pre-set number assigned to an ingredient in the Ingredient Library. This number is entered for each ingredient that will be factored into the calculated diet, as selected by the user from the first column of the Ingredient Library. The ingredient library name will automatically appear when the corresponding ingredient library number is entered into the calculator.

Maximum Purchase Price per Unit – The maximum price to be paid for an ingredient in the *Feed Price Evaluation* box based on the utilization rate in the diet and the pricing of the other ingredients.

Maximum Use Price per Unit – The maximum price per unit that can be charged for the feed ingredient when it is included in the diet entered in the *Feedstuff Specifications* box. This price is a factor of the initial purchase price after adjusting for storage shrink, handling shrink, and margin requirements (as entered in the Ingredient Library). If no adjustments are made in these three categories, the maximum purchase price per unit and the maximum use price per unit will be the same.

Example: Assume that wet distillers grains can be delivered to a custom beef feedlot at $40.00 per ton. The feed is stored on a slab and used up in two weeks. Based on previous research data, there is 3% shrinkage in the quantity purchased compared with the quantity delivered. This shrink occurs from loading, delivery, and unloading. Then, based on storage time, an additional 10% shrinkage can be observed when measuring the weight delivered to the feedlot versus the weight delivered to the pens of cattle. Therefore, the use price must cover this 13% loss in product up front in the billing procedure by increasing the use price by 13% above purchase price. A margin can then be added to this price to cover the costs of providing this ingredient in the ration. If we set the margin at 10% for this example, the maximum use price per unit totals $50.57 per ton fed. Because not all feeds have the same handling shrink, storage shrink, and margin requirements, the user can enter these values in the Ingredient Library for each individual ingredient. The purchase price and use price are then evaluated in the context of the ration provided to arrive at the maximum purchase and maximum use prices. If these maximums are less than the current pricing, the calculator indicates that the product is not a good buy.

Percent of Diet As-Fed – Percentage of the diet each ingredient contributes on an as-fed basis. The Batch Sheet used for mixing feed ingredients is based on these percentages, multiplied by the desired batch size.

Percent of Diet DM – Percentage that each ingredient contributes to the diet on a dry matter basis. These values should match the amounts in the column labeled *Fixed % of Diet DM* once the diet is complete.

Results Specifications – The nutrient specifications for the diet entered in the *Feedstuff Specifications* box.

Use Price – For the distributor, the use price is the price per pound that must be charged on the outgoing ingredient to satisfy shrinkage losses and provide the necessary margin to maintain the business. For the producer, the use price is the price per pound that will be paid for the ingredient plus the cost of shrinkage.

Utilization Price – The price to which a given feed ingredient must be reduced before the program will consider using it in the diet formulation.

Chapter 9

Transportation and Logistics in Distillers Grain Markets

Frank J. Dooley and Bobby J. Martens

In 2008, ethanol production continues its rapid expansion in capacity that began in 2002. The U.S. Department of Energy forecasts that 2009 ethanol production will reach 11 billion gallons, up from 2.1 billion gallons in 2002 (Energy Information Administration, 2008). Plant-level data, as tracked by *Ethanol Producer Magazine* (2008), suggest that industry capacity may reach as much as 13.2 billion gallons by the end of 2009. Further expansion is possible because the Renewable Fuels Standards of the Energy Independence and Security Act of 2007 mandates the use of 15 billion gallons of starch-based ethanol (largely to come from corn) by 2015. As a co-product of ethanol, distillers grain production tracks the explosive growth in ethanol capacity.

From 2004 to 2007, 88% of the U.S. corn production and 97% of ethanol production capacity, as well as 40% of U.S. beef and dairy production, were found in the Corn Belt (Table 9.1). In the nascent days of the U.S. ethanol industry, most of the distillers grains produced were consumed by the local feed market. Thus, distillers grain transportation movements were heavily dependent on trucks.

With the continued expansion of the U.S. ethanol industry, ethanol plants can now be described as origin mills because their production capacity is heavily concentrated in the same geographic area as the corn. The local market for distillers grains in the Corn Belt has been saturated and now requires that distillers grains be shipped to other regions of the United States or exported. Serving more distant markets leads ethanol producers to reconsider their shipping alternatives to include rail, containers, or barge. Transportation has become the third-highest ethanol plant expense, after feedstock

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Table 9.1. Distribution of corn, ethanol, livestock production, by census region, 2004 to 2007

Census Region	States	Corn Production[a]	Ethanol Production[b]	Beef and Dairy[a]	Hogs and Poultry[a]
			Percent		
1	CT, MA, ME, NH, RI, VT	0.0	0.0	0.5	0.0
2	NJ, NY, PA	1.7	0.0	3.0	1.9
3	IL, IN, MI, OH, WI	34.4	24.2	8.1	2.2
4	IA, KS, MN, MO, ND, NE, SD	53.3	72.8	32.3	5.1
5	DE, FL, GA, MD, NC, SC, VA, WV	2.4	0.0	6.1	36.9
6	AL, KY, MS, TN	2.9	0.7	6.5	25.2
7	AR, LA, OK, TX	3.3	0.2	22.8	24.6
8	AZ, CO, ID, MT, NM, NV, UT, WY	1.5	1.2	12.9	0.1
9	CA, OR, WA	0.4	0.9	7.7	3.9
	USA	100.0	100.0	100.0	100.0

Sources: [a]USDA-ERS, 2008; [b]*Ethanol Producer Magazine*, 2008.

and energy costs, further emphasizing the economic importance of finding low-cost transportation alternatives (Denicoff, 2007).

Transportation concerns for distillers grains can be characterized as being at either the plant or industry level. Examples of plant- or micro-level transportation issues include concerns about product shipping characteristics, equipment availability, rail car ownership, and rates. Industry- or macro-level issues center on modal share (or how much traffic is hauled by the different modes of truck, rail, and barge) as the geographic markets for distillers grains expand. In this chapter, plant-level issues will be addressed, and then transportation requirements for U.S. distillers grains will be estimated by identifying sources of production and points of consumption for distillers grains. In turn, inferences will be drawn about how distillers grains will be shipped, as well as when specific markets will be saturated.

Shipping Characteristics of Distillers Grains

Attributes such as moisture content, shelf life, and product density are key characteristics related to product shipment. As part of the dry-grind process, distillers grains are produced with a dry matter content of 30% to 35%, or conversely, a moisture content of 65% to 70%. This high-moisture-content product is known as wet distillers grains with solubles (WDGS), and it accounted for 37% of the total distillers grains marketed from ethanol plants in 2006 (Wu, 2008). With a shelf life of less than a week, WDGS must be shipped to users in close proximity to the ethanol plant (Elliott, Magnuson, and Wend, 2006). The high moisture content also means that 1,300 pounds per ton of the feed is water content, which adds to the transportation cost and thereby limits the market area. Additionally, flowability can be an issue with wet co-products.

Because of these characteristics, virtually all WDGS are shipped by truck to local feedlots; the average shipping distance was 61 miles in 2003 (USDA-NASS, 2006). Some ethanol plants located adjacent to feedlots use conveyors to transport the feed to cattle feedlots.

Despite these limitations, WDGS are popular for two reasons. First, an ethanol plant can lower its energy costs by avoiding the drying cost of the distillers grains. “Natural gas expenditures frequently represent

30% of the operating budget of dry mill plants" (Tiffany and Eidman, 2003).Second, WDGS provide a low-cost feed for farmers near the ethanol plant.

Most ethanol plants dry some of their distillers grains because the local demand is insufficient to consume the daily production of distillers grains in the wet format. Distillers dried grains with solubles (DDGS) have a dry matter content of approximately 90%, which extends the shelf life of the co-product. However, if the grains are not carefully manufactured, flowability issues can also occur with DDGS (Markham, 2005). Unless the moisture content of DDGS is under 11%, the grains can cake or solidify during shipment (Shurson, 2005). As a result, "workers sometimes hammer the car sides and hopper bottoms in order to induce flow. This can lead to severe damage to the rail cars themselves and can also pose worker safety issues" (Denicoff, 2007). Because of these problems, the Burlington Northern Santa Fe and Union Pacific railroads require that DDGS be shipped in hopper cars owned or leased by the shipper, rather than using carrier-owned equipment (Cooper, 2005).

A second key transportation attribute is co-product bulk density, which is measured as pounds per cubic foot. The density of DDGS averages 32 pounds per cubic foot, which means that the 4,500-cubic-foot capacity of a conventional grain hopper car is filled at a weight of 72 tons. However, the weight limit for traditional grain hopper cars is 100 tons, which means that DDGS "cubes out" or fills the volume of the car before the car reaches its maximum weight threshold.

To alleviate this bulk density problem, shippers are investing in jumbo hoppers, or rail cars with volumes of 6,300 cubic feet, which can haul 100 tons of DDGS. The nation's fleet of jumbo hopper cars increased by 11,000 in 2005 and 2006, with additional orders made for 14,000 cars (Dennison, 2007). These rail cars also have wider unloading chutes that facilitate faster unloading and improve flowability. Five-year lease rates for jumbo hopper cars range from $450 to $630 per month (Markham, 2005). The number of hopper cars leased depends on the location of destination markets for a particular ethanol plant and the plant's reliance on rail as a shipping mode.

Alternative Modes of Transportation for Distillers Dried Grains with Solubles

A 100-million-gallon plant operating 354 days per year produces 6,200 tons of DDGS per week. Storage capacity for DDGS at the ethanol plant is generally limited to two weeks. Thus, ethanol plants are highly dependent upon reliable transportation providers. DDGS are shipped by truck, rail, barge, or container. Modal choice is a function of the volume shipped, distance, rates, and the receiving capability at the destination.

Transportation rates can be extremely volatile, competitive, and reflective of local market conditions. Trucks are the most cost-effective mode for short-distance movements (up to 250 miles), while rail and barge are the preferred modes for longer distances and larger volume movements. In addition, rates can vary by season, as well as being subject to weather-related disruptions. Thus, any comparison of rates among transportation modes should be viewed with extreme trepidation. Nevertheless, examples of rates to haul DDGS are provided for August 2008 (Table 9.2). The rates are reflective of the normal shipment size and equipment configuration for a typical distance or length of haul for a particular mode.

A 100-million-gallon ethanol plant could ship 248 truckloads of DDGS per week, at a payload of 24 tons per truck (Table 9.2). The average length of haul for a movement of DDGS in 2003 was 80 miles at a cost of $4.00 per ton (USDA-NASS, 2006). Updated to 2008, the truck cost per ton mile would be $9.25 per ton, with each additional mile adding 10¢ per ton to the cost.[1] Truckers may be able to deliver two loads per day for round trip distances of up to 120 miles.

Rail rates are quoted from origins to destinations and differ by the number of cars shipped at one time, the number of origins per shipment, the distance traveled, and the type of equipment. Additional expenses related to hauling DDGS by rail include car ownership and applicable fuel surcharges. Rate quotes were obtained for DDGS from the Burlington Northern Santa Fe Railroad Web page (2008), for movements from

[1]The Iowa State Grain Truck Transportation Calculator is an interactive spreadsheet model found at http://www.extension.iastate.edu/agdmg/crops/xls/a3-29graintransportation.xls.

Table 9.2. Equipment payload, loads per week, and rates per ton, by mode, August 2008

Mode	Equipment Capacity Payload (tons)	Loads per Week for 100 Million Gallon Plant	Typical Trip One-Way Distance (miles)	Estimated Rate for Typical Trip ($ per load)	Cost per Ton per Mile
Containers	19	326	2,100 plus ocean crossing	$2,000	$0.050
Truck	24	258	80	$220	$0.115
Jumbo hopper, single car rate	100	62	800 1,900	$4,200 $4,900	$0.052 $0.025
Jumbo hopper, 100 car rate	100	62	800 1,900	$3,200 $3,900	$0.039 $0.020
Barge	1,500	4	1,400	$37,740	$0.018

southwest Iowa to Friona, Texas, and Swanson, California, at a distance of roughly 800 and 1,900 miles, respectively. For long-distance shipments, transit time can range from twelve days for unit trains to thirty days for single car shipments. Thus, the utilization of rail equipment is much less than that of truck transport, at 12 to 30 turns per year (Denicoff, 2007).

Since deregulation, the rail industry has steadily shifted traffic to trainload consignments of 80 to 100 rail cars depending upon the carrier. While trainload rates are published, relatively few feedlots have the ability to accept and store 10,000 tons of DDGS at one time. In addition, it would take eleven days for a 100-million-gallon ethanol plant to fill a train with DDGS.

Rates are quoted for a unit train loaded from one origin consisting of 95 to 100 jumbo hopper cars at $32 per ton to Friona, Texas, and $39 per ton to Swanson, California (Table 9.2). The rate per ton is $4.00 per ton higher if the 100-car train is loaded from three origins instead of one. Ethanol plants shipping at a single car rate pay an additional $10.00 per ton than the unit train rate. Shipping by jumbo hoppers lowers rates by $4.00 per ton relative to grain hopper cars.

DDGS can also be shipped by barge from the Upper Mississippi River to New Orleans and then transloaded onto an ocean-going vessel. The weekly USDA *Grain Transportation Report* provides barge rates for seven origins along the Mississippi River. The mid-Mississippi rate, applicable for ethanol plants in Northeast Iowa, was $25.16 per ton on August 12, 2008. The distance to Baton Rouge, Louisiana, is 1,450 miles and would take close to forty days to traverse (Vachal, Hough, and Griffin, 2005). Each barge can hold 1,500 tons, or the equivalent of 15 jumbo hopper cars. Barges are shipped as part of a tow of up to 15 separate barges. A 100-million-gallon ethanol plant can load four barges per week.

Despite their much smaller payload of 18 tons, containers are also being used to ship DDGS to Asia. Inland container ports near Chicago, Kansas City, Memphis, and Columbus are loading DDGS into containers as a backhaul to Asian markets (U.S. Grains Council, 2007). The August 2008 rate for shipping a 20-foot container to Asia is $2,000 per container (USDA-AMS, 2008). The time needed to deliver a container to Asia from

Chicago would be approximately ten days from Chicago to Long Beach, California, and an additional sixteen to eighteen days from Long Beach to Asia (U.S. Grains Council, 2007).

A comparison of rates would suggest that ethanol plants should always opt for jumbo hopper 100-car rates or barge rates because of the lower costs per ton per mile (Table 9.2). Yet, the northern portions of the Upper Mississippi River are closed to navigation from late November until late March in most years. Similarly, while most ethanol plants can load unit trains of DDGS, relatively few feedlots can receive that much feed at one time. Furthermore, the rail rate does not reflect an additional fixed cost of $500 per month for a rail hopper car lease. Finally, the equipment utilization is much lower for rail and barge compared with that of trucks. Instead of at least 1 load per day, trains haul 8 to 40 loads per year, while barges from the Upper Mississippi make four or five trips per year.

Modal Share for Distillers Grains

The remainder of this chapter considers the effect of the growth of the ethanol industry on the transportation for DDGS. Two prior analyses have estimated modal shares for truck, rail, and barge movements of distillers grains (Table 9.3). The initial work by Denicoff (2007) suggested that most DDGS would move by truck in 2005. Pentland (2008) argued that shippers will be dependent on truck transportation to move DDGS to markets because of capacity constraints for rail and barge traffic. Results from the most recent survey of ethanol plants showed that railroads' market share grew from 14% in 2005 to 57% in 2007 (Wu, 2008).

Given the continued growth of the U.S. ethanol industry, a transportation flow model was developed to provide additional perspectives about the shifts in distillers grain movements. By comparing results over time, the model

Table 9.3. Modal shares for dried distillers grain, 2005 and 2007

Mode	2005[a]	2007[b]
Truck	84%	43.5%
Rail	14%	56.5%
Barge	2%	0%
Total	100%	100%

Sources: [a]Denicoff, 2007; [b]Wu, 2008.

considers the magnitude of the new traffic upon the existing network, as well as providing consideration as to the geographic locations for corn, ethanol, and distillers grain production and consumption. In turn, effects on transportation requirements are inferred based upon whether the consumption of the distillers grains is within a state's borders. Distillers grains produced and consumed within a state are assumed to be transported by truck, while surplus production from a state is assumed to be shipped by rail or barge.

The model captures the flow of corn to two end uses, ethanol and livestock feed, as well as the flow of distillers grains for livestock feed (Figure 9.1). Secondary data represent state-level activity for the years 2004 through 2010. The 2004 model provides a baseline that reflects the market before the recent expansion of the ethanol industry. The 2007 model captures the effect of the first wave of ethanol construction, with the 2010 model anticipating the further expansion of ethanol capacity. Results are presented by census region (Figure 9.2).

Corn production data are from the USDA's Economic Research Service (USDA-ERS, 2008). Data for 2004 to 2007 are the reported state levels of corn production. For 2008 to 2010, corn production is forecast by determining the state proportion of average U.S. production for the period 2001 to 2007, and multiplying that value times the long-term USDA forecast (Westcott, 2008). Corn production is heavily concentrated in the Midwest states, with Census Regions 3 and 4 accounting for 87.6% of all corn production (Table 9.4). Five states—Illinois, Indiana, Iowa, Minnesota, and Nebraska—account for 65% of U.S. corn production.

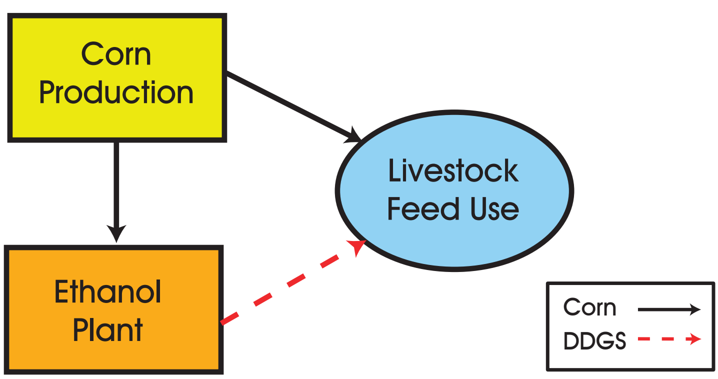

Figure 9.1. Transportation flows of corn and distillers grains

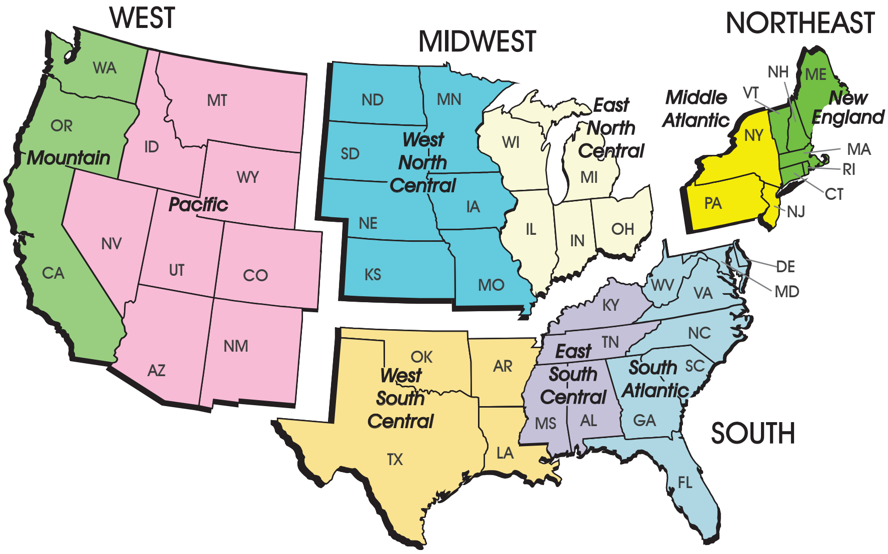

Figure 9.2. U.S. states by census regions

Ethanol plant capacities for plants operating and under construction by location are provided monthly from January 2005 through July 2008 by the Nebraska Energy Statistics Web site (2008). The yearly snapshot in this analysis uses the production capacity for July of each year. Three modifications were made to the data. First, the interest in this analysis is limited to dry-grind ethanol production because wet corn milling produces different co-products. Thus, all corn wet mills were excluded from the Nebraska data. Second, to obtain data for 2004, the Web sites for plants operating in 2005 were visited to determine a start-up date for each plant. Third, the plant data for 2009 assume that all plants under construction in 2008 will open in 2009. Data for 2010 include the capacities of an additional 11 dry-grind plants that currently have suspended operations, according to the *Ethanol Producer Magazine* (2008) Web site.

In 2004, 59 corn dry-grind plants operated at 2.6 billion gallons of capacity (Table 9.5). As of July 2008, 144 dry-grind ethanol plants were in operation with 8.2 billion gallons of capacity. By 2010, 189 dry-grind plants will be in operation with a capacity of 12.4 billion gallons. Almost 90% of the ethanol productive capacity is found in Census Regions 3 and 4. In 2008, Iowa, Nebraska, Minnesota, and Indiana accounted for 50% of industry capacity. While the U.S. Corn Belt is the region where most of the ethanol production capacity is located, ethanol production is steadily expanding to

Table 9.4. Historic and assumed corn production and region share, by year

Census Region	States	2004	2005	2006	2007	2008	2009	2010	Region Share
		million bushels							
1	CT, MA, ME, NH, RI, VT	0	0	0	0	0	0	0	0.0%
2	NJ, NY, PA	208	182	187	206	216	216	224	1.7%
3	IL, IN, MI, OH, WI	4,119	3,779	3,821	4,547	4,135	4,599	4,768	34.8%
4	IA, KS, MN, MO, ND, NE, SD	6,244	6,045	5,507	6,776	6,560	6,921	7,176	52.8%
5	DE, FL, GA, MD, NC, SC, VA, WV	300	271	285	303	252	314	326	2.4%
6	AL, KY, MS, TN	343	304	262	422	366	389	403	2.9%
7	AR, LA, OK, TX	362	315	265	555	477	441	458	3.4%
8	AZ, CO, ID, MT, NM, NV, UT, WY	179	176	168	198	220	212	220	1.6%
9	CA, OR, WA	52	43	39	68	60	58	60	0.4%
	USA	11,807	11,114	10,535	13,074	12,285	13,150	13,635	100.0%

Source: USDA-ERS, 2008.

Table 9.5. Historic and assumed dry-mill ethanol production and region share, by year

Census Region	States	2004	2005	2006	2007	2008	2009	2010	Region Share
		million gallons							
1	CT, MA, ME, NH, RI, VT	0	0	0	0	0	0	0	0.0%
2	NJ, NY, PA	0	0	0	0	50	274	274	1.7%
3	IL, IN, MI, OH, WI	670	710	736	1,291	2,300	3,126	3,163	26.0%
4	IA, KS, MN, MO, ND, NE, SD	1,887	2,013	2,782	3,729	5,158	7,225	7,647	63.0%
5	DE, FL, GA, MD, NC, SC, VA, WV	0	0	0	0	0	100	100	0.6%
6	AL, KY, MS, TN	23	23	33	33	33	133	133	0.9%
7	AR, LA, OK, TX	0	0	0	0	240	355	355	2.5%
8	AZ, CO, ID, MT, NM, NV, UT, WY	15	20	117	172	262	262	282	2.4%
9	CA, OR, WA	0	0	25	60	112	430	430	2.8%
	USA	2,595	2,766	3,693	5,285	8,154	11,904	12,384	100.0%
Number of plants		59	69	82	107	144	180	189	
Number of states		13	14	16	17	22	26	26	

Source: Nebraska Energy Statistics, 2008.

other regions across the country. The number of states with operating dry-grind ethanol plants doubled, from 13 in 2004 to 26 in 2010.

The amount of distillers grain production is a direct result of ethanol production. Each bushel of corn is assumed to produce 2.79 gallons of denatured ethanol and 17.5 pounds of DDGS. Thus, the distribution of ethanol by-products is identical to the distribution of dry-grind ethanol plants. As ethanol production expands, the volume of DDGS produced will rise almost fivefold between 2004 and 2010, from 8.14 to 38.84 million tons (Table 9.6).

Unlike the case of corn and ethanol production information, data for ethanol by-products consumption are not available at a national level, let alone a state level. Thus, livestock feed demand for ethanol by-products in this chapter are estimates obtained from a variety of sources. As such, the validity of the assumptions becomes critical. This analysis is based upon establishing an upper threshold for ethanol by-product consumption at the state level. This value is determined as the product of the state-level herd sizes for 10 classes of livestock and poultry and dietary inclusion rates, or the level of DDGS in their respective diets. Two adjustments were made over time. First, not all farms will feed DDGS as part of their animal diets. Thus, a market penetration rate is calculated to reflect the share of a particular class of livestock consuming DDGS as part of their diet. Second, animal populations are adjusted on an annual basis, based upon National Agricultural Statistics Service data (USDA-NASS, 2008).

State-level animal populations were obtained from the 2002 Census of Agriculture (USDA-NASS, 2004) for 10 classes of animals (cattle on feed, beef cows, milk cows, other cattle, breeding swine, market swine, layers, pullets, turkeys, and broilers). Adjustments to animal numbers are made based upon annual state-level updates as published by the National Agricultural Statistics Service. Southern states in Census Regions 5, 6, and 7 are where most of the nation's poultry is produced, while cattle production is concentrated in the Plains states in Regions 4 and 7, and pork production is concentrated in Regions 3, 4, and 5 (Table 9.7).

Annual feed consumption rates in pounds per head were adopted for the 10 classes of livestock and poultry from a variety of reports and conversations with animal nutrition experts (Table 9.8). A great deal of variation can be found

Table 9.6. Historic and assumed distillers grain production and region share, by year

Census Region	States	2004	2005	2006	2007	2008	2009	2010	Region Share
		million tons							
1	CT, MA, ME, NH, RI, VT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
2	NJ, NY, PA	0.00	0.00	0.00	0.00	0.16	0.86	0.86	1.7%
3	IL, IN, MI, OH, WI	2.10	2.23	2.31	4.05	7.21	9.80	9.92	26.0%
4	IA, KS, MN, MO, ND, NE, SD	5.92	6.31	8.72	11.69	16.17	22.66	23.98	63.0%
5	DE, FL, GA, MD, NC, SC, VA, WV	0.00	0.00	0.00	0.00	0.00	0.31	0.31	0.6%
6	AL, KY, MS, TN	0.07	0.07	0.10	0.10	0.10	0.42	0.42	0.9%
7	AR, LA, OK, TX	0.00	0.00	0.00	0.00	0.75	1.11	1.11	2.5%
8	AZ, CO, ID, MT, NM, NV, UT, WY	0.05	0.06	0.37	0.54	0.82	0.82	0.88	2.4%
9	CA, OR, WA	0.00	0.00	0.08	0.19	0.35	1.35	1.35	2.8%
	USA	8.14	8.67	11.58	16.57	25.57	37.33	38.84	100.0%

Source: USDA-ERS, 2008.

Table 9.7. Distribution of cattle, hogs, and chickens, and feed, by census region

Census Region	States	Region % of cattle	Region % of hogs	Region % of poultry	Region % of U.S. Feed Use
1	CT, MA, ME, NH, RI, VT	0.5	0.0	0.0	0.6
2	NJ, NY, PA	3.1	2.2	2.2	4.4
3	IL, IN, MI, OH, WI	8.3	17.4	2.3	11.3
4	IA, KS, MN, MO, ND, NE, SD	32.8	51.2	5.4	30.8
5	DE, FL, GA, MD, NC, SC, VA, WV	6.1	18.3	42.0	11.9
6	AL, KY, MS, TN	5.3	1.5	15.4	6.6
7	AR, LA, OK, TX	23.1	5.9	28.1	17.2
8	AZ, CO, ID, MT, NM, NV, UT, WY	13.0	3.1	0.1	9.1
9	CA, OR, WA	7.8	0.4	4.4	8.2
	USA	100.0	100.0	100.0	100.0

Source: USDA, 2004.

Table 9.8. Assumed corn and distillers grain intake per head, by class of livestock

Class of Livestock	Corn (lbs/head /yr)	Maximum Inclusion Rate of Distillers Grain	Distillers Grain (lbs/head/yr)[a]	Total Tons of Distillers Grain Fed Per Year
Beef cows	1,111.0	25%	277.8	4,625,661
Cattle on feed	6,151.6	25%	1,537.9	11,461,619
Milk cows	5,824.0	25%	1,456.0	6,627,682
Other cattle	862.9	20%	172.6	4,573,004
Breeding swine	1,299.2	10%	129.9	401,092
Market swine	574.0	10%	57.4	1,556,420
Layers	56.0	10%	5.6	934,910
Pullets	56.0	10%	5.6	265,479
Turkeys	59.4	10%	5.9	276,106
Broilers	6.3	10%	1.0	4,249,714
Total				34,971,687

Source: [a]Quear, 2008.

in recommended feeding rates from study to study. Based upon the animal population numbers and consumption rates, an upper limit for DDGS consumption is calculated to be 34.9 million tons. In contrast, Cooper (2005) estimated a national maximum threshold of 42 million tons. Cooper's value is much higher than our estimate because he assumed dietary inclusion rates of 40% for dairy and cattle rather than 20%, and 20% for hogs instead of 10%.

The projection of the Interagency Agricultural Projections Committee (IAPC) provides a short feature on DDGS as part of the report on *USDA Agricultural Projections to 2016*. The projections assume that only 75% of DDGS is used in the domestic livestock and poultry sectors, with 10% being exported and the remaining 15% going to domestic non-feed uses. Other uses of ethanol by-products include fertilizer, pet litter, and packaging materials. "Of the portion of distillers grains used for domestic livestock feeding, 80% is assumed to be used for beef cattle, 10% for dairy, and 5% each for poultry and hogs" (IAPC, 2007).

Cooper (2005) and the Renewable Fuels Association (2008) reported the distribution of distillers grain consumption among beef, dairy, swine, and poultry for the years 2001 to 2007 (Table 9.9). Consistent with IPAC, beef and dairy cattle consume most of the distillers grains on an annual basis (approximately 85%), while hogs consume around 11% and poultry consume the remaining 4%.

Using these values, one is able to calculate the tonnage of DDGS consumed by class of livestock and poultry following a three-step process. First, the Renewable Fuels Association (2008) also reports annual production levels of DDGS from 2001 to 2007, with production increasing from 3.4 to 16.1 million tons over that time period (Table 9.9). Exports are subtracted from production to arrive at net production available for domestic consumption. Export data for brewers or distillers spent grain are reported as part of the ERS Feed Grains Database in the Custom Queries section for the years 2001 to 2006. Over that time period, exports doubled, increasing from 0.94 to 1.96 million tons (Table 9.9). In 2006, exports accounted for 15% of U.S. DDGS production.

The second step is to multiply the allocation of DDGS by the net production available for domestic consumption, to arrive at the tons of

Table 9.9. Calculation of penetration rates of distillers grain consumption, by class of livestock, by year

DATA AVAILABLE	**Distribution of Distillers Grain Consumption (%), by Class[a]**						
Class of livestock	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Dairy	60	45	46	44	45	46	42
Cattle	36	35	39	37	37	42	42
Swine	2	15	11	16	13	9	11
Poultry	2	5	4	3	5	3	5
Total	100	100	100	100	100	100	100
	Distillers Grains Available for Consumption (million tons)						
STEP 1	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Total production[a]	3.42	3.97	6.39	8.05	9.92	13.23	16.09
Exports[b]	0.94	0.83	0.81	1.07	1.36	1.96	2.39
Exports as % of production	27.6	20.9	12.7	13.3	13.7	14.8	14.8
Net for domestic use	2.47	3.14	5.58	6.98	8.57	11.27	13.71
STEP 2	**Tons of Distillers Grains Consumed, By Class**						
Class of livestock	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Dairy (max tons = 6.6)	1.48	1.41	2.57	3.07	3.85	5.18	5.76
Cattle (max tons = 20.6)	0.89	1.10	2.18	2.58	3.17	4.73	5.76
Swine (max tons = 2.5)	0.05	0.47	0.61	1.12	1.11	1.01	1.51
Poultry (max tons = 5.2)	0.05	0.16	0.22	0.21	0.43	0.34	0.69
STEP 3	**Market Penetration for Distillers Grain Consumption (%), By Class**						
Class of livestock	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Dairy	22.4	21.3	38.8	46.4	58.2	78.3	86.9
Cattle	4.3	5.3	10.5	12.5	15.4	22.9	27.9
Swine	2.0	18.9	24.6	44.8	44.7	40.7	60.5
Poultry	1.0	3.0	4.3	4.0	8.2	6.5	13.2

Sources: [a]Renewable Fuels Association, 2008; [b]USDA-ERS, 2008 (http://www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx).

DDGS consumed annually by dairy cattle, beef cattle, swine, and poultry. For example, in 2007, dairy cattle consumed 42% of the 13.71 million tons available for consumption (Table 9.9). This means that dairy cattle consumed 5.76 million tons.

The final step is to determine the market penetration of DDGS among the different classes of livestock and poultry. Based on the assumed dietary inclusion rates of DDGS in the diets of the respective classes of livestock and poultry, the maximum tonnage of DDGS that can be consumed by dairy cattle, beef cattle, swine, and poultry is assumed to be 6.6, 20.6., 2.5, and 5.2 million tons, respectively (Table 9.9). Dividing the estimated tons consumed from step 2 by the maximum tons that can be consumed, an estimate of the market penetration rate can be determined, or the proportion of the animal population that is consuming DDGS.

Use of DDGS is approaching a 90% market penetration rate in dairy cattle diets, while 60% of the potential consumption has been achieved in the swine industry (Table 9.9). In both cases, typical farms are quite large, allowing the farming operation to utilize truckload quantities of DDGS in the diet. In contrast, only 28% and 13% of potential consumption of DDGS has been realized for beef cattle and poultry, respectively. To complete the model, market penetration rates were forecast for 2008, 2009, and 2010, using a trend projection (Figure 9.3). These rates were then used in the model to determine the level of DDGS consumption by state and by year. Total consumption was forecast to increase by approximately one million tons per year, from 13.7 million tons in 2007 to 14.8, 15.8, and 16.9 million tons in 2008, 2009, and 2010, respectively.

After all data calculations were completed, state-level consumption was subtracted from state-level production for DDGS for each year, or

$$\textit{Net DDGS}_{i,t} = \textit{Distillers Grain Production}_{i,t} - \textit{Distillers Grain for Livestock}_{i,t}$$

where i is a state among the 48 continental U.S. states, and t is the time period (2004 to 2010). This calculation determined whether a state had a surplus or deficit position. The changes were compared over time to identify the effects of shifts in DDGS and ethanol production. If *Net DDGS* was greater than zero, the state had a surplus of DDGS after all of the animals in that state had been fed DDGS given the assumed dietary inclusion

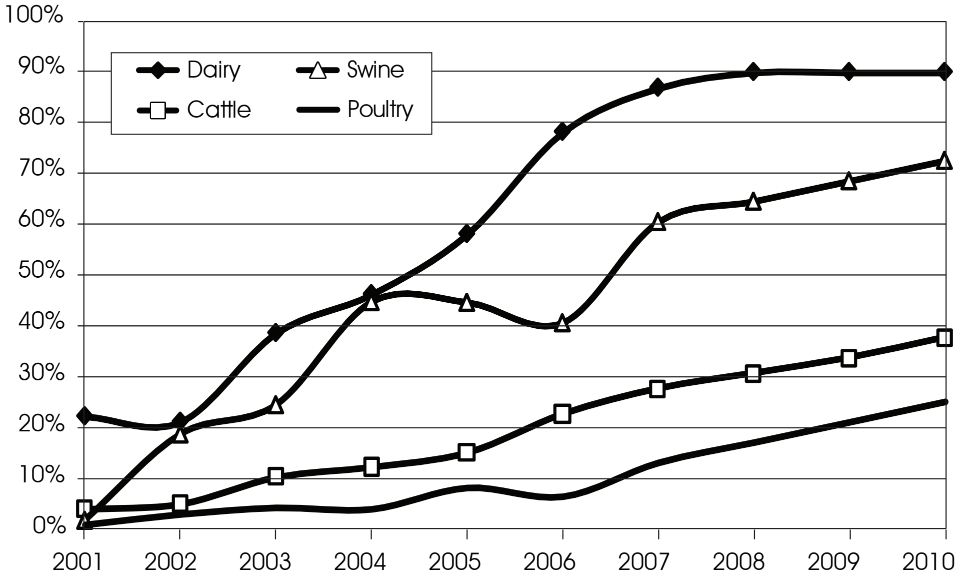

Figure 9.3. Forecast market penetration rates for distillers grain consumption rate, by class of animal

rates and market penetration rates. The remaining DDGS could then be either shipped to other states with a deficit or exported. In contrast, states with a negative *Net DDGS* balance were assumed to acquire DDGS from other states to meet livestock feed demands, given the livestock population, dietary inclusion rates, and market penetration rates.

The results of the model were validated by comparing predicted production and exports of DDGS with available data from the Renewable Fuels Association (2008) and the Economic Research Service (USDA-ERS, 2008) for the years 2004 to 2007. The model results were consistent with reported values for DDGS production and exports, especially for 2004 and 2007 (Table 9.10). Thus, the assumptions for dietary inclusion rates of DDGS in livestock feeds and market penetration rates of DDGS seem reasonable.

Model Results for Distillers Dried Grains with Solubles

In 2004, ethanol plants were present in 13 states, with a total production of 8.14 million tons of DDGS (Table 9.10). Nine states had surplus production, which was a result of the local demand for DDGS being saturated. The surplus was used to supply DDGS to other states and export

Table 9.10. Model validation and results for distillers grain production, consumption, and exports, 2004 to 2010

	Year						
Item	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
RFA and USDA reports							
RFA production (M tons)	8.05	9.92	13.23	16.09			
RFA consumption (M tons)	6.98	8.57	11.27	13.71			
USDA exports (M tons)	1.07	1.35	1.96	2.38			
Model results							
Production (M tons)	8.14	8.67	11.58	16.57	25.57	37.33	38.84
Consumption (M tons)	7.29	8.88	11.65	14.56	15.80	16.84	17.97
Exports (M tons)	0.85	-0.21	-0.07	2.02	9.77	20.49	20.86
Number of states:							
Producing distillers grains	13	14	16	17	22	26	26
With surplus distillers grains	9	8	7	8	11	15	14

Sources: Renewable Fuels Association, 2008; and USDA-ERS, 2008 (http://www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx).

0.85 million tons from the United States to foreign markets. By 2007, production had doubled to 16.6 million tons of DDGS, with production in 17 states, and surplus in 8 states. Over this time period, consumption was generally in balance with production. The model suggests, however, that the continued rapid expansion in ethanol capacity will accelerate production of DDGS relative to consumption over the next three years. Thus, exports will increase dramatically, growing tenfold, from 2.0 million tons in 2007 to 20.9 million tons by the year 2010.

In 2004, the nine states with surplus production of DDGS consumed 3.21 million tons and shipped 4.47 million tons elsewhere, of which 850,000 tons were exported (Table 9.11). The 39 deficit states produced only 450,000 tons of DDGS while consuming 4.08 million tons. With the expansion of ethanol production to 26 states by 2009, DDGS production is projected to increase to 37.3 million tons. Thus, over time, DDGS will become more geographically disperse, thereby reducing the distance to transport DDGS from surplus to deficit states. The number of states with saturated markets will increase to 14 of the 26 states producing DDGS in 2010. Those states will consume 7.54 million tons and export 25.06 million tons to other states or export markets. The other 34 states will produce 6.23 million tons but will still require an additional 10.43 million tons of DDGS to satisfy the assumed demand for feed.

States with the greatest surplus of DDGS are concentrated in the Corn Belt region (Figure 9.4). By 2010, Iowa, Nebraska, Indiana, Minnesota, South Dakota, and Illinois will all have surplus production of 2.0 million or more tons (Table 9.12). States with the largest deficits in 2010 are projected to be California, Texas, Oklahoma, and North Carolina. The Burlington Northern Santa Fe and Union Pacific railroads require that DDGS be shipped in hopper cars owned or leased by the shipper. However, both carriers apparently anticipate additional growth in traffic, because unit train rates have been implemented for DDGS from ethanol plants in the Midwest to cattle feed lots in Texas, New Mexico, and other locations.

A tenfold increase in exports in three years seems extreme. Thus, the assumptions in this study merit further consideration about the level of ethanol production, dietary inclusion rates, and market penetration rates.

Table 9.11. Net distillers grain position, by year

Census Region	States	Net Distillers Grain Position 2004	2005	2006	2007	2008	2009	2010
1	CT, MA, ME, NH, RI, VT	-0.08	-0.10	-0.14	-0.15	-0.15	-0.16	-0.16
2	NJ, NY, PA	-0.51	-0.63	-0.82	-0.93	-0.82	-0.14	-0.17
3	IL, IN, MI, OH, WI	1.03	0.92	0.59	1.98	5.02	7.54	7.57
4	IA, KS, MN, MO, ND, NE, SD	3.63	3.70	5.34	7.23	11.31	17.42	18.30
5	DE, FL, GA, MD, NC, SC, VA, WV	-0.53	-0.68	-0.72	-1.01	-1.12	-0.94	-1.05
6	AL, KY, MS, TN	-0.18	-0.27	-0.30	-0.45	-0.51	-0.27	-0.35
7	AR, LA, OK, TX	-0.90	-1.11	-1.53	-1.93	-1.39	-1.23	-1.48
8	AZ, CO, ID, MT, NM, NV, UT, WY	-0.70	-0.88	-1.00	-1.11	-0.97	-1.08	-1.10
9	CA, OR, WA	-0.91	-1.15	-1.49	-1.62	-1.58	-0.66	-0.70
	U.S. Exports	0.85	-0.21	-0.07	2.02	9.77	20.49	20.86
Number of States with Distillers Grain Surplus		9	8	7	8	11	15	14
	Distillers grains production	7.69	8.10	10.59	15.85	21.96	30.85	32.60
	Distillers grains consumption	3.21	3.76	4.79	7.00	6.65	6.91	7.54
	Available for export	4.47	4.34	5.80	8.85	15.31	23.93	25.06
Number of States with Distillers Grain Deficit		39	40	41	40	37	33	34
	Distillers grains production	0.45	0.58	0.99	0.73	3.61	6.49	6.23
	Distillers grains for livestock	4.08	5.12	6.86	7.56	9.15	9.93	10.43
	Imported distillers grains	(3.63)	(4.55)	(5.87)	(6.83)	(5.54)	(3.45)	(4.20)

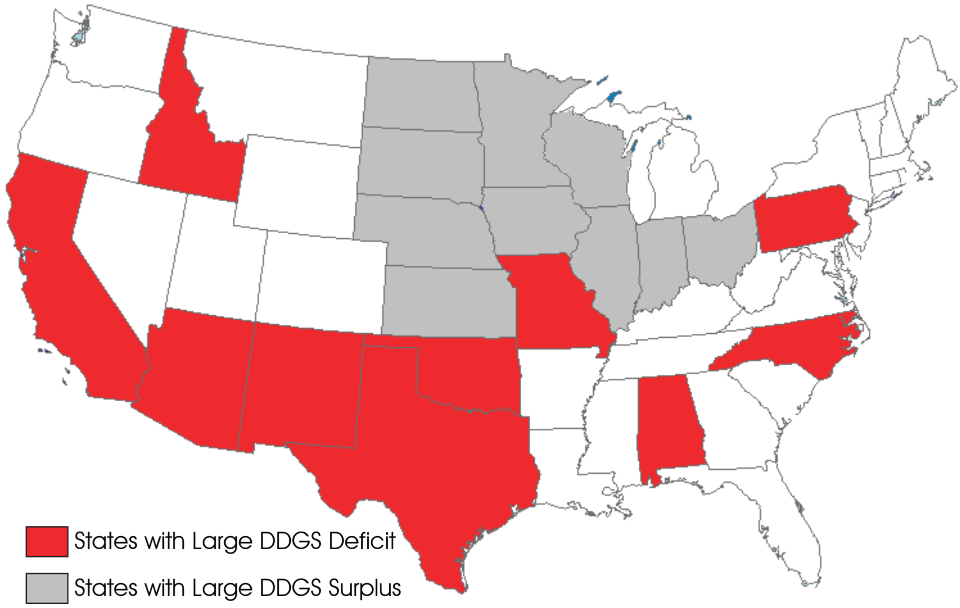

Figure 9.4. States with largest projected surpluses and deficits of distillers grains by 2010

First, the assumption of 12.4 billion gallons of dry-grind ethanol production capacity by 2010 is not unreasonable. This amount of ethanol production is consistent with the Renewable Fuels Standard as established by the Energy Independence and Security Act of 2007, which calls for 12 billion gallons of ethanol by 2010. Thus, it is likely that the DDGS will be produced in much higher volumes. As such, the volume of exports can be reduced by greater animal consumption.

Second, Cooper (2005) assumed much higher dietary inclusion rates for DDGS in the diets of dairy and beef cattle (40% versus 25%) and hogs (20% versus 10%). If his assumptions for inclusion rates are correct, the upper limit for DDGS consumption would be 20% higher, at 42 instead of 35 million tons. This would reduce exports by 4 million tons. It is difficult to judge the validity of this assumption given the rapid pace of adjustment in the industry.

Finally, the authors are unaware of other estimates of market penetration rates for different classes of livestock and poultry. One additional consider-

Table 9.12. Top surplus and deficit states for distillers grains

	2004	2005	2006	2007	2008	2009	2010
Surplus states				million tons			
Iowa	1.40	1.02	2.81	3.61	4.28	7.55	7.99
Nebraska	0.75	0.67	0.54	1.08	2.43	3.71	4.02
Indiana	0.18	0.16	0.12	0.65	1.54	3.07	3.05
Minnesota	0.53	0.86	1.08	1.16	1.45	2.30	2.61
South Dakota	1.24	1.27	1.26	1.62	2.43	2.46	2.43
Illinois	1.09	1.07	1.06	1.34	1.81	2.11	2.20
Ohio	-0.18	-0.22	-0.28	-0.35	0.71	1.27	1.25
North Dakota	0.07	0.06	0.04	0.33	0.29	0.95	0.97
Kansas	0.04	0.07	-0.11	-0.10	0.65	0.76	0.66
Wisconsin	-0.07	-0.06	-0.21	-0.02	0.62	0.61	0.59
Deficit states							
California	-0.71	-0.91	-1.16	-1.25	-1.31	-0.85	-0.90
Texas	-0.61	-0.75	-1.09	-1.35	-0.72	-0.48	-0.64
Oklahoma	-0.17	-0.21	-0.28	-0.34	-0.39	-0.42	-0.47
North Carolina	-0.18	-0.20	-0.19	-0.30	-0.34	-0.37	-0.41
Missouri	-0.38	-0.25	-0.27	-0.47	-0.23	-0.30	-0.38
Idaho	-0.20	-0.26	-0.38	-0.45	-0.34	-0.35	-0.31
Arizona	-0.09	-0.12	-0.12	-0.18	-0.22	-0.25	-0.29
New Mexico	-0.10	-0.13	-0.17	-0.22	-0.22	-0.22	-0.23
Alabama	-0.06	-0.09	-0.09	-0.14	-0.17	-0.20	-0.23
Pennsylvania	-0.27	-0.33	-0.41	-0.49	-0.52	-0.19	-0.20

ation is the length of time that a truckload of DDGS will last, given the herd size. Distributions of herd sizes are available for dairy cattle, beef cattle, and swine, which are assumed to consume 8 pounds, 4 pounds, and 1 pound of DDGS per day, respectively. Thus, at a feeding rate of one truckload per month (48,000 pounds), one could feed 200 dairy cows, 400 beef cattle, or 1,600 hogs.

Over 81% of the dairy cows are on farms greater than 100 head (Table 9.13). Thus, the penetration rate of 86.9% for the dairy sector seems reasonable, and further growth of DDGS for this class of livestock is probably limited (Table 9.9). While beef cattle and calves have a distribution similar to that of dairy cattle, their daily dietary inclusion rate is less: a truckload of DDGS feed will last twice as long. It seems reasonable that herds with at least 500 head of beef cattle, or 44% of the beef cattle inventory, will include DDGS in their diets. Thus, the market penetration rate for beef cattle could increase. With the low dietary inclusion rate of DDGS for hogs, it is likely that sizes of herds that consume it will be at least 1,500 head. Therefore, this assumed penetration rate of 72% seems reasonable. Comparable data on farm size were unavailable for poultry.

Modal Shares: Truck versus Rail

Results for DDGS production and consumption from Table 9.11 can be used to generate estimates of modal shares for truck versus rail/barge

Table 9.13. Distribution and days of feed from one truckload for dairy, cattle and calves, and hogs, by herd size, 2007

	Cumulative Distribution of Animals by Herd Size (%)			Days Fed with One Truckload of Distillers Grains		
Herd Size	**Dairy**	**Cattle & Calves**	**Hogs**	**Dairy**	**Cattle & Calves**	**Hogs**
Over 2000 head	25.7	23.3	56.0	1	2	10
1000-1999 head	41.8	31.4	81.5	4	8	32
500-999 head	54.1	44.2	91.0	8	16	64
100-499 head	81.2	78.2	95.5	20	40	160
50-99 head	94.3	89.4	99.0	80	160	640
1-49 head	100.0	100.0	100.0	240	480	1920
Penetration rate	86.9	27.9	60.5			

transportation, as well as the number of truckloads and rail carloads. DDGS produced and consumed within the boundaries of a particular state are assumed to be transported by truck. All production available for export from the surplus states is assumed to be shipped by rail. While values are reported as rail modal share or carloads, barge transportation would be competitive for many of the rail movements, primarily because much of the production of DDGS originates from states found along the Mississippi River system. Truckload capacities are 24 tons, while railcar capacities for jumbo hoppers are 100 tons (Table 9.2).

The predicted truck modal share for DDGS of 46.6% in 2007 is comparable to Wu's estimate (Tables 9.3 and 9.14). As U.S. demand for DDGS in livestock and poultry diets becomes saturated, more of the market will shift to rail and barge transportation to move the by-products to export markets. Thus, the modal share for truck transportation is expected to decline to 35% by 2010. Despite the decrease in truck modal share, the absolute number of truckloads will increase from 322,000 truckloads in 2007 to 574,000 by 2010, simply because of the much greater production of DDGS over time. Rail shipments are expected to almost triple, rising from 88,000 to 251,000 carloads over the same time period.

Future Expectations for Transportation of Distillers Dried Grains with Solubles

After 15 years of relative calm, transportation is once again emerging as an issue of concern for agricultural shippers and receivers, transportation firms, and public policymakers. The pace of change caused by the growth in ethanol production is rapid. Four observations are made with respect to the transportation of DDGS.

First, the effects of the production of ethanol and related products on transportation equipment and infrastructure are large in magnitude. In the short run, ethanol firms, truckers, and railroads are experiencing backlogs in orders for new hopper and tanker cars and difficulties in shipping DDGS. While challenging, these problems likely reflect short-term adjustments as opposed to long-term concerns. The railroads seemingly have the ability to manage this change. Continued increases in truck traffic will likely create greater equipment and infrastructure challenges, especially at the local level.

Table 9.14. Modal share and loads generated for distillers grains, by year

	2004	2005	2006	2007	2008	2009	2010
Modal share							
Truck	45.0%	50.0%	49.9%	46.6%	40.1%	35.9%	35.5%
Rail/barge	55.0%	50.0%	50.1%	53.4%	59.9%	64.1%	64.5%
Million tons of traffic	8.14	8.67	11.58	16.57	25.57	37.33	38.84
Loads of distillers grains (000)							
Truckloads	153	181	241	322	428	558	574
Railcars	45	43	58	88	153	239	251

Second, the effects of increased truck traffic will be experienced most in the communities and surrounding areas where new ethanol plants are located. An ethanol plant that produces 100 million gallons per year requires 110 truckloads of corn per day, while generating 35 truckloads each of ethanol and DDGS. While the economic development associated with new ethanol plants is welcome in rural communities, the increase in truck traffic may strain local highway maintenance budgets. The problem may be more serious in regions with bridges that are in poor condition.

Third, compared to the traditional grain sector, many ethanol plants have relatively little storage for corn and outputs. With as little as ten days to two weeks of storage capacity, these plants are heavily reliant on dependable providers of transportation service. As a corollary, railroads might increase their equipment utilization when shipping ethanol and DDGS as compared to corn. The predictable, steady nature of shipments from ethanol plants stands in sharp contrast to the seasonality associated with shipping corn.

Finally, while transportation challenges in the rapidly expanding ethanol industry certainly exist, there are also several examples of innovative responses to the challenges by entrepreneurs. For example, terminal facilities like Manly Terminal LLC in Manly, Iowa, and Gateway Terminals LLC in Sauget, Illinois, are poised to capture advantages of volume shipping for ethanol and DDGS. Finally, in Kankakee, Illinois, and elsewhere, shippers are loading DDGS in containers for shipment to Asia.

Overall, the prognosis for DDGS seems positive. As an industry in the midst of rapid expansion, uncertainty is high. Additional investment in transportation infrastructure and equipment will be required, especially for trucks and local highways. However, if the U.S. market for utilizing DDGS is saturated as soon as 2009, equipment concerns will shift to modes of transportation necessary for moving the by-product to export markets.

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Chapter 10

Quality and New Technologies to Create Corn Co-Products from Ethanol Production

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The objective of this chapter is to describe the quality characteristics of distillers dried grains with solubles (DDGS) and new technologies used to produce new fractionated corn co-products. Quality of a feedstuff can be defined in many ways, but as described in Webster's dictionary, it is the degree of excellence or superiority. Since corn co-products from ethanol production are sources of nutrients, high quality can be described as containing a consistently high level of economically important nutrients (e.g., energy, amino acids, and phosphorus) that are highly digestible for the animal. Another way of describing quality according to Webster's dictionary is the peculiar and essential character of something. Most corn co-products are produced as a result of the fermentation process used to produce ethanol and contain residual yeast and perhaps other compounds, which may provide additional health and nutritional benefits beyond the nutrients they provide to the animal's diet.

Variability in Nutrient Content and Digestibility of Distillers Dried Grains with Solubles

Perhaps the biggest challenge of using DDGS (referring to corn-based throughout unless otherwise noted) in animal feeds is to know the nutrient content and digestibility of the source being used. The nutrient content of DDGS can vary among U.S. DDGS sources (Table 10.1) and has been shown to vary over time within plants (Spiehs, Whitney, and Shurson, 2002).

Nutritionists want consistency and predictability in the feed ingredients they purchase and use. Because of the high crude protein content of

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Table 10.1. Averages and ranges (%) in composition of selected nutrients (100% dry matter basis) among 32 sources of U.S. corn distillers dried grains with solubles

Nutrient	Average (CV[a]	Range
Crude protein	30.9 (4.7)	28.7 - 32.9
Crude fat	10.7 (16.4)	8.8 - 12.4
Crude fiber	7.2 (18.0)	5.4 - 10.4
Ash	6.0 (26.6)	3.0 - 9.8
Lysine	0.90 (11.4)	0.61 - 1.06
Arginine	1.31 (7.4)	1.01 - 1.48
Tryptophan	0.24 (13.7)	0.18 - 0.28
Methionine	0.65 (8.4)	0.54 - 0.76
Phosphorus	0.75 (19.4)	0.42 - 0.99

Source: www.ddgs.umn.edu

[a]CV = coefficient of variation (standard deviation divided by the mean x 100).

DDGS, this co-product is often compared to soybean meal, but soybean meal is less variable than DDGS in nutrient content among different sources (Table 10.2). Crude fat was the only nutrient that had a higher coefficient of variation in soybean meal compared to DDGS, which was caused by three extreme values (3.27%, 3.55%, and 3.86%) in the samples collected (Urriola et al., 2006), since the fat content in soybean meal averages only about 1.74%. With the growing diversity of corn co-products coming onto the feed ingredient market, those produced by the ethanol industry are becoming less of a commodity compared to soybean meal because of the wide variability in nutrient content. To manage the variation among DDGS from different sources, some commercial feed manufacturers are beginning to require identity preservation of selected DDGS sources by limiting the number of suppliers in the company's preferred list. Olentine (1986) listed a number of variables in the raw materials and processing factors that contribute to variation in nutrient composition of corn co-products (Table 10.3).

Variation in Nutrient Content of Corn Affects the Nutrient Composition of Distillers Dried Grains with Solubles

Much of the variation in nutrient content of DDGS is likely due to the normal variation among corn varieties and geographic location where the corn is grown. Reese and Lewis (1989) showed that corn produced in Nebraska in 1987 ranged from 7.8% to 10.0% crude protein, 0.22% to 0.32% lysine, and 0.24% to 0.34% phosphorus (Table 10.4). When corn is fermented to produce ethanol and DDGS, the nutrients in DDGS become

Table 10.2. Variability (coefficients of variation, %) of selected nutrients among 32 U.S. sources of distillers dried grains with solubles versus 6 sources of U.S. soybean meal

Nutrient	DDGS	Soybean Meal
Crude protein	4.7	2.3
Crude fat	16.4	30.9
Crude fiber	18.0	9.5
Ash	26.6	6.6
Lysine	11.4	3.0
Methionine	8.4	5.3
Threonine	5.8	4.2
Tryptophan	13.7	7.3
Calcium	117.5	25.8
Phosphorus	19.4	9.1

Source: Soybean meal data is from Urriola et al., 2006.

Table 10.3. Factors influencing nutrient composition of corn co-products produced by the ethanol industry

Raw Materials	Processing Factors
Types of grains	Grind Procedure
Grain variety	Fineness
Grain quality	Duration
Soil conditions	Cooking
Fertilizer	Amount of water
Weather	Amount of pre-malt
Production and harvesting methods	Temperature and time
	Continuous or batch fermentation
Grain formula	Cooling time
	Conversion
	Type, quantity, and quality of malt
	Fungal amylase
	Time and temperature
	Dilution of converted grains
	Volume and gallons per bushel of grain
	Quality and quantity of grain products
	Fermentation
	Yeast quality and quantity
	Temperature
	Time
	Cooling
	Agitation
	Acidity and production control
	Distillation
	Type: vacuum or atmospheric, continuous, or batch

Table 10.3. Continued

	Direct or indirect heating
	Change in volume during distillation
	Processing
	Type of screen: stationary, rotating, or vibratory
	Use of centrifuges
	Type of presses
	Evaporators
	Temperature
	Number
	Dryers
	Time
	Temperature
	Type
	Amount of syrup mixed with grain

Source: Olentine, 1986.

Table 10.4. Overall average, minimum, and maximum values for nutrients in corn

Nutrient	Average	Minimum	Maximum
Crude protein, %	8.6	7.8	10.0
Lysine, %	0.26	0.22	0.32
Calcium, %	0.01	0.01	0.01
Phosphorus, %	0.28	0.24	0.34
Selenium, ppm	0.12	0.10	0.16
Vitamin E, IU/lb	3.9	1.9	5.8

Source: Reese and Lewis, 1989.
Note: On 88% dry-matter basis.

two to three times more concentrated, which contributes to the increased variability in nutrient content among DDGS sources.

Variation in the Rate of Solubles Added to Grains Affects the Nutrient Composition of Distillers Dried Grains with Solubles

The ratio of blending condensed distillers solubles with the grains fraction to produce DDGS also varies across ethanol plants. The typical nutrient content of each fraction is shown in Table 10.5. Because there are substantial differences in nutrient composition between these two fractions, it is understandable that the proportion of the grains and solubles blended together will have a significant effect on the final nutrient composition of DDGS. The American Association of Feed Control Officials defines DDGS as follows: "Distillers Dried Grains with Solubles

Table 10.5. Nutrient content and variability (%) of corn distillers grains and distillers solubles (100% dry matter basis)

	Average	Minimum	Maximum
Grains fraction			
Dry matter	34.3	33.7	34.9
Crude protein	33.8	31.3	36.0
Crude fat	7.7	2.1	10.1
Crude fiber	9.1	8.2	9.9
Ash	3.0	2.6	3.3
Calcium	0.04	0.03	0.05
Phosphorus	0.56	0.44	0.69
Solubles fraction			
Dry matter	27.7	23.7	30.5
Crude protein	19.5	17.9	20.8
Crude fat	17.4	14.4	20.1
Crude fiber	1.4	1.1	1.8
Ash	8.4	7.8	9.1
Calcium	0.09	0.06	0.12
Phosphorus	1.3	1.2	1.4

Source: Knott, Shurson, and Goihl, 2004.

is the product obtained after the removal of ethyl alcohol by distillation from yeast fermentation of a grain or a grain mixture by condensing and drying at least three-fourths of the solids of the resultant whole stillage by methods employed in the grain distilling industry."

Some ethanol plants add all of the condensed solubles produced to the grains fraction, while others add substantially less solubles before drying. At least one ethanol plant is attempting to burn most, if not all, of the solubles produced as a fuel source for the ethanol plant. This practice substantially changes the nutrient composition of the resulting distillers dried grains (DDG) compared to the nutrient composition of DDGS.

Ganesan, Rosentrater, and Muthukumarappan (2005) evaluated the effects on protein and fat content of adding 10%, 15%, 20%, and 25% condensed distillers solubles (dry basis) to the grains fractions to produce DDGS (Table 10.6). The fat content of DDGS increased from 8.79% to 11.77% for the 10% and 25% solubles addition, respectively. The protein content decreased from 30.54% to 26.02% with the addition of 10% and 25% solubles, respectively. Therefore, the nutrient content of DDGS can be substantially altered based on the amount of solubles added to the grains fraction.

Table 10.6. Average fat and protein content of distillers dried grains with solubles with four different solubles percentages

Nutrient, % db	10% Solubles	15% Solubles	20% Solubles	25% Solubles	SEM
Fat	8.79[b]	7.53[b]	12.68[a]	11.77[a]	1.7
Protein	30.54[a]	30.16[a]	27.23[b]	26.02[c]	0.26

Source: Ganesan, Rosentrater, and Muthukumarappan, 2005.
[a,b,c] Means within same row not sharing a common superscript are different ($P < .05$).

Variation in the Rate of Solubles Addition to Grains Affects Nutrient Digestibility of Distillers Dried Grains with Solubles

Noll, Parsons, and Walters (2006) evaluated the nutrient composition and digestibility of different DDGS batches produced with varying levels of solubles added to the wet grains. The solubles were added at approximately 0%, 30%, 60%, and 100% of the maximum possible addition to the grains, which corresponds to 0, 12, 25, and 42 gallons of syrup added to the grains fraction per minute. Dryer temperatures decreased as the rate of solubles addition to the grains decreased because less moisture was present in the grains and syrup mixture before going into the dryer. Samples of DDGS were analyzed for color, particle size, moisture, crude fat, crude protein, crude fiber, ash, phosphorus, lysine, methionine, cystine, and threonine. Digestible amino acids were determined using cecectomized roosters, and nitrogen-corrected true metabolizable energy (TME_n) was determined using intact young turkeys. As shown in Table 10.7, increasing the amounts of solubles resulted in darker-colored DDGS (reduced L* and b*; lightness and yellowness) and increased crude fat, ash, TME_n (poultry), magnesium, sodium, phosphorus, potassium, chloride, and sulfur but had minimal effects on crude protein and amino acid content and digestibility.

Effects of Color of Distillers Dried Grains with Solubles on Amino Acid Digestibility

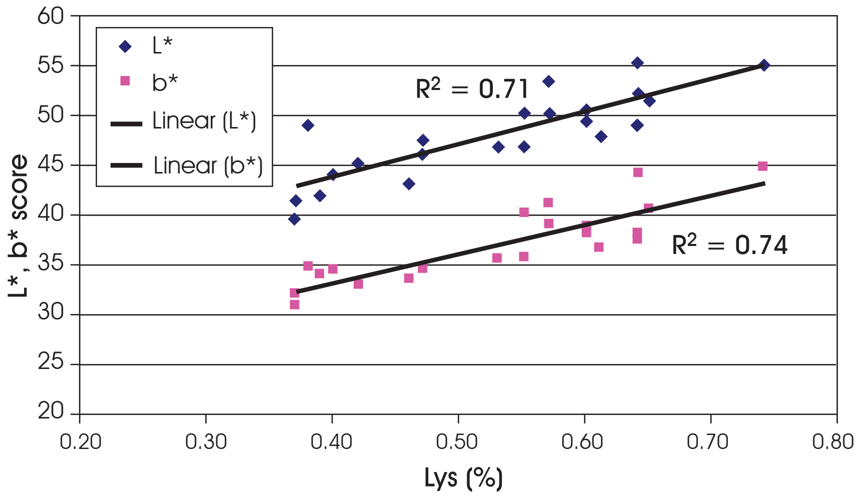
Amino acid digestibility of feed ingredients is very important when evaluating ingredients and formulating diets for swine and poultry. Lightness and yellowness of the color of DDGS appear to be reasonable predictors of digestible lysine content among golden DDGS sources for poultry (Figure 10.1; Ergul et al., 2003) and swine (Pederson, Pahm, and Stein, 2005). True lysine digestibility coefficients ranged from 59% to 83% in poultry (Ergul et al., 2003), and from 44% to 63% in swine (Stein et al., 2006).

Table 10.7. Effects of increasing solubles addition to the grains fraction during production of distillers dried grains with solubles on color, nutrient content, TME_n (poultry), and amino acid digestibility (100% dry matter basis)

Measurement	0 gal/min	12 gal/min	25 gal/min	42 gal/min	Pearson Correlation Coefficient	P Value
Color L*[a]	59.4	56.8	52.5	46.1	- 0.98	0.0001
Color a*[a]	8.0	8.4	9.3	8.8	0.62	0.03
Color b*[a]	43.3	42.1	40.4	35.6	- 0.92	0.0001
Moisture, %	9.52	9.75	10.74	13.83	0.93	0.06
Crude fat, %	7.97	9.14	9.22	10.53	0.96	0.04
Crude protein, %	31.96	32.65	32.46	31.98	0.03	NS
Crude fiber, %	9.17	7.76	10.08	6.50	- 0.51	NS
Ash, %	2.58	3.58	3.72	4.62	0.97	0.03
Lysine, %	1.04	1.05	1.09	1.04	0.02	NS
Methionine, %	0.63	0.64	0.59	0.62	- 0.13	NS
Cystine, %	0.61	0.61	0.53	0.62	0.16	NS
Threonine, %	1.20	1.22	1.20	1.20	- 0.18	NS
Phosphorus, %	0.53	0.66	0.77	0.91	0.99	0.002
TME_n, kcal/kg	2712	2897	3002	3743	0.94	0.06
Lys digestibility, %	78.2	76.0	69.7	75.0	- 0.90	NS
Met digestibility, %	90.9	88.6	86.3	87.3	- 0.92	NS
Cys digestibility, %	87.2	87.6	80.7	80.3	- 0.95	NS
Thr digestibility, %	85.9	83.2	80.5	77.3	- 0.99	0.02
Arg digestibility, %	92.1	90.7	86.7	88.5	- 0.99	0.07

Source: Noll, Parsons, and Walters, 2006.

[a] L* = lightness of color (0 = black, 100 = white). The higher the a* and b* values, the higher the amount of redness and yellowness, respectively.



Source: Ergul et al., 2003.

Figure 10.1. Regression of digestible lysine (%) and color (L*, b*)

Cromwell, Herkleman, and Stahly (1993) evaluated the relationship between Hunter Lab color scores of various sources of DDGS and the content of acid detergent insoluble nitrogen and growth performance of pigs (Table 10.8). They fed a blend of the three darkest DDGS sources and a blend of the three lightest-colored DDGS sources to chicks and pigs and showed that, in both cases, feeding the blend of the darkest DDGS sources resulted in a reduced rate and efficiency of gain compared to feeding the blend of the lightest-colored sources. They concluded that rate and efficiency of gain are correlated with the color of the DDGS, as well as the concentrations of crude protein, lysine, sulfur amino acids, acid detergent insoluble nitrogen, and acid detergent fiber in DDGS.

Urriola (2007) showed that the lysine content ranged from 0.52% to 1.13% and the standardized true ileal lysine digestibility ranged from 17.7% to 74.4% among 34 different DDGS sources. Because of our need to know the amino acid digestibility for swine and poultry, which varies among DDGS sources, current research is evaluating the accuracy of several in vitro laboratory procedures to predict these values before formulating and manufacturing diets.

It is likely that much of the difference in lysine digestibility among DDGS sources is due to drying time and temperature used. Dryer tem-

Table 10.8. Effect of acid detergent insoluble nitrogen (ADIN) and color score on growth performance of pigs fed three blended sources of distillers dried grains with solubles

DDGS Source	L*[b]	a*[b]	b*[b]	ADIN, %	ADG, g[a]	ADFI, g[a]	F/G[a]
A	29.0	6.5	12.7	27.1	218	1,103	5.05
E	31.1	6.1	13.1	36.9			
G	38.8	6.8	16.5	16.0	291	1,312	4.52
I	41.8	6.5	18.8	26.4			
B	53.2	4.7	21.8	8.8	390	1,416	3.61
D	51.7	7.1	24.1	12.0			

Source: Cromwell, Herkleman, and Stahly, 1993.
[a]Significant differences among diets ($P < .01$).
[b]L* = lightness of color (0 = black, 100 = white). The higher the a* and b* values, the higher the amount of redness and yellowness, respectively.

peratures can range from 260° to 1150° F, depending on the ethanol plant. Since the amount of heat and length of heating time are highly correlated to lysine digestibility, it is not surprising that a fairly wide range of lysine digestibility exists among DDGS sources.

Availability of Phosphorus in Distillers Dried Grains with Solubles

The phosphorus content of DDGS is approximately 0.75% on a dry matter basis, which is three times greater than that of corn. In corn, only 14% of the total phosphorus is digestible for swine, but the apparent total tract phosphorus availability is increased to approximately 59% after fermentation (Pedersen, Boersma, and Stein, 2007). The phosphorus digestibility in DDGS corresponds to availability values between 70% and 90% relative to those for dicalcium phosphate. Therefore, with DDGS inclusion in swine diets, the utilization of organic phosphorus will increase, which in turn will reduce the need for supplemental inorganic phosphorus (i.e., dicalcium phosphate or monocalcium phosphate). However, Xu et al. (2006a,b) and Xu, Whitney, and Shurson (2006a) showed that feeding diets containing DDGS reduces the concentration of phosphorus in manure; dry matter digestibility is also reduced, and fecal excretion (manure volume) is increased in nursery pigs but not in growing-finishing pigs (Xu, Whitney, and Shurson, 2006b). The net result is a slight reduction or no change in total phosphorus excretion in manure with DDGS inclusion.

Similarly, the phosphorus availability in DDGS is also high for poultry diets; it was estimated to be between 54% and 68% (Lumpkins and Batal, 2005). Comparing different DDGS sources, Martinez Amezcua, Parsons, and Noll (2004) obtained bioavailability estimates for phosphorus of 69%, 75%, 82%, and 102%, suggesting that phosphorus availability varies among DDGS sources, but DDGS provide an excellent source of available phosphorus for poultry diets.

Presence of Potential Contaminants or Antinutritional Factors

Mycotoxins

Mycotoxins can be present in corn co-products if the grain delivered to the ethanol plant is contaminated. Mycotoxins are not destroyed during the ethanol production process or the drying process to produce corn co-products. However, the risk of mycotoxin contamination is very low because many ethanol plants monitor grain quality and reject sources that may be contaminated with mycotoxins.

When samples of corn co-products are tested, only high-performance liquid chromatography (HPLC) should be used. For mycotoxins, HPLC is the detection reference method for DDGS. Many test kit products based on Enzyme-Linked ImmunoSorbent Assay initially developed for basic commodities such as corn and wheat are known to provide incorrect, false positive readings and elevated mycotoxin levels when used with DDGS and should be avoided. These kits are established and developed to accurately detect mycotoxins in grains but not in DDGS. The difference is likely due to interferences by compounds unique to DDGS but not to whole grain.

To accurately detect mycotoxins and determine their level in DDGS, careful and methodical sampling procedures must be followed. This is because mycotoxins can be present in isolated parts of a grain or grain co-product container or truck, in very small quantities (parts per million or billion [ppb]). For example, one sample collected from a truck or a container could contain >100 ppb, with a different sample collected from the same truck being non-detectable (< 1 ppb). Therefore, it is extremely important to collect multiple small samples from each load or shipment rather than one large sample.

Sulfur

Distillers grains with and without solubles can sometimes be high in sulfur and contribute significant amounts of sulfur to the diet. If more than 0.4% sulfur from feed (dry matter basis) and water is consumed, polioencephalomalacia in cattle can occur. Furthermore, sulfur interferes with copper absorption and metabolism, which is worsened in the presence of molybdenum. Therefore, in geographic regions where high sulfur levels are found in forages and water, the level of DDGS in the diet may need to be reduced (Tjardes and Wright, 2002).

Salt

The sodium content of DDGS can range from 0.01% to 0.48%, averaging 0.11%. Therefore, dietary adjustments for sodium content may be necessary for poultry if the source of DDGS being used contains high levels of sodium in order to avoid potential problems with wet litter and dirty eggs.

Antimicrobial Residues

Virginiamycin is the only FDA-approved antimicrobial additive that can be used in very small quantities to control bacterial infections in fermenters during the ethanol production process. However, there are no antibiotic residues in distillers grains co-products because these antibiotics are destroyed at a temperature of > 200° C in the distillation towers (Shurson et al., 2003). Ethanol plants are encouraged to work with their antibiotic vendors to obtain an annual certified test and to keep the certification on file, demonstrating that no detectable levels of antibiotics are present in corn co-products.

Physical Characteristics of Distillers Dried Grains with Solubles that Affect Quality

Flowability

Flowability is defined as the ability of granular solids and powders to flow during discharge from transportation or storage containments. Flowability is not an inherent natural material property, but rather a consequence of several interacting properties that simultaneously influence material flow (Rosentrater, 2006). Flowability problems may arise from a number of synergistically interacting factors, including product moisture, particle size distribution, storage temperature, relative humidity, time, compaction pressure distribution within the product mass, vibrations during transport, and/or variations in the levels of these factors throughout the storage process (Rosentrater, 2006). Other factors that may affect flowability include chemical constituents, protein, fat, starch, and carbohydrate levels, as well as the addition of flow agents.

Since flow behavior of a feed material is multidimensional, there is no single test that completely measures the ability of a material to flow (Rosentrater, 2006). Shear testing equipment is used to measure the strength and flow properties of bulk materials. It is also used to measure the amount of compaction as well as the bulk strength of materials (Rosentrater, 2006). Another approach for assessing the flowability of granular materials involves measuring four main physical properties: angle of repose, compressibility, angle of spatula, and coefficient of uniformity (e.g., cohesion) (Rosentrater, 2006).

Unfortunately, DDGS can have some very undesirable handling characteristics related to poor flowability under certain conditions (AURI and Minnesota Corn Growers Assoc., 2005). Reduced flowability and bridging of DDGS in bulk storage containers and transport vehicles limit the acceptability of DDGS for some suppliers because customers (feed mills) do not want to deal with the inconvenience and expense of handling a feedstuff that does not flow through their milling systems.

Very few studies have attempted to characterize factors that affect flowability of DDGS. The Agricultural Utilization Research Institute (AURI) and the Minnesota Corn Growers Association (2005) studied a limited number of DDGS samples under laboratory conditions. They reported that relative humidity greater than 60% seemed to reduce flowability of a DDGS sample, which is likely due to the product's ability to absorb moisture. Besides the relative humidity, other suggested factors that may affect DDGS flowability include particle size, content of solubles, dryer temperature, and moisture content at dryer exit.

Johnston et al. (2007) conducted an experiment at a commercial dry-grind ethanol plant to determine if selected additives would improve flowability of DDGS. The treatments consisted of moisture content of DDGS (9% vs. 12%) and flowability additive treatments: no additive (control); a moisture migration control agent at 2.5 kg/metric ton (DMX-7, Delst, Inc.); calcium carbonate at 2% (calcium carbonate, Unical-P, ILC

Resources); or a clinoptilolite zeolite at 1.25% (zeolite, St. Cloud Mining Co.). The flowability additives were included at the desired level to about 2,275 kg of DDGS using a vertical-screw feed mixer and augered into truck compartments. The time required to unload each compartment was recorded. The flow rate of DDGS at unloading was higher for the 9% compared with 12% moisture level (620 vs. 390 kg/min). The flow rates of DDGS at unloading were 509 (control), 441 (DMX-7), 512 (calcium carbonate), and 558 (zeolite) kg/min. None of the flowability additives created flow rates that differed significantly from the control.

Color

As mentioned earlier, the color of DDGS can vary from very light golden yellow to very dark brown and is commonly measured in the laboratory using either Hunter Lab or Minolta colorimeters. These methods are used extensively in the human food and animal feed industries to measure the extent of heat damage (browning) in heat-processed foods (Ferrer et al., 2005) and feed ingredients (Cromwell, Herkleman, and Stahly, 1993). This system measures lightness (L* reading; 0 = dark, 100 = light), redness (a* reading), and yellowness (b* reading) of color. Color differences among DDGS sources are due to the amount of solubles added to grains before drying, the type of dryer and drying temperature, and the natural color of the feedstock grain being used.

The color of corn kernels can vary among varieties and has some influence on the final DDGS color. Corn-sorghum blends of DDGS are also somewhat darker in color than corn DDGS because of the bronze color of many sorghum varieties.

When a relatively high proportion of solubles is added to the mash (grains fraction) to make DDGS, the color becomes darker. Noll, Parsons, and Walters (2006) evaluated the color of DDGS batches prepared with approximately 0%, 30%, 60%, and 100% of the maximum possible amount of syrup added to the mash before drying (corresponding to 0, 12, 25, and 42 gallons/minute of solubles). As shown in Table 10.9, increasing the solubles addition rate to the mash resulted in a decrease in L* (lightness) and b* (yellowness), with an increase in a* (redness). Similar results were also reported by Ganesan, Rosentrater, and Muthukumarappan (2005).

Table 10.9. The effect of the rate of solubles addition to mash on color characteristics of distillers dried grains with solubles

Color (CIE Scale)	0 Gal/Min	12 Gal/Min	25 Gal/Min	42 Gal/Min	Pearson Correlation	P Value
L*[a]	59.4	56.8	52.5	46.1	- 0.98	0.0001
a*[a]	8.0	8.4	9.3	8.8	0.62	0.03
b*[a]	43.3	42.1	40.4	35.6	- 0.92	0.0001

Source: Adapted from Noll, Parsons, and Walters, 2006.
[a] L* = lightness of color (0 = black, 100 = white). The higher the a* and b* values, the higher the amount of redness and yellowness, respectively.

When heat is applied to feed ingredients, a browning or Maillard reaction occurs, resulting in the formation of high molecular weight polymeric compounds known as melanoidins. The degree of browning (measured via absorbance at 420 nm) is used to assess the extent of the Maillard reaction in foods, which affects amino acid digestibility, especially for lysine. Lightness and yellowness of DDGS color appear to be reasonable predictors of digestible lysine content for poultry (Ergul et al., 2003) and swine (Cromwell, Herkleman, and Stahly, 1993; Pederson, Pahm, and Stein, 2005).

Some dry-grind ethanol plants use process modifications to produce ethanol and DDGS. For example, some plants use cookers to add heat for fermentation and use fewer enzymes, while other plants use more enzymes and do not rely on the use of cookers to facilitate fermentation. Theoretically, use of less heat could improve amino acid digestibility of DDGS, but no studies have been conducted to determine how these processes affect final nutrient composition and digestibility.

Smell

High-quality, golden DDGS have a sweet, fermented smell. Dark-colored DDGS sources that have been overheated have a burned or smoky smell.

Bulk Density, Particle Size, and pH

Bulk density affects transport and storage costs and is an important factor to consider when determining the storage volume of transport vehicles, vessels, containers, totes, and bags. It also affects the amount of ingredient segregation that may occur during handling of complete feeds. Low bulk density ingredients have higher cost per unit of weight. High bulk density

Table 10.10. Particle size, bulk density, and pH of 34 sources of distillers dried grains with solubles

	Average	Range	SD	CV, %
Particle size, µm	665	256 - 1087	257.48	38.7
Bulk density, lbs/ft^3	31.2	24.9 – 35.0	2.43	7.78
pH	4.14	3.7 – 4.6	0.28	6.81

Source: Shurson, 2005 (unpublished data).

particles settle to the bottom of a load during transport, whereas low bulk density particles rise to the top of a load.

Samples of DDGS were collected by researchers at the University of Minnesota (unpublished data) in 2004 and 2005 (34 samples from ethanol plants in 11 different states). As shown in Table 10.10, average particle size was 665 µm but particles had an extremely large range, from 256 to 1087 µm. The pH of DDGS sources averages 4.1 but can range from 3.6 to 5.0.

Pelleting

The high fiber and fat content of DDGS makes it difficult to produce a firm pellet with minimal fines using conventional pelleting processes. Furthermore, adding DDGS to swine and poultry diets reduces the throughput of pellet mills.

Shelf Life

Preservatives and mold inhibitors are commonly added to wet distillers grains (~50% moisture) to prevent spoilage and extend shelf life. However, since the moisture content of DDGS is usually between 10% to 12%, there is minimal risk of spoilage during transit and storage unless water leaks into transit vessels or storage facilities. There are no published data demonstrating that preservatives and mold inhibitors are necessary to prevent spoilage and extend shelf life of DDGS.

Unless the moisture content exceeds 12% to 13%, the shelf life of DDGS appears to be stable for many months. In a field trial performed by the U.S. Grains Council, a sample of DDGS was shipped from an ethanol plant in South Dakota in a 40-foot container to Taiwan. Upon arrival, the DDGS sample was placed into 50 kg bags and stored in a covered steel pole barn for ten weeks during the course of the dairy feeding trial on a commercial dairy farm located about 20 km south of the Tropic of Cancer. Environmental temperatures averaged more than 32 °C and humidity was in excess of 90% during this storage period. There was no change in peroxide value (measure of oxidative rancidity of oil) in samples collected at arrival and again after the ten-week storage period, presumably because of the high amount of natural antioxidants present in corn, which are further increased by the heating process (Adom and Liu, 2002; Dewanto, Wu, and Liu, 2002).

Hygroscopicity

Limited information exists regarding the hygroscopicity, or ability to attract moisture, of DDGS. However, the U.S. Grains Council sponsored a broiler field trial in Taiwan, in which moisture content of DDGS was monitored during storage at a commercial feed mill from March to June of 2004. A random sample of DDGS was obtained weekly from storage at the feed mill and analyzed for moisture over a thirteen-week storage period. Moisture content increased from 9.05% at the beginning to 12.26% at the end of the thirteen-week storage period. Therefore, it appears that under humid climatic conditions, the moisture content of DDGS will increase during long-term storage.

Potential for Improving Quality and Consistency of Corn Co-products

One reason nutrient content is so variable in corn co-products is that different laboratories use different analytical methodologies. As a result of this industry-wide problem, the American Feed Ingredient Association, Renewable Fuels Association, and National Corn Growers Association evaluated and published the most appropriate methods for analyzing moisture, crude protein, crude fat, and crude fiber in DDGS in 2007 (Table 10.11).

Summary of Quality Characteristics of Distillers Dried Grains with Solubles

There are many factors that influence DDGS quality. Variability in nutrient content of DDGS appears to be primarily attributable to the inherent variation in nutrient content of corn and the amount of solubles added to the grains fraction. Nutrient digestibility is also affected by the amount of solubles added to the grains when producing DDGS, but the dryer type, time, and temperature have a significant impact on the heat damage to

Table 10.11. American Feed Ingredient Association analytical method recommendations for moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles

Analyte	Method	Method Description
Moisture	NFTA 2.2.2.5	Lab dry matter (105° C / 3 hrs.)
Crude protein	AOAC 990.03 [a]	Crude protein in animal feed – combustion
	AOAC 2001.11[a]	Crude protein in animal feed and pet food (copper catalyst)
Crude fat	AOAC 2001.11	Oil in cereal adjuncts (petroleum ether)
Crude fiber		Crude fiber in animal feed and pet food (F.G. crucible)

[a]Methods are statistically similar, and either is acceptable for use on DDGS.

protein—and the resulting reduction in amino acid digestibility. Color, particularly lightness and yellowness, has been shown to be a reasonable predictor of amino acid digestibility, especially for lysine.

Sulfur and sodium (salt) can vary substantially among DDGS sources because of the use of small amounts of chemicals containing these compounds during the ethanol production process. As a result, sulfur and salt levels should be monitored and diet formulation adjustments should be made when DDGS contains high levels of these minerals for cattle and poultry, respectively. Although the prevalence of mycotoxins in DDGS is very low, if mycotoxin-contaminated corn is used to produce ethanol and DDGS, these mycotoxins will still be present and concentrated by about three times the initial level found in corn. Virginiamycin is the only FDA-approved antimicrobial for ethanol production and is used in very small amounts to control bacterial infections in fermenters. Because of the chemical nature of this antimicrobial compound and the high temperature during the DDGS production process, there are no detectable residues in DDGS.

Particle size, bulk density, color, smell, and flowability can vary among DDGS sources and thus are part of the quality characteristics. Based on limited field trials, DDGS appear to be very stable under extreme climate conditions of high temperatures and humidity for at least two to three months without oxidative rancidity of fat. However, because the chemical characteristics of DDGS cause the grains to attract moisture, moisture content can increase slightly over a two- to three-month storage period.

Many fuel ethanol plants have implemented extensive quality control procedures to improve the nutritional and economical values of the produced DDGS. The feed and ethanol industries have also published analytical procedures they recommend for determining moisture, crude protein, crude fat, and crude fiber for DDGS, which will promote more uniform comparisons of levels of these nutrients among sources.

New Fractionation Technologies = New Corn Co-products

Fractionation of corn kernels into different components has been utilized to produce various industrial and food-grade products for many years. More recently, corn fractionation technologies are being developed, evaluated, and implemented by some ethanol plants in an attempt to remove non-fermentable components of the corn kernel and improve ethanol yield. There are several advantages of using fractionation technologies to produce ethanol and new corn co-products:

- A higher percentage of starch entering the ethanol fermentation tanks increases ethanol yield by approximately 10%.
- Fewer enzymes can be used for ethanol production because there is less interference between the oil- and starch-digesting enzymes during fermentation if the corn germ (the portion of the corn kernel containing oil) is removed prior to fermentation.
- There is less co-product mass to dry at the end of the ethanol production process, resulting in lower drying costs and potentially less heat damage to proteins.
- Less energy and water is needed to produce ethanol and corn co-products.
- Oil extraction from the corn germ reduces the need for frequent cleaning of the system, and the high-value oil can be sold or used for other applications such as biodiesel production.
- An increase in the number of fractionated co-products may add value and provide more diversified markets for the co-products.

Adoption of these technologies is being accelerated to increase ethanol yield from a bushel of corn because of increased demand and cost of corn, high natural gas prices, and the potential for reduced capital costs by implementing fractionation technologies. Furthermore, some ethanol plants desire a more diversified portfolio of corn co-products to target specific markets.

The Basics of Fractionation

Fractionation involves separating the corn kernel into three components: the endosperm, germ, and bran (tip and pericarp). The endosperm represents about 83% of the corn kernel and is primarily composed of starch, whereas the germ (about 12% of the kernel) is high in oil, protein, ash, and non-fermentable carbohydrates. The remaining bran portion is almost exclusively composed of fiber (non-fermentable carbohydrates).

There are a number of fractionation technologies being developed, but they have not yet become a significant part of ethanol and co-product production. These technologies can be divided into two categories:

- Front-end fractionation
  This involves separating the endosperm, germ, and bran fractions before fermentation. The endosperm fraction (rich in starch) is fermented to produce ethanol and a corn co-product. Corn oil is extracted from the germ fraction and marketed or utilized for various industrial applications, leaving the corn germ meal as a feed co-product. The bran fraction is also separated and used as a high-fiber feed, primarily for ruminants.

- Back-end fractionation
  This involves a two-step process to extract corn oil after the entire corn kernel is fermented to produce ethanol. Crude corn oil is extracted from thin stillage, resulting in low-fat syrup, which undergoes a second extraction along with whole stillage to separate more corn oil. The remaining residue is used to produce low-fat distillers grains.

General Nutrient Composition of New Fractionated Corn Co-products

Because fractionation is a new and emerging technology in fuel ethanol production, there are limited nutrient composition data for the resulting co-products. Dry matter, crude protein, crude fat, crude fiber, and ash concentrations for most of the known fractionated co-products are shown in Table 10.12.

In general, most fractionated corn co-products are higher in crude protein and crude fiber than DDGS and are lower in crude fat. Although

Table 10.12. Nutrient composition (%) of new fractionated corn distillers co-products (dry matter basis)

Company Co-product	Dry Matter	Crude Protein	Crude Fat	Crude Fiber	Ash
Typical corn DDGS	89.3	30.9	10.7	7.2	6.0
Poet Dakota Gold HP	91.6	44.8	3.9	7.3	2.1
Poet Dakota Bran	ND[a]	14.6	9.8	3.8	4.6
Poet Dehydrated Corn Germ	93.2	16.9	18.9	5.5	5.8
Maize Processing Innovators Quick Germ/Quick Fiber DDGS	ND	49.3	3.9	6.8	3.2
Maize Processing Innovators E-Mill DDGS	ND	58.5	4.5	2.0	3.2
Cereal Process Technologies Hi-Protein DDGS	ND	35.0-37.0	4.0-6.0	4.0-6.0	ND
Renessen Enhanced DDGS	ND	40.0-50.0	2.5-4.0	7.0-11.0	ND
Solaris NeutraGerm	97.0	17.5	45.0	6.0	1.9
Solaris Probran	90.0	9.5	2.0	16.6	1.0
Solaris Glutenol	90.0	45.0	3.3	3.8	4.0
Solaris Energia	90.0	30.0	2.5	8.2	2.5
FWS Technologies Enhanced DDGS	ND	35.0-37.0	6.5	ND	3.8
De-Oiled DDGS	89.9	31.3	2.3	ND	6.2
J. Jireh Products Dried Condensed Solubles	93.4	21.6	4.7	3.1	8.3

[a]ND = not determined.

the amino acid concentration may increase somewhat in many of these high-protein fractionated co-products, the protein quality (amino acid balance) is still poor relative to the requirements of monogastric animals. The reduced fat and increased fiber content of these fractions may result in lower energy value for swine and poultry. Therefore, their feeding and economic value may be reduced compared to DDGS for swine and poultry. However, the nutrient composition of these co-products would likely have greater value in ruminant diets because amino acid balance of corn protein is not as critical for ruminants as it is for swine and poultry. Furthermore, the increased amount of readily fermentable fiber can provide a good source of energy, and the lower fat content may allow higher dietary inclusion rates for lactating dairy cows while avoiding concerns of milk fat depression.

Potential Feeding Value of New Fractionated Corn Co-products for Livestock and Poultry

Because most of the new fractionation technologies have not been fully implemented and are being evaluated, limited quantities of fractionated corn co-products are being produced and are available commercially. As a result, there are limited published data on the efficiency and quality of these fractionated corn co-products in livestock and poultry feeds. Until such data become available, it is difficult to determine the comparative feeding values, dietary inclusion rates, and comparative nutritional and economic values of these co-products.

The following is a summary of recent studies conducted to evaluate selected fractionated co-products for various farm animal species.

Poultry. A high-protein hydrolyzed corn co-product obtained from the National Renewable Energy Laboratory was evaluated for nutrient content and digestibility, and for its feeding value in turkey starter diets (Abe et al., 2004). Dry matter, ash, fat, fiber, protein, starch, and sugar content were 95.9%, 1.43%, 10.7%, 3.9%, 57.8%, 1.6%, and 2.0%, respectively. The lysine, arginine, tryptophan, threonine, cystine, and methionine content as a percentage of crude protein were 1.99%, 2.63%, 0.34%, 3.14%, and 2.1%, respectively, and digestibility coefficients were 68.1%, 79.0%, 64.0%, 75.2%, 78.3%, and 85.9%, respectively. The nitrogen-corrected true metabolizable energy (TME_n) was 2,692 kcal/kg on an as-fed basis. When 0%, 5%, 10%, 15%, and 20% of this co-product were added to the diets and fed from three to eighteen days of age, there was a linear decrease in the average daily gain at day eleven, and a cubic effect from day eleven to eighteen. These results suggest that up to 10% of this co-product can be used effectively up to day fourteen, and higher inclusion rates may provide satisfactory growth for turkeys older than two weeks.

Batal (2007) determined the nutrient digestibility of DDGS, high protein distillers dried grains with solubles (HP-DDGS), dehydrated corn germ, and bran for poultry; the results are shown in Table 10.13. These results indicate that new fractionation technologies used in ethanol pro-

Table 10.13. Nutrient content and digestibility of distillers dried grains with solubles, high protein distillers dried grains with solubles, dehydrated corn germ, and corn bran for poultry

Nutrient	DDGS	HP-DDGS	Dehydrated Corn Germ	Bran Cake
Crude protein, %	27.0	44.0	15.5	11.6
Crude fiber, %	7.0	7.0	4.5	4.5
Crude fat, %	10.0	3.0	17.0	7.8
TME_n, kcal/kg	2,829	2,700	2,965	2,912
Lysine, %	0.79	1.03	0.83	0.43
Lysine availability, %	81	72	80	68
Lysine as a % of CP	2.9	2.3	5.4	3.7
Phosphorus, %	0.77	0.35	1.18	No data
P bioavailability, %	60	47	31	No data

Source: Batal, 2007.

duction result in co-products that have unique nutritional properties, and knowledge of their nutritional value is essential in order to assess their economic and feeding value.

HP-DDGS (33% protein, 0.33% phosphorus on a 90% dry matter basis) and corn germ meal (14% crude protein and 1.22% phosphorus) were fed to chicks and precision-fed roosters to determine the TME_n, amino acid digestibility, and phosphorus bioavailability for poultry (Kim et al., 2008). The TME_n and amino acid digestibility in corn germ meal were significantly higher compared to HP-DDGS, while phosphorous bioavailability was similar between DDGS and HP-DDGS (60% vs. 58%, respectively) but lower for corn germ meal (25%). These results suggest that corn germ meal is a better source of energy, with higher amino acid digestibility than high HP-DDGS, but DDGS and HP-DDGS are better sources of bioavailable phosphorus than is corn germ meal for poultry.

Swine. Widmer, McGinnis, and Stein (2007) conducted three experiments to determine energy, phosphorus, and amino acid digestibility in high protein distillers dried grains (without solubles) (HP-DDG) and corn germ compared to corn. The digestible and metabolizable energy content of corn (4,056 and 3,972 kcal/kg of dry matter, respectively) was similar to that in corn germ (3,979 and 3,866 kcal/kg, respectively) but was surprisingly lower than that in HP-DDG (4,763 and 4,476 kcal/kg, respectively). True total tract digestibility of phosphorus was higher in HP-DDG (69%) compared to corn germ (34%), similar to values obtained by Kim et al.

(2008) in poultry. Standardized ileal digestibilities for crude protein and all amino acids except arginine, lysine, glycine, and proline were higher in HP-DDG than in corn germ. Therefore, HP-DDG has higher levels of digestible energy, phosphorus, and most amino acids than does corn germ for swine.

Widmer et al. (2008) also evaluated the effects on growth performance, carcass quality, and palatability of pork when feeding DDGS (10% or 20% of the diet), HP-DDG (replaced 50% or 100% of soybean meal), and corn germ (5% or 10% of the diet) to growing-finishing pigs. Results from this study showed that feeding diets containing 20% DDGS or high dietary inclusion rates of HP-DDG had no negative effect on growth performance, carcass composition, muscle quality, or eating characteristics of bacon and pork chops but it may decrease pork fat quality. Similarly, feeding diets containing up to 10% corn germ had no negative effects on growth performance, carcass composition, carcass quality or eating characteristics of bacon and pork loins but increased final body weight and improved bacon fat quality (reduced iodine value).

Stein et al. (2005) conducted two studies to determine the digestibility of energy, crude protein, and amino acids from a yeast product extracted from ethanol co-product streams. The concentration of digestible and metabolizable energy in the yeast product was 5,600 and 5,350 kcal/kg of dry matter, respectively, which is 138% to 134% of the value found in corn (4,071 and 3,992 kcal/kg, respectively). The standardized ileal digestibility coefficients were also high for crude protein (74.8%), lysine (82.2%), methionine (88.6%), threonine (71.1%), tryptophan (82.2%), isoleucine (79.5%), leucine (84.0%), and valine (74.5%). These results suggest that this yeast product can be an excellent source of energy and digestible amino acids in swine diets.

Dairy. Kelzer et al. (2007) conducted a study to determine protein fractions and evaluate differences in rumen undegradable protein (RUP), RUP digestibility (dRUP), and amino acid concentrations in corn germ, corn bran, HP-DDGS, two sources of DDG, wet corn gluten feed, and wet distillers grains. A comparison of the nutrient concentrations in these corn by-products is shown in Table 10.14. Concentrations of RUP, dRUP, lysine, and methionine were different among corn milling co-product sources.

Table 10.14. Comparison of protein fraction concentrations as a percentage of crude protein among seven corn milling co-products

Protein fraction, % CP	Corn Germ	Corn Bran	High Protein DDGS	DDGS 1	DDGS 2	Wet Corn Gluten Feed	Wet Distillers Grains
Crude protein, % DM	16.3	13.5	47.2	30.1	28.9	26.7	29.9
Non-protein nitrogen	30.0	33.5	7.4	17.0	17.9	36.6	18.6
Rapidly degradable true protein	15.0	4.0	0.6	7.0	2.1	15.9	2.4
Moderately degradable true protein	38.1	54.3	82.4	67.0	41.0	33.2	53.1
Slowly degradable true protein	13.5	6.0	8.8	4.8	11.1	10.1	11.0
Undegraded true protein	3.4	2.2	0.8	4.2	27.9	4.1	14.9
Rumen undegraded protein	16.5	20.7	55.2	33.2	56.3	11.5	44.7
RUP digestibility	66.8	65.8	97.7	92.0	91.9	51.0	93.1
Lysine	2.9	3.2	2.0	1.9	1.9	3.5	1.9
Methionine	1.9	1.4	3.2	2.0	2.4	1.6	2.3

Source: Kelzer et al., 2007.

Corn germ produced as a co-product from ethanol production has been evaluated as an energy supplement for lactating dairy cows (Abdelqader et al., 2006). All diets contained a 5-to-45 forage-to-concentrate ratio, whereby forage was 60% corn silage and 40% alfalfa hay, and the concentrate contained 0%, 7%, 14%, or 21% of diet dry matter as corn germ. The addition of corn germ had no effect on dry matter intake, but increased concentrations of corn germ resulted in a quadratic response for milk yield, energy-corrected milk, milk fat concentration, and milk fat yield. Milk fat yield decreased when cows were fed the diet containing 21% corn germ meal, and milk protein content decreased linearly with increased corn germ in the diet, but milk protein yield and feed efficiency were not affected. These results suggest that adding corn germ at 7% and 14% of diet dry matter will increase milk and milk fat yield, but at the 21% level the concentration of milk fat will decrease.

Janicek et al. (2007) evaluated the effects of 10%, 17.5%, and 25% corn bran (replacing a portion of corn silage and alfalfa on a dry matter basis) on milk yield of lactating dairy cows. Moisture, crude protein, neutral detergent fiber, nonfiber carbohydrate, ether extract, and phosphorus content of the corn bran were 8.2%, 12.9%, 30.4%, 45.0%, 9.9%, and 0.70%, respectively. When corn bran increased from 10% to 25%, there were no effects on dry matter intake or milk fat yield, but milk yield, milk protein yield, and feed conversion all increased. The decrease in milk fat concentration with increasing levels of corn bran, coupled with the increase in total milk yield, resulted in no differences between dietary treatments in 3.5% fat-corrected milk.

Beef. Bremer et al. (2006) evaluated a low-protein corn co-product called Dakota Bran Cake (DBRAN) on feedlot performance and carcass characteristics for finishing cattle. Diets contained 0%, 15%, 30%, or 45% DBRAN or 30% DDGS, replacing corn on a dry matter basis. Final body weight, average daily gain, and feed conversion increased linearly, and daily dry matter intake responded in a positive quadratic manner as the level of DBRAN increased in the diet. There were no differences among dietary treatments in carcass characteristics except for a linear increase in hot carcass weight for steers fed increasing levels of DBRAN. These results suggest that feeding DBRAN at up to 45% of the diet improves growth performance with no effects on carcass characteristics, and that DBRAN has approximately 100% to 108% of the energy value of corn.

DDGS from a traditional dry-grind ethanol production process was compared to DDGS obtained from a partial fractionation process at a level of 13% of the diet on a dry matter basis (Depenbusch et al., 2008). No differences in dry matter intake, average daily gain, gain efficiency, or carcass characteristics were observed for heifers fed either diet, but those fed the traditional DDGS diet consumed more feed. These results suggest that moderate inclusion levels of DDGS in flaked corn diets for finishing heifers can provide satisfactory growth performance and carcass characteristics.

Summary: Use of Fractionated Corn Co-products in Livestock Feed

Corn fractionation has been used for many years to produce specialized industrial and food-grade products. In order to minimize cost and improve ethanol yields, fuel ethanol plants are beginning to implement "front-end" processes to separate the endosperm (starch-rich fraction) from the non-fermentable fractions, including the germ and bran. "Back-end" fractionation technologies are used to extract corn oil from the co-product streams, resulting in higher protein and fiber but lower oil content of the resulting feed ingredient co-products. The number of published scientific studies that evaluate these fractionated corn co-products in livestock and poultry feeds has been limited. Until more research is conducted, it is difficult to determine the co-products' comparative feeding value, dietary inclusion rates, and comparative nutritional and economic value. However, all of the fractionated co-products produced have nutritional value and feeding applications in animal feeds.

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