Overview of Swine Nutrition Research on the Value and Application of Distiller's Dried Grains with Solubles Produced by Minnesota and South Dakota Ethanol Plants

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Goal

The overall goal of this research program has been to increase the use of distiller's dried grain with solubles (DDGS), produced by ethanol plants in Minnesota and South Dakota, in practical swine diets. Swine nutritionists have been reluctant to use significant quantities of DDGS in commercial diets for several reasons including: variability in nutrient content, low digestibility of amino acids, low energy relative to corn, questionable phosphorus availability, and cost competitiveness relative to corn, soybean meal and dicalcium phosphate. These concerns are based on published nutrient composition and digestibility values in NRC (1998), Heartland Lysine Feed Ingredient Database, and Feedstuffs Reference Issue.

History, Funding, and Objectives

In order to accomplish the goal of increasing the use of DDGS in swine diets, a group of ethanol plant managers in Minnesota and South Dakota formed an informal group which also included John Goihl (Agri-Nutrition Services), Steve Markham (Commodity Specialists, Inc.) and Dr. Jerry Shurson (University of Minnesota) to develop a research plan. Through funding provided primarily by the ethanol plants, and support from the Minnesota Corn Growers Association (see funding summary attachment), we conducted a series of experiments to determine if there is higher nutritional value of DDGS compared to other industry sources and compared to published nutrient content and digestibility values. In order to attempt to differentiate Minnesota and South Dakota DDGS from other DDGS sources in the ethanol industry, a series of experiments were conducted to:

- Determine the nutrient content and digestibility of DDGS
- Determine the variability in nutrient content within participating plants
- Determine the impact of adding DDGS on manure management, gas, and odor emissions
- Determine the effects of formulating grow-finish diets on a total amino acid basis on growth performance, carcass characteristics, and pork quality
- Determine the economic value of DDGS in swine diets

Results

In general, results of these studies showed:

- Higher nutrient levels and digestibility compared to a common DDGS source in the ethanol industry
- Higher nutrient levels and digestibility compared to published reference values
- No detrimental effects on ammonia, hydrogen sulfide or odor emissions from swine manure
- A significant reduction in phosphorus content in manure

- DDGS can be added up to 20% of the diet if formulated on a total amino acid basis without negative effects on growth performance (higher amounts can likely be used if diets are formulated on a digestible amino acid basis).
- Adding DDGS has no negative effects on pork quality except increasing the amount of unsatuated fat and reduced fat firmness with increasing dietary inclusion rates
- Can be effectively used as a partial replacement for corn, soybean meal and dicalcium phosphate and be an economical addition to practical swine diets

Publications, Presentations, and Education

Results from these studies have been presented to scientists and feed industry nutritionists at Midwest and National American Society of Animal Science meetings, as well as at a variety of ethanol industry workshops and conferences (see the attached publication list). As a result of these presentations and publications, our Swine Nutrition Research Team has received, and continue to receive a large number of requests for more detailed information from pork producers and feed industry nutritionists. Our plan is to publish a research summary in the form of a Minnesota-South Dakota DDGS User's Manual to in order to meet this demand and provide a condensed version of this research information to current and potential DDGS users. We have also been involved in a number of radio interviews and press releases sponsored by the Minnesota Corn Growers Association.

Future Research

Our research focus this year, is to complete the approved performance studies with sows (gestation and lactation) and nursery pigs. In addition, we are planning a second grow-finish experiment to demonstrate that formulating diets on a digestible amino acid basis allows higher inclusion rates of DDGS than if diets are formulated on a total amino acid basis. In addition, results from informal field studies suggest that adding DDGS to grow-finish diets reduces the need for antibiotics and alleviates gut health problems in commercial operations. A series of three or four experiments are planned to be conducted to determine the benefits of DDGS on gut health. Finally, two additional studies may be conducted to evaluate operations management in ethanol plants to determine ways of improving quality and consistency of DDGS and explore ways of developing an identity preservation system to potentially meet the demands of prospective export markets.

Nutrient Database for Distiller's Dried Grains with Solubles Produced from New Ethanol Plants in Minnesota and South Dakota

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Reliable values for the nutrient content of feed ingredients are essential to swine nutritionists in order for more precise diet formulations. Because distiller's feeds are by-products of a process designed primarily for ethanol production, a number of factors can influence the nutritional and physical characteristics of the resulting distiller's feeds such as selection of grains, type of fermentation (continuous vs. batch) and drying temperature and duration (Carpenter, 1970; Olentine, 1986). Research demonstrating product variability among DDGS sources (Carpenter, 1970; Cromwell and Stahly, 1986; Cromwell et al., 1993), high NDF content (Cromwell and Stahly, 1986), and relatively low lysine levels relative to other amino acids (Wahlstrom et al., 1970; Cromwell et al., 1983), have discouraged nutritionists from using substantial amounts of distiller's feeds in swine diets.

Very little research has been conducted on distiller's by-products within the last 15 years. However, the ethanol industry has changed during that time. Modern fermentation technology, lower drying temperatures, and better quality control methods have been implemented in new ethanol plants. The current published values for distillers dried grains with solubles (DDGS) reflect the composition of products produced nearly 20 years ago. Feed manufacturers strive to identify ingredient suppliers that provide consistent, well-defined nutrient levels and quality in their product. To potentially increase use of DDGS in swine diets, research needs to be conducted using DDGS from new ethanol plants to have more precise estimates of the nutrient composition of DDGS.

The objectives of this study were to identify nutrient values of DDGS produced in 10 new ethanol plants (less than 5 yr. old) in the Minnesota-South Dakota (MNSD) region, determine nutrient variability among and within plants, and compare MNSD DDGS to reference values (NRC, 1998; Feedstuffs Reference Issue, 1999; and Heartland Lysine, 1998) and DDGS produced by older Midwestern plants (OMP). Year to year differences were also examined in this study.

Samples of DDGS were collected every two months during 1997 (n=38), 1998 (n=50), and 1999 (n=30) from ethanol plants in the Minnesota-South Dakota region. Eight plants submitted 12 samples each and two plants submitted 11 samples each for a total of 118 samples. A DDGS sample from an older Midwestern plants that was considered standard for the industry was also collected for comparison purposes. The main distinctive visual difference in the OMP sample compared to the MNSD DDGS samples was that it was darker in color. Older ethanol plants may not be capable of using modern fermentation and processing technology or be able to provide the level of quality control compared to newer ethanol plants. Older-style plants use large fermenters that are operated on a continuous basis compared to a batch basis used in newer ethanol plants. Furthermore, these older, larger ethanol plants typically obtain grain from a large geographical area. Excessive heat may also be used during drying of the DDGS in older plants, which contributes to the darker color of DDGS and potentially reduced nutrient digestibility. Therefore, differences in fermentation methods and heat processing can ultimately affect the nutrient profiles and amino acid digestibility of the final product.

All samples were sent to the University of Missouri (Columbia, MO) for amino acid analysis and Iowa Testing Laboratory Inc. (Eagle Grove, IA) for proximate analysis and mineral analysis. Digestible and metabolizable energy values were calculated using the following formulas:

$$DE\ \ kcal/kg = [((\%CP * 4) + (\%NFE * 4) + (\%Fat * 9)) * 4.54] * 2.205$$
$$ME\ \ kcal/kg = [DE * ((0.96 – ((0.2 * \%CP)/ 100))] * 2.205$$

Nutrient values of the MNSD DDGS were compared to published values in NRC (1998), Heartland Lysine Amino Acid Database (1998), and Feedstuffs Reference Issue (1999), as well as the sample of DDGS collected from an older Midwestern plant (Tables 1,2, and 3).

Maximum energy intake is essential to pig performance in all phases except during the gestation and late finishing phases. Consequently, the higher crude fat content of MNSD DDGS compared to OMP DDGS results in improved nutritional value and is an advantage to the pig. Higher crude fat content in the MNSD DDGS contributes to higher DE and ME values and helps negate the energy dilution effect of the high fiber content in the DDGS.

All 11 essential amino acids were higher in Minnesota-South Dakota DDGS than the sample OMP DDGS in this study, potentially making MNSD DDGS a more valuable source than other DDGS sources since less lysine supplementation would be needed to meet the desired lysine level in the diet. However, the variability in lysine and methionine levels among plants is of some concern because precise diet formulations require predictability of amino acid levels in MNSD DDGS. Because variability does exist between plants, nutritionists need to become familiar with nutrient levels and variability within individual plants before formulating diets using DDGS.

When compared to NRC (1998), MNSD DDGS is higher in crude fat, calculated DE, calculated ME, lysine, methionine, and threonine levels. These results will improve diet formulation precision when using DDGS from MNSD ethanol plants.

One of the most important conclusions that can be drawn from this study is that variability exists within and among ethanol plants and among published reference sources. Nutritionists considering using DDGS in swine diets should be aware that there is considerable variation in the nutrient content of DDGS among plants, even plants using the same fermentation and processing technology. A complete chemical analysis should be conducted a minimum of once yearly on the DDGS source to account for differences in nutrient composition due to corn crop. More frequent chemical analysis will help the nutritionist determine typical variability within the plant supplying DDGS. Nutritionists should avoid frequent changes in DDGS supplier, and develop a working relationship with their supplier to communicate openly about nutrient variability in the product and quality control measures that can prevent variability.

Table 1. Proximate analysis of DDGS originating from newer (< 5 years old) ethanol plants in Minnesota and South Dakota compared to a standard OMP sample and referenced values.[1]

Sample origin	# of samples	DM (%)	CP (%)	Fat (%)	Fiber (%)	Ash (%)	NFE (%)	ADF (%)	NDF (%)	DE[2] (kcal/kg)	ME[2] (kcal/kg)
MN-SD											
Aberdeen	12	87.4 (1.7)	30.8 (10.2)	10.2 (10.5)	8.9 (11.1)	6.3 (14.8)	43.8 (8.8)	14.2 (8.0)	46.2 (10.0)	3909 (2.9)	3541 (3.2)
Bingham Lk	12	90.2 (1.0)	30.9 (7.6)	10.7 (6.1)	9.1 (6.6)	6.4 (15.1)	43.8 (8.4)	18.1 (7.5)	44.4 (5.0)	3883 (3.9)	3510 (4.0)
Benson	12	88.4 (1.0)	30.1 (2.7)	11.2 (5.0)	8.3 (5.6)	5.4 (11.4)	45.0 (2.9)	14.8 (51.8)	37.0 (19.7)	4020 (1.2)	3645 (1.2)
Claremont	12	89.1 (1.3)	31.4 (2.1)	11.4 (5.5)	9.2 (5.9)	5.6 (8.8)	42.4 (3.2)	13.8 (—)	40.5 (4.9)	3982 (0.9)	3599 (0.9)
Luverne	12	87.2 (1.1)	29.8 (3.3)	11.7 (7.4)	8.3 (8.8)	5.8 (11.6)	44.9 (3.9)	16.0 (55.8)	36.8 (20.6)	4022 (2.1)	3654 (2.2)
Morris	12	90.0 (2.0)	30.7 (6.8)	10.2 (9.1)	8.8 (9.3)	5.5 (16.7)	44.8 (7.2)	15.8 (8.4)	44.5 (4.3)	3945 (1.5)	3568 (1.5)
Preston	11	88.7 (1.5)	28.7 (5.7)	11.4 (7.0)	8.4 (8.9)	6.7 (7.4)	44.9 (4.9)	16.3 (54.2)	36.7 (23.1)	3971 (1.5)	3610 (1.7)
Scotland	11	89.8 (1.4)	31.6 (4.9)	10.8 (4.4)	9.7 (5.2)	5.7 (16.3)	42.2 (5.3)	18.5 (10.1)	49.1 (3.1)	3932 (1.5)	3550 (1.8)
Winnebago	12	90.0 (0.6)	28.7 (4.1)	10.7 (5.9)	8.3 (5.7)	5.4 (12.5)	46.9 (2.8)	15.4 (11.2)	42.8 (3.7)	3995 (1.3)	3629 (1.3)
Winthrop	12	88.7 (0.8)	29.5 (3.3)	10.8 (5.5)	8.7 (4.3)	5.2 (7.6)	45.8 (3.8)	17.1 (6.6)	41.9 (2.4)	3989 (0.7)	3621 (0.7)
1997 – 99	118	88.9 (1.7)	30.2 (6.4)	10.9 (7.8)	8.8 (8.7)	5.8 (14.7)	44.5 (6.1)	16.2 (28.4)	42.1 (14.3)	3965 (2.2)	3592 (2.4)
OMP DDGS	4	88.3 (0.9)	28.1 (2.4)	8.2 (12.6)	7.1 (4.2)	6.3 (17.5)	50.3 (5.9)	16.7 (—)	35.4 (—)	3874 (0.2)	3521 (0.3)
Reference[3]											
NRC		93.0	29.8	9.0	4.8			17.5	37.2	3449	3038
HL		90.8	28.5								
FRI		93.0	29.0	8.6	9.1	4.8					3848

[1] Nutrient values expressed on 100% dry matter basis. Coefficients of variation presented in parenthesis.

[2] DE = [(CP * 4) + (NFE * 4) + (Fat * 9)] * 4.54, ME = DE * [(0.96 - (0.2 * CP))/100].

[3] References are: Nutrient Requirements of Swine, 10th ed., 1998. (NRC)
Heartland Lysine, Inc. Amino Acid Digestibility Tables, 1998. (HL)
Feedstuffs Reference Issue, Vol. 71 Num. 31, July 30, 1999. (FRI)

Table 2. Essential amino acid level of DDGS originating from newer (< 5 years old) ethanol plants in Minnesota and South Dakota compared to a standard OMP sample and referenced values.[1]

Sample origin	# of samples	Arg (%)	His (%)	Ile (%)	Leu (%)	Lys (%)	Met (%)	Phe (%)	Thr (%)	Trp (%)	Val (%)
MN-SD											
Aberdeen	12	1.31 (6.2)	.82 (5.3)	1.14 (7.5)	3.69 (5.3)	1.02 (9.6)	.65 (9.8)	1.53 (5.0)	1.21 (5.6)	.27 (9.1)	1.56 (6.2)
Bingham Lk	12	1.23 (2.1)	.78 (2.1)	1.10 (5.4)	3.51 (3.2)	.91 (2.9)	.53 (5.1)	1.47 (3.7)	1.12 (2.5)	.25 (5.9)	1.46 (2.8)
Benson	12	1.15 (11.5)	.75 (8.6)	1.17 (8.0)	3.62 (6.7)	.74 (17.8)	.53 (6.2)	1.50 (7.0)	1.17 (6.3)	.24 (9.1)	1.55 (8.5)
Claremont	12	2.17 (4.2)	.77 (4.3)	1.15 (6.0)	3.53 (3.1)	.91 (10.1)	.50 (2.5)	1.46 (2.8)	1.12 (3.4)	.26 (5.8)	1.50 (3.7)
Luverne	12	1.25 (6.5)	.78 (7.0)	1.07 (8.7)	3.42 (6.3)	.94 (11.3)	.58 (9.4)	1.42 (6.7)	1.14 (7.4)	.25 (7.3)	1.47 (8.3)
Morris	12	1.15 (11.5)	.73 (9.0)	1.15 (9.7)	3.47 (6.1)	.79 (25.7)	.49 (8.7)	1.42 (6.4)	1.12 (6.7)	.24 (13.9)	1.49 (7.2)
Preston	11	1.18 (5.5)	.76 (7.8)	1.05 (11.1)	3.43 (7.9)	.85 (7.2)	.55 (10.2)	1.43 (7.8)	1.14 (7.9)	.24 (6.7)	1.43 (10.1)
Scotland	11	1.25 (7.8)	.79 (7.2)	1.17 (8.2)	3.81 (7.5)	.78 (11.2)	.69 (6.4)	1.57 (7.3)	1.14 (6.0)	.25 (6.9)	1.53 (7.5)
Winnebago	12	1.11 (9.9)	.75 (7.6)	1.05 (8.3)	3.48 (5.6)	.72 (19.7)	.53 (3.9)	1.41 (6.7)	1.07 (6.4)	.21 (8.4)	1.47 (7.1)
Winthrop	12	1.13 (8.7)	.72 (8.0)	1.16 (5.6)	3.55 (3.3)	.80 (16.4)	.49 (5.4)	1.48 (3.2)	1.12 (3.1)	.25 (8.9)	1.51 (6.1)
1997 - 99	118	1.20 (9.1)	.76 (7.8)	1.12 (8.7)	3.55 (6.4)	.85 (17.3)	.55 (13.6)	1.47 (6.6)	1.13 (6.4)	.25 (6.7)	1.50 (7.2)
OMP DDGS	4	.92 (18.7)	.61 (15.2)	1.00 (9.1)	2.97 (12.4)	.53 (26.5)	.50 (4.5)	1.27 (8.1)	.98 (7.3)	.19 (19.8)	1.39 (2.3)
Reference[2]											
NRC		1.22	.74	1.11	2.76	.67	.54	1.44	1.01	.27	1.40
HL		1.21	.75	1.09	3.27	.81	.63	1.43	1.11	.20	1.43
FRI		1.08	.65	1.08	2.90	.65	.65	1.29	1.02	.22	1.43

[1] Nutrient values expressed on 100% dry matter basis. Coefficients of variation presented in parenthesis.

[2] References are: Nutrient Requirements of Swine, 10th ed., 1998. (NRC)
Heartland Lysine, Inc. Amino Acid Digestibility Tables, 1998. (HL)
Feedstuffs Reference Issue, Vol. 71 Num. 31, July 30, 1999. (FRI)

Table 3. Mineral composition of DDGS originating from newer (< 5 years old) ethanol plants in Minnesota and South Dakota compared to a standard OMP sample and referenced values.[1]

Sample origin	# of samples	Ca (%)	P (%)	K (%)	Mg (%)	S (%)	Na (%)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)
MN-SD											
Aberdeen	12	.03 (44.9)	.85 (15.3)	.84 (14.3)	.32 (14.0)	.33 (21.8)	.15 (28.8)	72.1 (39.6)	21.3 (57.5)	6.0 (24.8)	175.7 (60.9)
Bingham Lk	12	.03 (13.9)	.94 (6.9)	.99 (9.5)	.34 (7.5)	.68 (23.8)	.16 (96.2)	56.6 (8.0)	15.5 (9.1)	5.3 (8.8)	98.1 (13.1)
Benson	12	.08 (17.4)	.92 (7.1)	.99 (5.3)	.35 (6.0)	.40 (16.4)	.21 (19.4)	110.0 (31.2)	15.4 (14.2)	6.3 (12.0)	118.7 (5.9)
Claremont	12	.07 (51.2)	.95 (4.7)	1.06 (7.1)	.34 (4.7)	.38 (40.8)	.20 (55.2)	130.0 (24.0)	15.3 (11.2)	5.4 (15.2)	144.7 (12.6)
Luverne	12	.05 (36.6)	.91 (3.1)	.97 (7.6)	.37 (5.2)	.47 (29.4)	.20 (24.4)	96.7 (24.2)	17.4 (27.9)	6.3 (15.4)	106.9 (25.2)
Morris	12	.13 (33.6)	.82 (12.2)	.94 (10.9)	.34 (13.3)	.74 (21.9)	.51 (44.8)	44.7 (11.7)	16.0 (15.7)	7.6 (18.9)	156.4 (31.3)
Preston	11	.06 (50.6)	.99 (8.2)	1.04 (7.6)	.36 (6.4)	.37 (37.9)	.20 (49.8)	312.1 (18.9)	17.8 (25.5)	5.9 (14.6)	103.2 (16.5)
Scotland	11	.03 (21.1)	.70 (6.4)	.69 (10.6)	.25 (10.7)	.46 (6.4)	.12 (9.4)	60.2 (7.8)	10.7 (12.9)	6.1 (14.8)	90.5 (15.4)
Winnebago	12	.06 (15.2)	.89 (5.5)	.84 (4.4)	.33 (4.3)	.54 (14.3)	.17 (32.8)	52.2 (6.9)	13.8 (4.4)	4.7 (10.8)	75.3 (13.9)
Winthrop	12	.07 (15.3)	.94 (5.6)	1.03 (5.5)	.35 (4.7)	.36 (9.7)	.46 (34.4)	55.1 (10.5)	14.7 (9.9)	5.3 (19.0)	124.3 (19.1)
1997 - 99	118	.06 (57.2)	.89 (11.7)	.94 (14.0)	.33 (12.1)	.47 (37.1)	.24 (70.5)	97.5 (80.4)	15.8 (32.7)	5.9 (20.4)	119.8 (41.1)
OMP DDGS	4	.44 (34.7)	.90 (7.5)	.99 (8.7)	.40 (3.3)	.51 (43.5)	.28 (65.2)	80.2 (30.5)	49.5 (66.6)	13.5 (63.6)	219.2 (52.5)
Reference[2]											
NRC		.22	.83	.90	.20	.32	.27	86	26	61	276
FRI		.38	1.02	1.08	.38	.32	.86	91	32	54	323

[1] Nutrient values expressed on 100% dry matter basis. Coefficients of variation presented in parenthesis.

[2] References are: Nutrient Requirements of Swine, 10th ed., 1998. (NRC)
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Dietary Nutrient Balance and Determination of Digestible Energy and Metabolizable Energy Values of Distiller's Dried Grains with Solubles

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Reliable and consistent nutrient values of feed ingredients are essential to swine nutritionists. Because distiller's dried grains with solubles are a co-product of a process designed primarily for ethanol production, a number of factors can influence the nutritional and physical characteristics of the product. Variability in nutritional properties can be the result of corn crop used, percent solubles added back to distiller's dried grains, completeness or duration of the fermentation process which affects the degree of starch removal, or temperature and duration of drying (Carpenter, 1970; Olentine, 1986).

Carpenter (1970) compiled a nutrient database from samples supplied by numerous companies during a three-year period. Cromwell et al. (1993) studied the physical, chemical, and nutritional characteristics of DDGS from nine sources. The results of both studies demonstrated that there is tremendous variability in the nutritional characteristics of DDGS from different sources.

Published feed ingredient tables used by nutritionists do not distinguish nutrient profiles among ingredient sources. In fact, one of the common reasons why more nutritionists do not use DDGS in swine diet formulations is because of product variability and lack of knowledge of DDGS nutrient values from specific sources.

Discrepancies exist among published feed ingredient tables regarding the nutrient composition of DDGS. The energy density of DDGS (dry-matter basis) is listed as 3032 kcal ME/kg in NRC (1998), 3838 kcal ME/kg in Feedstuffs Reference Issue (1999), 3773 kcal ME/kg in Feed Co-Products of the Dry Corn Milling Process (1997) and 3732 kcal ME/kg in Distillers Feeds (2000). Crude protein levels (dry-matter basis) are less variable but still range from 27.78% in the Feed Co-Products of the Dry Corn Milling Process (1997) to 29.6% in Distillers Feeds (2000). Total phosphorus levels (dry-matter basis) for DDGS cited in Feed Co-Products of the Dry Corn Milling Process (1997), Distillers Grains (2000) and NRC (1998) are similar (0.79, 0.82% and 0.83%, respectively) but are much lower than 1.02% in Feedstuffs Reference Issue (1999). These discrepancies suggest that more definitive nutrient values are needed for DDGS.

This study was conducted to determine DE and ME values for MNSD DDGS. These values were then compared to current published book values (Feed Co-Products of the Dry Corn Milling Process, 1997; NRC, 1998; Feedstuffs Reference, 1999; Distillers Grains, 2000). Additionally, the effects of adding 10, 20, or 30% MNSD DDGS to corn-soybean meal diets for grow-finish pigs on energy, nitrogen, and phosphorus digestibility and excretion were examined.

Sixteen grower pigs weighing 28.6 ± 2.2 kg and 31.2 ± 7.3 kg during the 1st and 2nd balance trials, respectively, and 16 finisher pigs weighing 84.4 ± 6.2 kg and 76 ± 10.6 kg during the 1st and 2nd balance trials, respectively, were randomly assigned to one of four corn-soybean meal based dietary treatments: control (0% DDGS), 10% DDGS, 20% DDGS, and 30% DDGS. Diets were formulated to contain the same level of apparent digestible lysine and total P within each of the two phases. Pigs were housed in individual metabolism crates for 10 days and limit fed an average of 1031 g/d and 1139 g/d during the grower phases of the 1st and 2nd balance trials, respectively and 1767 g/d and 1814 g/d during the finisher phases of the 1st and 2nd balance trials, respectively. Urine and feces were collected on day 8 to 10 of the 10-day period. Feed, feces, and urine were analyzed for nitrogen, phosphorus, and gross energy content. Digestible and metabolizable energy values were determined during both the 1st and 2nd balance trials, while nitrogen and phosphorus retention were determined only during the 1st balance trial. Digestible and metabolizable energy concentrations for the MNSD DDGS were variable and it is difficult to assign a specific value for the DE and ME content of MNSD DDGS based on this study. However, even the lowest estimates of energy density in MNSD DDGS indicate that the DDGS product from the Minnesota-South Dakota region is at least equal the published values in NRC (1998), Feedstuffs Reference Issue (1999), Distillers Grains (2000) and Feed Co-Products of the Dry Corn Milling Process (1997) and may be higher. Adding DDGS to the diet increased gross energy intake but DE and ME (%) began to decrease when 20% was added to the grower diets and when 30% DDGS was added to finisher diets.

Table 1. Composition, calculated and analyzed nutrient analysis (as-fed basis) of grower and finisher diets.

	Grower Diets				*Finisher Diets*			
Ingredient	*Control*	*10% DDGS*	*20% DDGS*	*30% DDGS*	*Control*	*10% DDGS*	*20% DDGS*	*30% DDGS*
Corn, %	68.12	61.31	54.50	47.68	82.11	73.90	65.69	57.48
Soybean meal (44%), %	29.30	26.37	23.44	20.51	15.34	13.80	12.27	10.74
MNSD DDGS, %	0.00	10.00	20.00	30.00	0.00	10.00	20.00	30.00
Limestone, %	0.93	1.01	1.09	1.18	0.81	0.92	1.04	1.15
Dicalcium phosphate, %	0.75	0.50	0.25	0.00	0.85	0.57	0.28	0.00
Salt, %	0.50	0.45	0.40	0.35	0.50	0.45	0.40	0.35
Vitamin premix[1], %	0.30	0.27	0.24	0.21	0.30	0.27	0.24	0.21
Trace mineral premix[2], %	0.10	0.09	0.08	0.07	0.10	0.09	0.08	0.07
Calculated Analysis								
Est. ME (kcal/kg)	3264	3220	3176	3131	3297	3250	3202	3154
Crude protein, %	18.68	19.67	20.67	21.66	13.73	15.21	16.7	18.19
Total lysine, %	1.02	1.00	0.97	0.95	0.65	0.66	0.68	0.69
App. dig. lysine, %	0.83	0.83	0.83	0.83	0.51	0.51	0.51	0.51
Methioine + Cystine,%	0.62	0.60	0.59	0.58	0.51	0.51	0.50	0.50
Threonine, %	0.78	0.80	0.83	0.86	0.57	0.62	0.67	0.72
Tryptophan, %	0.24	0.24	0.24	0.23	0.17	0.17	0.18	0.18
Calcium, %	0.62	0.60	0.58	0.56	0.56	0.55	0.54	0.53
Phosphorus, %	0.52	0.52	0.52	0.52	0.49	0.49	0.49	0.49
Analyzed Levels								
Crude protein, %	17.14	18.56	18.83	20.39	17.14	14.91	16.04	16.95
Total lysine, %	0.97	1.05	0.94	0.93	---	---	---	---
Methioine + Cystine,%	0.61	0.66	0.67	0.68	---	---	---	---
Threonine, %	0.69	0.76	0.74	0.77	---	---	---	---
Tryptophan, %	0.20	0.20	0.20	0.20	---	---	---	---
Calcium, %	0.77	0.69	0.70	0.72	0.77	0.67	0.61	0.60
Phosphorus, %	0.45	0.47	0.44	0.45	0.45	0.44	0.45	0.48

[1] Nutrients provided per kg of vitamin premix: vitamin A 2,205,000 IU, vitamin D_3 551,250 IU, vitamin E 9188 IU, vitamin K 1471 mg, riboflavin 2205 mg, niacin 13230 mg, pantothenic acid 8820 mg, vitamin B_{12} 11 mg, pyridoxine 293 mg, folic acid 368 mg, biotin 73 mg, choline 194,774 mg, thiamine 221 mg

[2] Nutrients provided per kg of trace mineral premix: iodine 600 mg, selenium 99 mg, zinc 100,019 mg, iron 100,019 mg, copper 6615 mg, manganese 29988 mg

Table 2. Effect of dietary treatment on energy digestibility in first trial (dry-matter basis).

Variable	*Control*	*10% DDGS*	*20% DDGS*	*30% DDGS*	*CV (%)*
<u>Grower</u>					
GE intake (kcal/d)	3856 ^{a}	4024 ^{a,b}	3844 ^{a}	4263 ^{b}	6.51
DE intake (kcal/d)	3341	3556	3313	3586	6.38
ME intake (kcal/d)	3314	3533	3282	3554	6.45
DE intake/GE intake (%)	86.69 ^{a,b}	88.36 ^{a}	86.19 ^{b}	84.14 ^{c}	1.64
ME intake/GE intake (%)	86.02 ^{a,b}	87.80 ^{a}	85.37 ^{b,c}	83.39 ^{c}	1.93
DE DDGS*	----	5862 ^{a}	4478 ^{b}	4024 ^{b}	10.15
ME DDGS*	----	5827 ^{a}	4338 ^{b}	3957 ^{b}	10.43
<u>Finisher</u>					
GE intake (kcal/d)	6446 ^{a}	6720 ^{b}	6738 ^{b}	6829 ^{b}	3.00
DE intake (kcal/d)	5574	5970	5785	5783	6.03
ME intake (kcal/d)	5465	5912	5724	5663	6.38
DE intake/GE intake (%)	86.40	88.86	85.82	84.65	4.12
ME intake/GE intake (%)	84.70 ^{a,b}	87.99 ^{a}	84.89 ^{a,b}	82.90 ^{b}	4.50
DE DDGS*	----	5398 ^{a}	4153 ^{b}	3937 ^{b}	14.40
ME DDGS*	----	4820 ^{a}	3959 ^{b}	3794 ^{b}	14.69

a,b,c P < .10
* DE DDGS = (DE intake – (((1-% DDGS in diet)*ADFI) * DE control diet))/(% DDGS in trt diet *ADFI)
ME DDGS = (ME intake – (((1-% DDGS in diet)*ADFI) * ME control diet))/(% DDGS in trt diet*ADFI)

Table 3. Effect of dietary treatment on energy digestibility in second trial (dry-matter basis).

Variable	*Control*	*10% DDGS*	*20% DDGS*	*30% DDGS*	*CV (%)*
<u>Grower</u>					
GE intake (kcal/d)	4360	4309	4540	4661	0.00
DE intake (kcal/d)	3754 ^{a}	3705 ^{a}	3791 ^{a,b}	3872 ^{b}	2.31
ME intake (kcal/d)	3643 ^{a,b}	3578 ^{a}	3650 ^{a,b}	3736 ^{b}	2.78
DE intake/GE intake (%)	86.10 ^{a}	85.97 ^{a}	83.50 ^{a,b}	83.06 ^{b}	2.31
ME intake/GE intake (%)	83.56 ^{a}	83.02 ^{a,b}	80.40 ^{b}	80.16 ^{b}	2.79
DE DDGS*	----	2830	3314	3537	18.52
ME DDGS*	----	2551	3053	3347	24.83
<u>Finisher</u>					
GE intake (kcal/d)	7109	7175	7371	7543	0.00
DE intake (kcal/d)	3754 ^{a}	3950 ^{b}	3620 ^{c}	3872 ^{b}	2.75
ME intake (kcal/d)	3643 ^{a}	3824 ^{b}	3480 ^{c}	3736 ^{a,b}	2.95
DE intake/GE intake (%)	86.10 ^{a}	86.73 ^{a}	82.86 ^{b}	83.06 ^{b}	2.76
ME intake/GE intake (%)	83.56 ^{a}	83.94 ^{a}	79.64 ^{b}	80.16 ^{b}	2.97
DE DDGS*	----	3026 ^{a}	4090 ^{b}	3485 ^{a,b}	16.62
ME DDGS*	----	3010 ^{a}	3945 ^{b}	3328 ^{a,b}	16.79

a,b,c P < .10
* DE DDGS = (DE intake – (((1-% DDGS in diet)*ADFI) * DE control diet))/(% DDGS in trt diet *ADFI)
ME DDGS = (ME intake – (((1-% DDGS in diet)*ADFI) * ME control diet))/(% DDGS in trt diet*ADFI)

Figure 1. Comparison of DE values (dry-matter basis) of DDGS from first balance trial with NRC (1998).

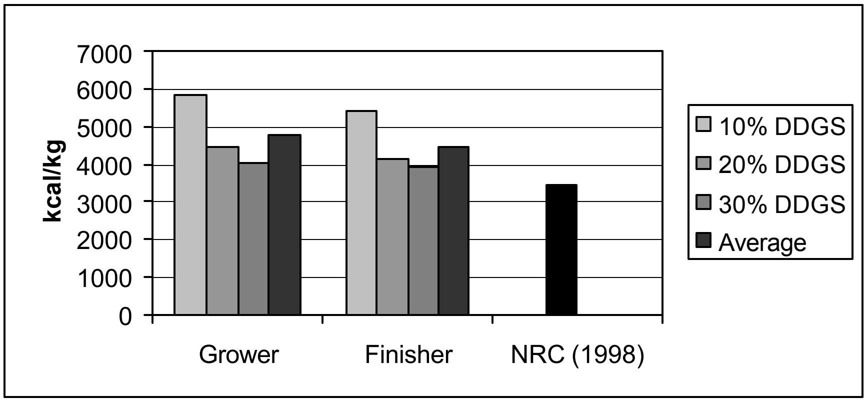

Figure 2. Comparison of ME values (dry-matter basis) of DDGS from first balance trial with NRC (1998), Feedstuffs Reference Issue (1999), Feed Co-Products of the Dry Corn Milling Process (1997), and Distillers Grains (2000).

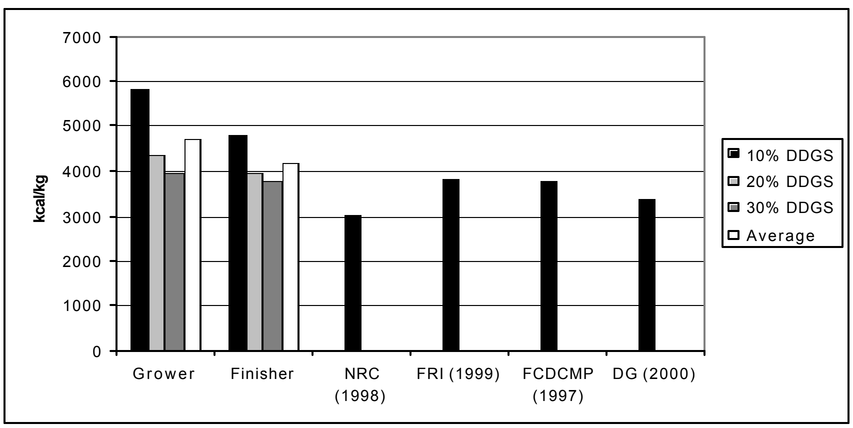

Figure 3. Comparison of DE values (dry-matter basis) of DDGS from second balance trial with NRC (1998).

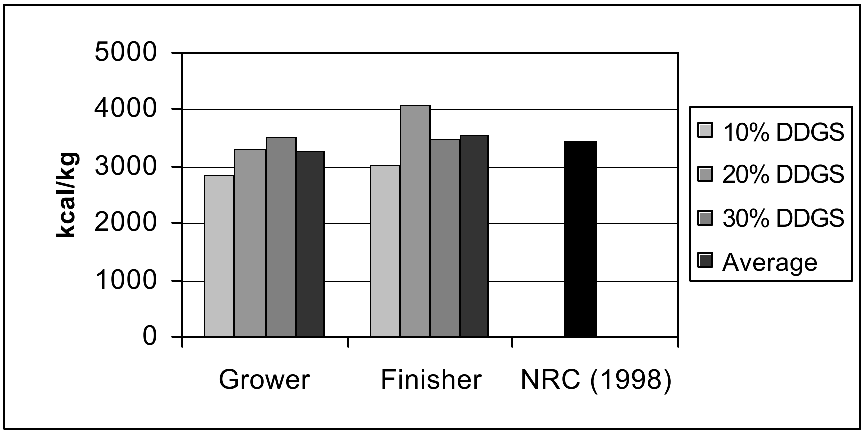

Figure 4. Comparison of ME values (dry-matter basis) for DDGS from second balance trial with NRC (1998) Feedstuffs Reference Issue (1999) Feed Co-Products of the Dry Corn Milling Process (1997) and Distillers Grains (2000).

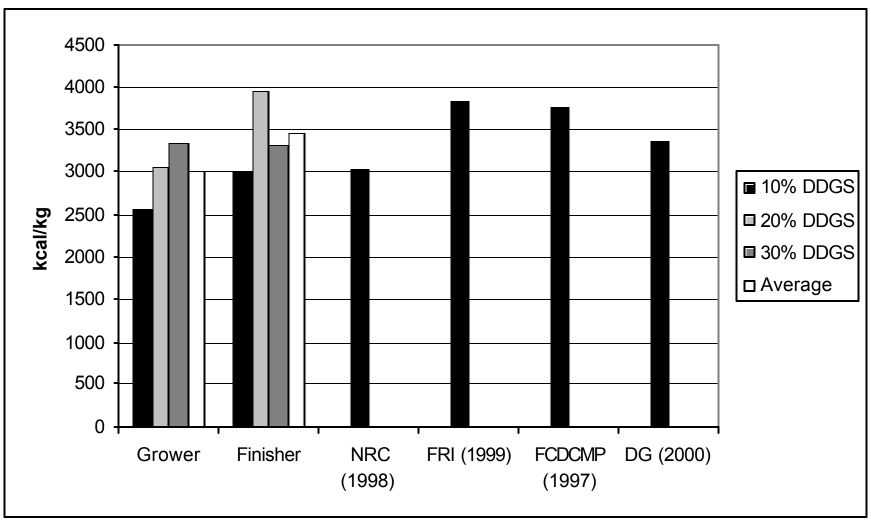

Table 4. Effect of dietary treatment on nitrogen and phosphorus intake, excretion, and retention (dry-matter basis).

Variable	*Control*	*10% DDGS*	*20% DDGS*	*30% DDGS*	*CV*
<u>Grower Phase</u>					
N intake (g/d)	21.21 [a]	25.94 [b]	23.99 [b]	28.53 [c]	6.34
Total N excreted (g/d)	9.86 [a]	10.54 [a]	10.89 [a]	18.69 [b]	18.37
N retained (%)	53.77 [a]	59.35 [a]	54.54 [a]	34.26 [b]	16.21
P intake (g/d)	5.41 [a,b]	5.04 [a,c]	5.64 [b]	4.92 [c]	6.86
Total P excreted (g/d)	2.47	2.03	2.16	2.39	18.09
P retained (%)	54.79 [a,b]	59.87 [a,b]	61.20 [a]	51.39 [b]	12.47
<u>Finisher Phase</u>					
N intake (g/d)	35.40 [a]	44.14 [b]	42.62 [b]	46.32 [c]	2.98
Total N excreted (g/d)	18.13 [a]	20.96 [a,b]	24.49 [b]	31.78 [c]	16.20
N retained (%)	48.57 [a]	52.47 [a]	42.46 [a,b]	31.30 [b]	23.02
P intake (g/d)	9.03 [a]	8.57 [b]	10.02 [c]	7.99 [d]	3.06
Total P excreted (g/d)	4.49	3.32	4.06	3.83	29.46
P retained (%)	49.98	61.28	59.34	52.03	24.29

a,b,c,d $P < .10$

Phosphorus digestibility was improved when DDGS was added to the diet at levels up to 20%, but nitrogen intake and excretion were increased when DDGS was added to the diet. This is due to low lysine levels in the DDGS.

When formulating diets to contain DDGS, published reference sources offer a conservative estimate of the DE and ME content of the DDGS product from the Minnesota-South Dakota region. Actual DE and ME content of the MNSD DDGS may be as high as 4032 and 3847 kcal/kg, respectively. Based on this study DDGS may be added at levels up to 10% in grower diets and up to 20% in finisher diets without adversely affecting phosphorus and energy digestibility but nitrogen excretion may increase at these levels.

Odor Characteristics of Swine Manure and Nutrient Balance of Grow-Finish Pigs Fed Diets with and without Distillers Dried Grains with Solubles

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Pork producers feeding grower-finisher diets containing DDGS have reported a "change" in odor in finishing barns compared to feeding corn-soybean meal diets. Research has consistently demonstrated that the addition of complex carbohydrates, such as cellulose, β-glucans and other non-starch polysaccharides, to the diet increases fecal nitrogen excretion and decreases urinary nitrogen excretion (Mroz et al., 1993; Kirchgessner et al., 1994; Kreuzer and Machmuller, 1993). By reducing the nitrogen excretion in urine as urea and shifting the nitrogen excretion to feces in the form of bacterial protein, ammonia volatilization can be reduced (Kreuzer and Machmuller, 1993). Additionally, it has been shown by Cahn and co-workers (1997, 1998a, 1998b) that increasing non-starch polysaccharide content in the diet enhances microbial activity in the large intestine, resulting in increased volatile fatty acid excretion in the feces, which, in turn, reduces the pH of the slurry. Since ammonia is more volatile at higher pH levels, this causes a reduction in ammonia emission from manure storage facilities.

Distillers dried grains with solubles from new (< 5 yr.) ethanol plants in the Minnesota-South Dakota region have an average crude fiber content of 8.8 % with 16.2% ADF and 42.1% NDF, which is higher than 10.8 % ADF and 3.2% NDF for corn and 14.9% ADF and 10.6% NDF for soybean meal (NRC, 1998). Soluble fiber content of MNSD DDGS (0.7%) is lower and insoluble fiber (42.2%) higher than corn (1.7 and 4.7%, respectively for soluble and insoluble fiber) and soybean meal (1.6 and 13.2%, respectively for soluble and insoluble fiber). Based upon the fiber characteristics of MNSD DDGS and the relationship between dietary level of non-starch polysaccharides and ammonia emissions, we conducted a study to determine the effects of adding 20% DDGS to a corn-soybean meal diet on odor, ammonia, and hydrogen sulfide emissions during the grow-finish phase, and to determine energy, nitrogen, and phosphorus balance of pigs fed a diet containing 20% DDGS.

A 10-week trial was conducted to determine odor, hydrogen sulfide, and ammonia emission of manure from grow-finish pigs fed diets with and without DDGS from a Minnesota ethanol. Additionally, a balance trial was conducted to determine energy, nitrogen, and phosphorus balance in the diets. Twenty barrows with average initial weight of 57.6 ± 3.8 kg were used for the 10-week trial. Pigs were randomly allotted by weight and ancestry to one of two dietary treatments (10 pigs/treatment). Four pigs from each treatment group (n=8) were randomly selected and immediately placed in individual stainless steel metabolism cages, where they remained for 14 d. The remaining 12 pigs were group-housed in fully-slatted pens in the grow-finish room of the Swine Research Facility and allowed *ad libitum* access to feed of their respective experimental diets. The four smallest pigs were used as potential replacements for experimental pigs during the 10-wk trial in the event that experimental pigs would need to be removed due to low feed consumption or poor health. These four pigs were housed in the grow-finish room and fed the same diets as the experimental pigs (2 pigs/treatment).

At the end of the 14-d experimental period, pigs were removed from the metabolism cages, weighed and group-housed in the grow-finish room. The 8 experimental pigs in the grow-finish room were weighed and placed in metabolism cages. This rotation continued every 14 d for the 10-wk duration of the study, resulting in 5 experimental periods. Experimental period 1 occurred during wk 1 and 2, experimental period 2 during wk 3 and 4, experimental period 3 during wk 5 and 6, experimental period 4 during wk 7 and 8, and experimental period 5 during wk 9 and 10 of the 10-wk study. Pigs in metabolism cages were fed three times daily as close to *ad libitum* access to feed as possible, without allowing feed wastage. A three-phase dietary sequence was used, with each phase having two dietary treatments. Each phase contained a typical corn-soybean meal control diet and a diet containing 20% MNSD DDGS, with DDGS replacing corn and soybean meal in the diet. Total phosphorus and total lysine were held constant within phase.

Table 1. Composition and calculated nutrient analysis of dietary treatments.

	Phase I (55-73 kg)		*Phase II (73-91 kg)*		*Phase III (91-109 kg)*	
Ingredient	*Control*	*DDGS*	*Control*	*DDGS*	*Control*	*DDGS*
Corn, %	81.36	68.57	84.07	66.34	86.32	68.60
MNSD DDGS, %	0.00	20.00	0.00	20.00	0.00	20.00
SBM (44%), %	16.43	9.19	13.82	11.60	11.64	9.51
Limestone, %	0.68	1.05	0.69	1.16	0.68	0.99
Salt, %	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[1], %	0.30	0.30	0.30	0.30	0.30	0.30
Trace mineral premix[2], %	0.10	0.10	0.10	0.10	0.10	0.10
L-lysine HCl, %	0.00	0.15	0.00	0.00	0.00	0.00
Dicalcium phosphate, %	0.64	0.15	0.53	0.00	0.46	0.00
Calculated Analysis						
Est. ME (kcal/kg)	3312	3276	3320	3282	3327	3290
Crude protein, %	14.14	17.74	13.23	15.38	12.46	15.74
Calcium, %	0.51	0.51	0.48	0.52	0.45	0.45
Total phosphorus, %	0.45	0.45	0.42	0.42	0.40	0.40
Total lysine, %	0.54	0.54	0.48	0.48	0.43	0.43
Methionine + Cystine, %	0.43	0.47	0.41	0.43	0.40	0.44
Threonine, %	0.43	0.46	0.40	0.40	0.37	0.41
Tryptophan, %	0.13	0.13	0.12	0.12	0.11	0.11

[1] Nutrients provided per kg of complete feed: vitamin A 1361 IU, vitamin D_3 340 IU, vitamin E 5.67 IU, vitamin K 0.91 mg, riboflavin 1.36 mg, niacin 8.16 mg, pantothenic acid 5.44 mg, vitamin B_{12} 0.01 mg, pyridoxine 0.18 mg, folic acid 0.23 mg, biotin 0.04 mg, choline 120 mg, thiamine 0.14 mg

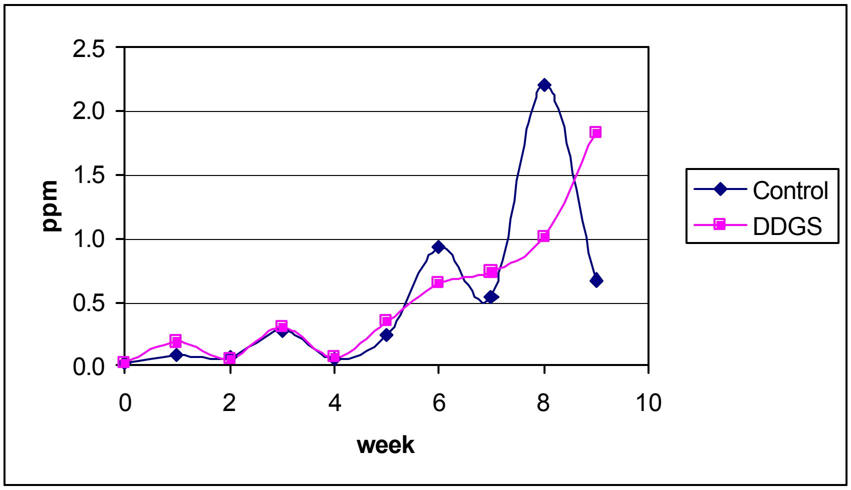
[2] Nutrients provided per kg of complete feed: iodine 0.12 mg, selenium 0.02 mg, zinc 20.57 mg, iron 20.57 mg,cooper 1.36 mg, manganese 6.17 mg

Manure (urine/feces mixture) from each pig in the metabolism cages (n=8) was collected once daily except during the last 3 d of wk 2, 6, and 10 (experimental periods 1, 3, and 5, respectively) when urine and feces we collected separately and used in nutrient balance determinations. Manure volume was recorded at each collection. Individual manure samples from pigs in metabolism cages (n=8) were thoroughly mixed to ensure uniform consistency of each sample. Each sample was then divided equally into two separate plastic buckets to get a total of 16 manure containers (2 containers/pig). The contents of each container was emptied according to dietary treatment into corresponding deep pit simulator models (DPSM) (n=16) which were stored in two nutrient balance rooms of the Swine Research Facility

Air samples were collected from each DPSM at the beginning of each week. Air samples were analyzed for hydrogen sulfide concentration using the Jerome™ meter (Arizona Instrument Corporation, Jerome Instrument Division) and ammonia concentration using Sensidyne™ tubes (Gastec Corp., Yokohama, Japan). In addition, the 16 air samples collected during wk 0, 2, 5, and 8 were evaluated for odor utilizing an odor panel and olfactometer, which is the standard method used to measure odors (Riskowski et al., 1991; Al-Kanai et al., 1992; Hobbs et al., 1995).

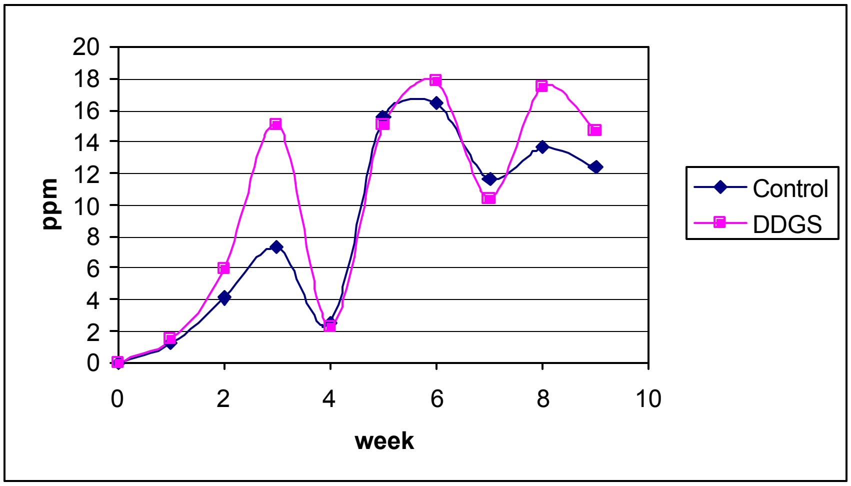
In this study, adding 20% MNSD DDGS to a corn-soybean meal diet did not affect hydrogen sulfide, ammonia, or odor levels in manure stored for 10 weeks. Nitrogen intake and excretion increased when DDGS was added to the diet but this did not appear to have an adverse effect on ammonia emissions from the manure storage facility during the 10-wk study. Phosphorus retention and excretion were not affected by dietary treatment, but level of inorganic phosphorus supplementation was reduced in diets containing 20% DDGS, thereby reducing diet cost. Dietary DE and ME levels were lower in the DDGS diets, providing 95-96% of the DE and ME of the corn-soybean meal control diet.

Figure 1. Hydrogen sulfide levels obtained from air space of DPSM containing manure from pigs fed diets with and without 20% MNSD DDGS.



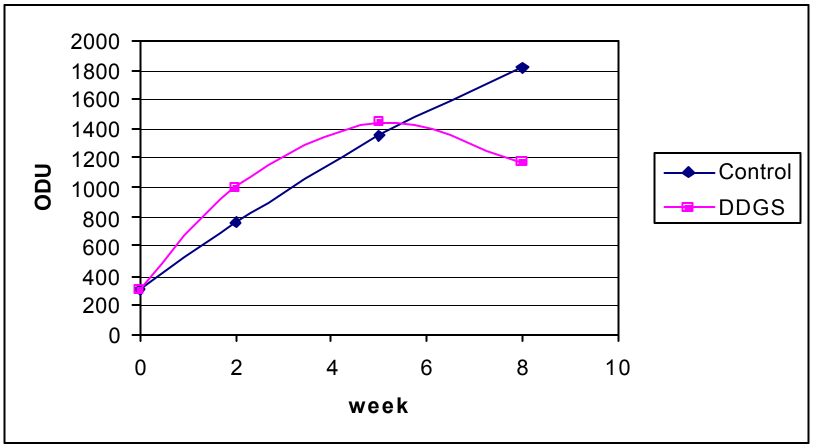
CV = 49.45 MSE ± .0426 P = 0.39

Figure 2. Ammonia levels obtained from air space of DPSM containing manure from pigs fed diets with and without 20% MNSD DDGS.



CV = 18.21 MSE ± .0876 P = 0.17

Figure 3. Odor detection threshold of air samples collected from DPSM containing manure from pigs fed diets with and without 20% MNSD DDGS.



CV = 8.11 MSE ± .1152 P = 0.99

Table 2. Effect of dietary treatment on overall nitrogen and phosphorus intake, excretion, and retention (dry-matter basis) and dietary DE and ME intake.

	Control	*20% DDGS*	*SE*	*P-value*
Nitrogen				
N intake (g/d)	44.91	56.06	0.24	0.0001
N retention (%)	57.36	53.42	0.02	0.1332
N excretion (g/d)	19.51	26.30	0.93	0.0021
Phosphorus				
P intake (g/d)	9.65	10.73	0.05	0.0001
P retention (%)	49.06	49.19	0.03	0.9739
P excretion (g/d)	4.94	5.45	0.32	0.3017
Energy				
DE (kcal/kg)	3398	3480	35.82	0.1448
ME (kcal/kg)	3293	3367	35.27	0.1681
DE intake/GE intake (%)	88.67	85.06	0.01	0.0123
ME intake/GE intake (%)	85.99	82.31	0.01	0.0159

The DDGS product from a Minnesota ethanol plant can be added to grow-finish diets at levels up to 20% without adversely affecting odor, ammonia, or hydrogen sulfide emissions from stored manure. Because nitrogen intake and excretion are higher in DDGS diets compared to corn-soybean meal diets, supplementation with synthetic amino acids may be of benefit. Phosphorus concentration in stored manure from pigs fed 20% DDGS was lower than phosphorus concentration in manure from pigs fed the control, which may be of benefit to producers who need to develop manure management plans to prevent excess phosphorus application on cropland. Dietary DE and ME of a diet containing 20% DDGS is nearly equal to that of a corn-soybean meal diet, suggesting that growth performance would not be adversely affected by inclusion of DDGS in the diet.

Apparent Ileal Amino Acid Digestibility of Corn Distiller's Dried Grains with Solubles Produced from New Ethanol Plants in Minnesota and South Dakota.

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Accurate and consistent nutrient values of various sources of a feed ingredient, particularly amino acids levels, are essential for accurate formulation of swine diets. Historically, the use of corn DDGS in swine diets has been limited by variable nutrient levels (Carpenter, 1970; Cromwell, 1993), reduced protein (amino acid) digestibility (Wahlstrom et al, 1970), and an amino acid profile that is not well-suited for pigs (Cromwell et al., 1983). However, the construction of new ethanol plants with newer fermentation and drying technologies and procedures during the past decade, may result in a DDGS nutrient values and digestibility different than those listed in published references (NRC, 1998; Heartland Lysine, 1998; Feedstuffs Reference Issue, 1999).

This study was conducted to determine apparent ileal amino acid digestibility of DDGS from a new ethanol plant (< 5 yrs.) in Minnesota. These values were then compared to values cited in current reference publications (NRC, 1998; Heartland Lysine, 1998; Feedstuffs Reference Issue, 1999) and a sample of DDGS from an older Midwestern plant (OMP). Ten barrows averaging 38.5 ± 3.6 kg BW from the West Central Research and Outreach Center in Morris, MN were delivered to the Swine Research Facility in St. Paul, MN for use during this study. Pigs were surgically fitted with a simple T-cannula at the ileal-cecal junction using a procedure adapted from Sauer et al., (1983). Pigs were allowed a 10 d recovery and acclimation period, following which pigs were randomly allotted to one of four dietary treatments for Period I. There were a total of 6, 11-d experimental periods (4 periods for Experiment 1 and 2 periods for Experiment 2).

Pigs were fed an amount of their respective experimental diets equivalent to 3% of their body weight divided into two equal daily portions and fed at 7:00 and 19:00 hr. Feed intake never exceeded 3% of body weight daily to prevent displacing the cannula. Pigs were fed their respective experimental diets for 9 d prior to digesta and fecal collection. The morning following the second day of digesta collection, all pigs were weighed and feed levels adjusted accordingly. Pens were powerwashed and the pigs were assigned a new experimental diet. Four experimental diets were used during Experiment 1 to determine apparent ileal amino acid digestibility of MNSD DDGS. A typical corn-soybean meal grower diet was used as a control. Three additional experimental diets contained 30, 60, or 90 % DDGS, with DDGS replacing corn and soybean meal in the diet. Total phosphorus and calcium levels were held constant across diets During Experiment 2, two experimental diets were used in a 2 x 2 Latin square design. Diets contained 90% MNSD DDGS or 90% OMP DDGS. All diets were fed in meal form.

Amino acid composition, apparent ileal and total tract digestible amino acids levels of MNSD and OMP DDGS are shown in Table 2. Coefficients of variation are shown in parenthesis next to the value represented. Apparent ileal digestible amino acid levels for DDGS produced in ethanol plants in the Minnesota-South Dakota region appear to be higher than or equal to digestible amino acid levels cited in NRC (1998), except methionine and phenylalanine, which were slightly lower than NRC values. Apparent ileal digestible amino acid levels in Heartland Lysine (1998) were similar to MNSD DDGS values except for lysine, which was higher in the MNSD DDGS and methionine and phenylalanine, which appeared lower in MNSD DDGS. All apparent ileal digestible amino acid levels in Feedstuffs Reference Issue (1999) were slightly higher than MNSD DDGS, with the exception of arginine, which appears higher in the MNSD DDGS. Total lysine content was the most variable (CV=10.1%) of the amino acids measured.

Table 1. Composition and nutrient content of dietary treatments in Experiment 1.

	Experiment 1				Experiment 2	
Ingredient	*Control*	*30% MN DDGS*	*60% MN DDGS*	*90% MN DDGS*	*90% MN DDGS*	*90% OMP DDGS*
MNSD DDGS, %	0.00	30.00	60.00	90.00	90.00	90.00
Corn/soy blend, %	72.77	53.53.	34.30	0.00	----	----
Corn starch, %	20.99	10.50	0.00	4.33	4.33	5.54
Corn oil, %	2.50	2.50	2.50	2.50	2.50	2.50
Dicalcium phosphate, %	1.98	1.20	0.42	0.04	0.04	0.00
Calcium carbonate, %	0.71	1.22	1.73	2.08	2.08	0.91
Salt, %	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin/TM premix, %	0.45	0.45	0.45	0.45	0.45	0.45
Chromic oxide, %	0.10	0.10	0.10	0.10	0.10	0.10
Calculated Nutrient Levels						
ME, kcal/kg	3414	3330	3246	3260	3260	3036
Crude protein, %	24.85	26.59	28.32	25.12	25.12	20.08
Total Calcium, %	0.86	0.86	0.86	0.86	0.86	0.86
Total Phosphorus, %	0.77	0.77	0.77	0.77	0.77	0.77
Total Lysine, %	1.57	1.40	1.22	0.73	0.73	0.36
Total Met+Cys, %	0.70	0.78	0.86	0.80	0.80	0.67
Total Tryptophan, %	0.34	0.32	0.30	0.21	0.21	0.13
Total Threonine, %	1.02	1.05	1.08	0.90	0.90	0.67
Analyzed Nutrient Levels						
ME, kcal/kg*	3463	3489	3577	3612	3707	3837
Crude protein, %	23.06	29.48	31.38	27.48	27.40	25.37
Total Calcium, %	0.97	1.21	1.17	1.23	0.73	0.94
Total Phosphorus, %	0.65	0.95	0.81	0.80	0.85	0.89
Total Lysine, %	1.43	1.25	1.15	1.06	0.94	0.45
Total Methionine , %	0.37	0.42	0.48	0.40	0.48	0.43
Total Tryptophan, %	0.29	0.34	0.38	0.22	0.24	0.17
Total Threonine, %	0.96	1.05	1.20	0.99	1.04	0.84
Total Valine, %	1.23	1.30	1.49	1.30	1.44	1.20
Total Isoleucine, %	1.06	1.03	1.21	1.01	1.03	0.85
Total Leucine, %	2.15	2.72	3.22	2.68	3.13	2.47
Total Histidine, %	0.67	0.73	0.84	0.68	0.72	0.51
Total Phenyalanine, %	1.28	1.38	1.59	1.28	1.36	1.09
Total Arginine, %	1.72	1.52	1.39	1.32	1.19	0.79

*DE = [(CP * 4) + (NFE * 4) + (Fat * 9)] * 4.54
ME = DE * [(0.96 - (0.2 * CP))/100].

Table 2. Amino acid composition, apparent ileal and total tract digestible levels of MNSD and OMP DDGS (dry-matter basis).

	Amino Acid Composition		Apparent Ileal Digestible Amino Acid Levels		Total Tract Digestible Amino Acid Levels	
Amino Acid	*MNSD*	*OMP*	*MNSD*	*OMP*	*MNSD*	*OMP*
Arg, %	1.19 (4.2)	0.92	0.90 (6.0)	0.60 (8.00)	0.89 (12.6)	0.42 (17.4)
His, %	0.76 (4.3)	0.61	0.51 (5.6)	0.30 (9.4)	0.59 (3.7)	0.27 (16.1)
Ile, %	1.14 (6.0)	1.00	0.72 (10.3)	0.42 (15.5)	0.76 (7.8)	0.32 (36.2)
Leu, %	3.57 (3.1)	2.97	2.57 (6.8)	1.84 (6.9)	2.97 (4.7)	1.63 (12.3)
Lys, %	0.83 (10.1)	0.53	0.44 (12.7)	0.00 (380)	0.42 (11.8)	0.00 (87.1)
Met, %	0.55 (2.5)	0.50	0.32 (15.0)	0.24 (13.6)	0.32 (10.2)	0.15 (33.6)
Phe, %	1.48 (2.8)	1.27	0.89 (7.6)	0.68 (9.8)	1.11 (5.0)	0.60 (15.5)
Thr, %	1.13 (3.4)	0.98	0.62 (9.6)	0.36 (12.7)	0.74 (7.3)	0.32 (24.1)
Trp, %	0.24 (5.8)	0.19	0.15 (8.2)	0.15 (7.5)	0.19 (3.7)	0.14 (8.8)
Val, %	1.51 (3.7)	1.39	0.92 (9.9)	0.51 (14.7)	1.04 (6.4)	0.54 (23.6)

Note: Coefficient of variation shown in parenthesis

Table 3. Comparison of total and apparent digestible amino acid levels (dry-matter basis) between MNSD DDGS, NRC (1998), Heartland Lysine (1998), and Feedstuffs Reference Issue (1999).

	Total Amino Acid Levels					Apparent Digestible Amino Acid Levels				
Amino Acid	*MNSD*	*OMP*	*NRC 1998*	*HL 1998*	*FRI 1999*	*MNSD*	*OMP*	*NRC 1998*	*HL 1998*	*FRI 1999*
Arg, %	1.19	1.07	1.22	1.21	1.08	0.90	0.60	0.88	0.87	0.68
His, %	0.76	0.68	0.74	0.75	0.65	0.51	0.30	0.45	0.49	0.49
Ile, %	1.14	1.04	1.11	1.09	1.08	0.72	0.42	0.73	0.70	0.91
Leu, %	3.57	3.22	2.76	3.27	2.90	2.57	1.84	2.10	2.49	2.58
Lys, %	0.83	0.68	0.67	0.81	0.65	0.44	0.00	0.31	0.35	0.42
Met,%	0.55	0.49	0.54	0.63	0.65	0.32	0.24	0.39	0.45	0.55
Phe, %	1.48	1.30	1.44	1.43	1.29	0.89	0.68	1.09	1.09	1.14
Thr, %	1.13	0.99	1.01	1.11	1.02	0.62	0.36	0.56	0.60	0.73
Trp, %	0.24	0.22	0.27	0.20	0.22	0.15	0.15	0.14	0.10	n/a
Val, %	1.51	1.31	1.40	1.43	1.43	0.92	0.51	0.88	0.93	1.16

The significant differences in amino acid intake between pigs fed the MNSD DDGS and the pigs fed the OMP DDGS demonstrates the substantial difference in amino acid composition of the DDGS from the two sources. Differences in amino acid retention between the MNSD DDGS and OMP DDGS demonstrates a significant difference in amino acid digestibility between the diets containing DDGS from the two sources. Total amino acid levels for all 10 essential amino acids were higher in the Minnesota-South Dakota produce compared to DDGS from an older plant in the Midwest. Apparent ileal and total tract digestible amino acid levels of the MNSD DDGS were significantly higher than that of the sample of DDGS produced in an older Midwestern plant, except tryptophan, which was similar between the two DDGS sources, indicating that the amino acid digestibility of the MNSD is superior to DDGS from some other sources.

Table 4. Comparison of amino acid intake (g/d) between diets containing 90% MNSD DDGS and 90% OMP DDGS (dry-matter basis).

Amino Acid	*90% MNSD*	*90% OMP*	*P-value*	*CV*
Arginine, g/d	25.40	16.65	0.0006	8.98
Histidine, g/d	15.43	10.70	0.0013	9.02
Isoleucine, g/d	22.08	18.08	0.0218	9.18
Leucine, g/d	66.95	52.12	0.0089	9.13
Lysine, g/d	20.18	9.51	0.0001	8.92
Methionine, g/d	10.21	9.04	0.1118	9.27
Phenylalanine, g/d	28.96	23.07	0.0128	9.15
Threonine, g/d	22.32	17.84	0.0136	9.15
Tryptophan, g/d	5.22	3.57	0.0001	9.05
Valine, g/d	30.86	25.45	0.0252	9.19
Total Amino Acid, g/d	523.94	432.08	0.0253	9.18

Table 5. Comparison of dietary amino acid retention (%) between diets containing 90% MNSD DDGS and 90% OMP DDGS (dry-matter basis).

Amino Acid	*90% MNSD*	*90% OMP*	*P-value*	*CV*
Arginine, %	73.43	55.82	0.0230	12.70
Cystine, %	61.15	39.55	0.0042	13.57
Histidine, %	71.34	43.60	0.0002	8.64
Isoleucine, %	64.02	39.54	0.0021	12.93
Leucine, %	79.44	56.88	0.0002	5.63
Lysine, %	47.45	-3.78	0.0013	58.14
Methionine, %	65.81	48.48	0.0127	12.22
Phenylalanine, %	72.90	52.06	0.0019	8.93
Threonine, %	59.86	36.47	0.0005	9.94
Tryptophan, %	67.45	68.22	0.8591	8.72
Valine, %	65.87	39.49	0.0004	10.17
Total Amino Acid, %	67.83	45.52	0.0008	8.96

The DDGS produced in the Minnesota ethanol plant appears to be higher than or equal to digestible amino acid levels cited in commonly used reference tables such as NRC (1998), Feedstuffs Reference Issue (1999) and Heartland Lysine (1998). Because accurate and consistent nutrient values of various sources of a feed ingredient, particularly amino acids levels, are essential for accurate formulation of swine diets, it may be advisable for nutritionists to determine total amino acid levels within individual plants before formulating diets using DDGS, rather then relying on the amino acid values listed in commonly used reference tables.

The two DDGS samples selected for use in the study represent the wide variation in quality of DDGS available to producers. Significant differences in amino acid intake between pigs fed the MNSD DDGS and the pigs fed the OMP DDGS demonstrates the substantial difference in amino acid composition of the DDGS from the two sources. Differences in amino acid retention between the MNSD DDGS and OMP DDGS demonstrate a significant difference in amino acid digestibility between the diets containing DDGS from the two sources. Because a large variation exists in digestible amino acid levels between DDGS from various sources, nutritionists need to become familiar with amino acid levels and variability within individual plants before formulating diets using DDGS.

Availability of Phosphorus or Growing Swine in Distiller's Dried Grains with Solubles Produced from Ethanol Plants in the Minnesota and South Dakota Region

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Increasing environmental concern over excess nutrients, including phosphorus, overloading the environment has increased the search to evaluate alternatives that decrease the amount of phosphorus excreted in manure from swine. Distiller's dried grains with solubles (DDGS) has historically contained high levels of available phosphorus. The predominant form of phosphorus in cereal grains and oilseed meals is phytic acid (phytate), which cannot be utilized by the pig. The National Research Council (NRC, 1998) lists the total phosphorus content of DDGS at 0.77%, with a relative bioavailability of 77%, giving an available phosphorus content of 0.59%. In comparison, corn and soybean meal contain approximately 0.28% and 0.65-0.69% total phosphorus, with relative bioavailabilities of 14% and 0.23-0.31%, respectively. Phosphorus consumed by the pig but not available is excreted and increases the phosphorus level in manure. Utilizing ingredients containing highly available phosphorus allows the formulation of diets containing decreased levels of unavailable phosphorus. Previous research conducted by our group indicates that DDGS originating from ethanol plants in the Minnesota and South Dakota region contains higher levels of total phosphorus (0.89%) compared to NRC (1998) levels. In addition, different processing techniques during the production of DDGS, including enzymes used during the fermentation process, may affect availability of the phosphorus in the final product. To properly formulate diets and decrease the amount of phosphorus excreted, more precise estimations of phosphorus bioavailability are necessary.

This project was designed to determine the availability of phosphorus in DDGS originating from ethanol plants in the Minnesota and South Dakota region. A total of 38 crossbred growing barrows (6 wks of age) (5-6 pigs for each of seven treatments) were used to evaluate DDGS phosphorus bioavailability. Pigs were randomly allotted by weight and ancestry to one of seven dietary treatments. Pigs were placed in individual stainless steel collection cages at the St. Paul Swine Research and Teaching unit, and fed either a control diet (100% basal diet, formulated to contain 0.29% total P), or one of six diets. Dicalcium phosphate was used as a reference standard (assuming 100% phosphorus bioavailability). Graded levels of dicalcium phosphate were added to the basal diet to obtain three formulated levels of total phosphorus (0.34, 0.39, and 0.44%) for treatments 2, 3, and 4, respectively. Similarly, three levels of DDGS were incorporated into the basal diet to supply the same formulated levels of phosphorus as contributed by dicalcium phosphate for treatments 5, 6, and 7. Ingredient and nutrient composition of the experimental diets is provided in Table 1. Pigs were allowed a 7-day acclimation period to ensure all pigs were eating well and were adjusted to the individual metabolism crates. A 5-day collection period immediately followed the acclimation period. Pigs were fed at a level of 2% of their initial body weight twice daily of their respective diets for the entire 12-day study. Temperature was maintained at approximately 72 °F throughout the experiment, and all animals were allowed ad libitum access to water.

Pigs were weighed initially and feed allowance determined. Amount of feed added was recorded daily, and feed not consumed or spilled was removed, weighed, and subtracted from feed added to determine daily feed consumption. Feces and urine were collected during the 5-d collection period to determine phosphorus excretion. All feces generated from each individual pig over the 5-day period was collected daily and frozen for later subsequent analysis. Total urinary output was collected from each pig daily in plastic containers located under funnels of the metabolism cages. One hundred milliliters of 6N HCl was added to urine collection containers daily to limit microbial growth. Total urine volume was measured daily, and a 200-ml subsample collected and frozen. Fecal and urinary samples were pooled for each pig at the end of the experiment. Pigs were also weighed at the end of the collection period to determine average daily gain.

Table 1. Nutrient composition of experimental diets.

	Control	Dicalcium phosphate			DDGS		
Item	**Trt 1**	**Trt 2**	**Trt 3**	**Trt 4**	**Trt 5**	**Trt 6**	**Trt 7**
Ingredients							
DDGS, %	0.00	0.00	0.00	0.00	8.99	17.97	26.96
Corn starch, %	53.30	53.17	53.02	52.88	48.52	43.73	38.94
Soybean meal, 44%	41.91	41.79	41.67	41.56	38.13	34.37	30.60
Corn oil, %	3.00	2.99	2.98	2.98	2.73	2.46	2.19
Limestone, %	1.19	1.19	1.18	1.18	1.08	0.98	0.87
Dicalcium phosphate, %	0.00	0.27	0.54	0.81	0.00	0.00	0.00
Vitamin premix, %	0.40	0.40	0.40	0.40	0.36	0.33	0.29
Trace mineral premix, %	0.20	0.20	0.20	0.20	0.18	0.16	0.15
Calculated values							
Dry matter, %	95.30	95.31	95.32	95.32	94.74	94.19	93.63
Crude protein, %	18.60	18.55	18.50	18.45	19.44	20.29	21.13
Crude fat, %	3.58	3.57	3.56	3.55	4.17	4.76	5.35
Crude fiber, %	3.06	3.05	3.04	3.04	3.52	3.98	4.45
ME, kcal/kg	3694	3684	3674	3664	3650	3605	3560
Lysine, %	1.23	1.23	1.22	1.22	1.19	1.16	1.12
Met and Cys, %	0.50	0.50	0.50	0.50	0.50	0.49	0.49
Threonine, %	0.72	0.72	0.72	0.71	0.75	0.77	0.80
Tryptophan, %	0.27	0.27	0.27	0.27	0.27	0.26	0.26
Calcium, %	0.60	0.66	0.71	0.77	0.55	0.50	0.46
Total phosphorus, %	0.29	0.34	0.39	0.44	0.34	0.39	0.44
Ca:P ratio	2.07	1.94	1.82	1.75	1.62	1.28	1.05
Analyzed values - RAL							
Total phosphorus, %	0.32	0.35	0.39	0.42	0.35	0.38	0.51

Pigs weighed 44.3 lbs (Root MSE = 11.9) and 53.0 (Root MSE = 13.6) at the beginning and end of the experimental period, respectively. Average daily gain (ADG) and average daily feed intake (ADFI) averaged 0.65 and 1.64 lb/d, respectively. Initial and final weight, ADG, ADFI, and feed conversion did not differ across treatments (P > .10). Total phosphorus intake and excretion levels are provided in Figures 1 and 2. Actual phosphorus intake, as determined from analyzed phosphorus levels of each diet, ranged from 2.33 g/d (control diet) to 3.91 g/d (DDGS diet with .44% total P, treatment 7). Phosphorus intake increased linearly with increasing inclusion of dicalcium phosphate and DDGS (P < .01). Fecal and urinary phosphorus excreted ranged from 812 and 86 mg/d (control) to 1382 and 361 mg/d (treatment 7), respectively. Increasing phosphorus level in the diet, regardless of source, resulted in a linear increase in fecal and urinary phosphorus excretion (P < .01). Total phosphorus excretion ranged from 898 mg/d (control) to 1743 mg/d (treatment 7). Phosphorus retention (phosphorus intake – excretion) (Figure 3) increased linearly (P < .01) with increasing P intake. However, P retention (% of intake) (Figure 4) did not differ between dietary treatments (P > .10).

Figure 1. Phosphorus intake level (mg/d).

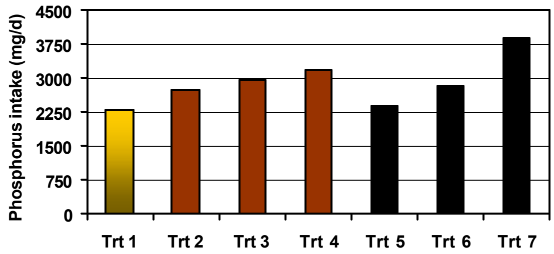


Figure 2. Phosphorus excreted (mg/d).

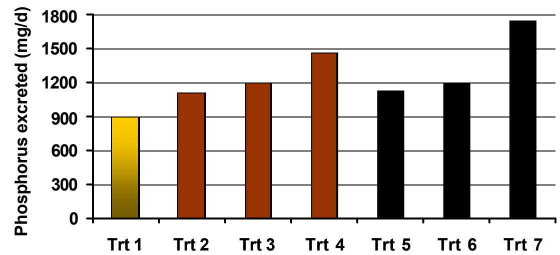


Figure 3. Phosphorus retained (mg/d).

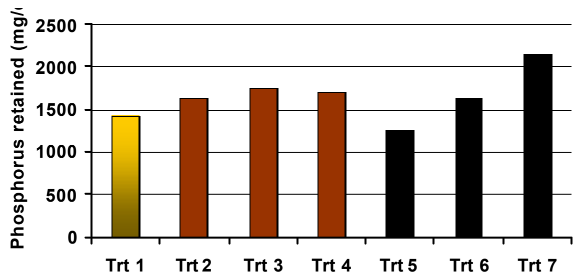
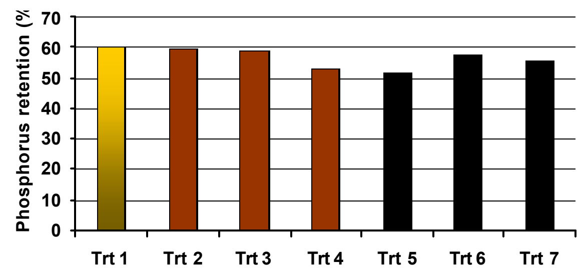


Figure 4. Phosphorus retention (% of intake).



A linear regression analysis was conducted for P excreted and P retained relative to P intake for dicalcium phosphate and DDGS separately. The slope ratios of the regression lines from each phosphorus source were used to determine phosphorus availability. Availability of phosphorus in dicalcium phosphate was assumed to be 100%. Slopes for phosphorus excreted and retained were 0.354 and 0.646 (dicalcium phosphate, r^2 = 0.42 and 0.72) and 0.405 and 0.595 (DDGS, r^2 = 0.55 and 0.73), respectively. Availability of phosphorus, determined from the ratio of the slopes for DDGS and dicacium, was 87.5% (excretion data) and 92.2% (retention data).

Figure 5. Regression analysis: P excreted.

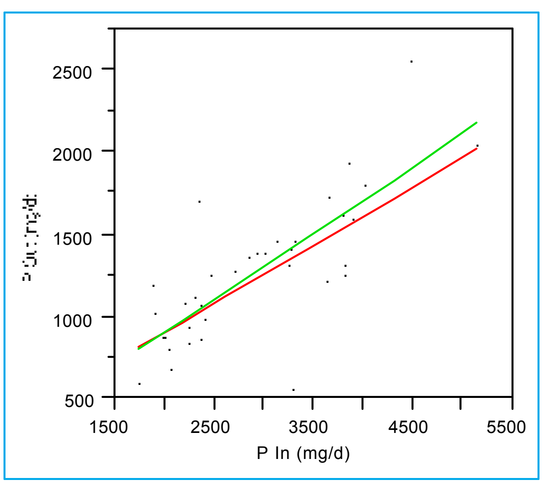
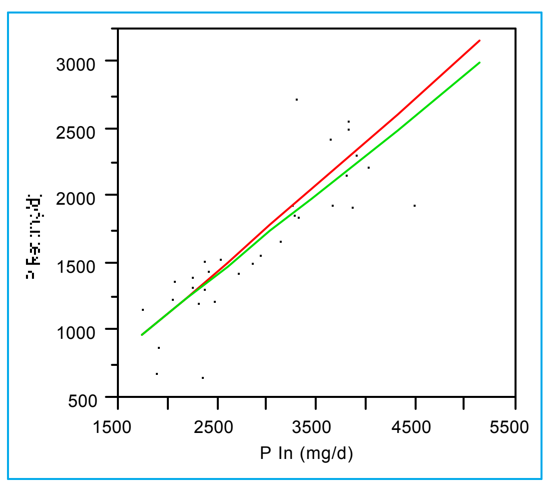


Figure 6. Regression analysis: P intake.



These results suggest that DDGS from the MN-SD region is an excellent source of available phosphorus for growing swine, and that phosphorus availability is higher than listed in NRC (1998). Including DDGS in the diet for growing swine can significantly reduce the level of phosphorus supplementation needed to meet the nutritional requirements of the pig, while decreasing the amount of phosphorus excreted in manure.

Growth Performance and Carcass Characteristics of Grow-Finish Pigs Fed Increasing Amounts of Distillers Dried Grains with Solubles.

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Introduction

Poor amino acid balance and digestibility have resulted in conservative and somewhat variable recommendations involving maximum inclusion rates of Distillers Dried Grains with Solubles (DDGS) in grow-finish swine diets. In the Feed Co-Products Handbook (1997), the authors recommend that no more than 7.5% DDGS be used in diets for growing pigs (40-120 lbs) and no more than 10% DDGS be used in diets for finishing pigs (120 lbs-market). The Pork Industry Handbook recommends that no more than 10% DDGS be included in diets for growing and finishing pigs. In a literature review by Newland and Mahan (1990), the authors suggest that up to 20% DDGS can be added to grow-finish diets without reducing pig performance, if synthetic lysine and tryptophan are added to the diet. Results from our previous studies have shown that total and apparent digestible lysine in DDGS from Minnesota and South Dakota (MNSD) ethanol plants is higher than values published in NRC (1998), Heartland Lysine ingredient database, and the 1999 Feedstuffs reference issue. Total methionine in MNSD DDGS is comparable to the NRC (1998) value but lower than Heartland Lysine and (1999) Feedstuffs Reference Issue estimates. Apparent digestible methionine from MNSD DDGS is lowest of all published values. Apparent digestible threonine and tryptophan are higher in MNSD DDGS than published values. These differences suggest that greater inclusion rates of MNSD DDGS may be possible before requiring the addition of synthetic amino acids to maintain proper amino acid balance.

Many swine nutritionists formulate corn-soybean meal diets using total amino acid levels and apply recommended amino acid ratios to these totals. This approach is generally accepted when using corn and soybean meal, but may not apply when other ingredients such as DDGS are added to the diet. There are also different opinions on what these ratios should be. The University of Illinois has conservatively recommended dietary ratios of 100, 62, 67, and 18 for lysine, methionine+cystine, threonine, and tryptophan, respectively. An informal survey of feed industry nutritionists suggests that ratios of 100, 57, 65, and 18 for lysine, methionine+cystine, threonine, and tryptophan, respectively, may be more appropriate. Kansas State University recommends ratios of 100, 55, 65, and 18 for lysine, methionine+cystine, threonine, and tryptophan, respectively on a total basis, and 100, 52, 58, and 17 for lysine, methionine+cystine, threonine, and tryptophan, respectively, on an apparent digestible basis.

The relatively low digestible lysine:threonine ratio in corn-soybean meal-DDGS diets is a potential concern and may determine the maximum amount of DDGS that can be included in grow-finish diets. This is especially a concern when a large amount of synthetic lysine is included in the diet to meet lysine requirements of the pig. When using diet formulations based on total amino acid levels, the ratio of digestible lysine:threonine, lysine:methionine+cystine, and lysine:tryptophan ratios are below recommended levels when DDGS is added at 15% or more in the diet.

Research has shown a significant effect of diet on pork carcass quality, including carcass lean and fat content and pork processing and palatability characteristics of pork products. Pale muscle color and poor water-holding capacity are two of the most economically-important pork quality traits that have been an issue. In addition, excess fat content and decreased lean decrease the price paid to producers in packer price-matrix systems. Belly firmness and quality of fat in the belly are also important carcass quality traits. Relatively little information is available on the effect of feeding DDGS on these carcass and muscle quality characteristics.

Experimental methods

This study was conducted to determine if adding increasing amounts of DDGS to grow-finish diets in a phase feeding program will provide equal growth performance and carcass quality when diets containing DDGS are formulated to contain the same level of total lysine, phosphorus and ME basis. The trial was conducted in the grow-finish unit at the West Central Research and Outreach Center, Morris. A total of 24 pens were used, with 10 grow-finish pigs/pen for a total of 240 crossbred pigs. Pigs weighing approximately 60 lbs were blocked by weight (low, medium, and high), sex and litter. Each block was randomly assigned to one of four dietary treatment sequences in a 5-phase grow-finish feeding program (6 replications/treatment).

Ingredient and nutrient composition (formulated and analyzed) of experimental diets are provided in Tables 1 and 2. Diets within each phase of growth were formulated to contain equivalent levels of total lysine, ME, calcium, total phosphorus, vitamins and trace minerals. Amino acid values obtained from a previous DDGS experiment were used in the formulation. The ME value used for DDGS was 1600 kcal/lb and the ME value for soybean oil was 3300 kcal/lb. Dietary lysine levels were set at 1.1, 1.0, .85, .72, and .64% for phases I-V, respectively, based on mixed sex pigs averaging 1.7 lbs gain/day, 3.1 F/G, and 52% lean. The Phase I corn-soybean meal-3 lb synthetic lysine control diet has a minimum ratio of 100, 55, 65, an 20 for lysine, methionine+cystine, threonine, and tryptophan, respectively. All DDGS diets in Phase I, and all diets in Phase II, III, IV, and V exceed this minimum ratio of total amino acids. All diets contain 3 lbs of synthetic lysine. Because DDGS contains approximately 10% fat, decreasing amounts of soybean oil was added as DDGS inclusion level increased to provide equal dietary ME concentration and prevent total dietary fat levels from exceeding 7.5%. Feed samples were obtained from each batch of feed and analyzed for nutrient content.

Pigs were weighed and feed disappearance determined every two weeks during the trial. Diet switches were made weekly when average pen weight of any pen was within 5 lbs of the target end weight for the phase. Once the average pen weight reached 250 lbs, pigs were tattooed and shipped to Morrell Foods, in Sioux Falls, SD for slaughter. Carcasses were weighed and 10^{th} rib fat thickness, loin depth, and percent lean were measured with a Fat-O-Meater. Approximately 24 h postmortem, 112 bellies from the left sides of two slaughter groups were retrieved and subjected to a firmness test. The firmness test consisted of measuring belly length on a flat surface (L) and then placing it skin-side down on a stainless steel smoke stick. The distance between the two ends of the suspended belly (D) was then measured. Belly thickness, not including the skin, was determined by inserting a probe at the scribe line midway between the cranial and caudal ends. Fat samples were taken midway between the cranial and caudal ends of the belly at a point just dorsal of the scribe line and were packaged and transported to the South Dakota State University Meat Laboratory and analyzed for iodine absorption number. Vacuum packaged boneless loin sections (n = 110) from the left sides of carcasses from two slaughter groups were weighed, removed from vacuum packages, allowed to drip for approximately 15 min, and reweighed. From these data, purge loss was determined and expressed as a percentage of initial loin weight. Loins were then cut in half and ultimate pH of the longissimus dorsi in the caudal end of the cranial loin section was measured. A chop designated for drip loss was removed and trimmed of all subcutaneous fat and extra muscles. The remaining loin section was frozen for subsequent shear force measurement. Drip loss chops were assessed for color, marbling, and firmness according to NPPC (1999) standards. Additionally, L* color value was measured on drip loss chops using a Minolta Chroma Meter CR-310 colorimeter with a D65 illuminant. Chops were then weighed and retail wrapped on styrofoam trays. After 24 h, chops were reweighed and drip loss was determined and expressed as a percentage of initial weight.

Two chops (2.5 cm thick) from each frozen loin section were cut and placed in freezer storage for 1 to 2 weeks. Chops were then thawed for 24 h at 1ºC and cooked at 190.5ºC for 10.5 min. The resulting average final internal temperature of the chops was 68ºC. Cooked chops were cooled to room temperature (˜20ºC) before three 1.27-cm-diameter cores per chop (six cores per animal) were removed parallel to the longitudinal orientation of the muscle fibers. Individual cores were sheared once, and an average peak shear force was calculated and recorded for each pair of chops. Chops were weighed before and after cooking to determine cooking loss.

Table 1. Ingredient composition of experimental diets.

	Control	10% DDGS	20% DDGS	30% DDGS
Phase I				
Corn	66.05	51.55	51.55	44.35
SBM, 46%	27.25	23.00	23.00	20.75
Soybean oil	4.00	3.05	3.05	2.60
DDGS	0.00	20.00	20.00	30.00
Dicalcium phosphate	1.15	0.50	0.50	0.20
Limestone	0.85	1.20	1.20	1.40
Salt	0.30	0.30	0.30	0.30
Vitamin/Trace Mineral	0.25	0.25	0.25	0.25
L-lysine HCl	0.15	0.15	0.15	0.15
Phase II				
Corn	69.90	62.40	55.20	47.85
SBM, 46%	23.50	21.50	19.25	17.25
Soybean oil	4.00	3.60	3.15	2.65
DDGS	0.00	10.00	20.00	30.00
Dicalcium phosphate	1.15	0.85	0.55	0.25
Limestone	0.75	0.95	1.15	1.30
Salt	0.30	0.30	0.30	0.30
Vitamin/Trace Mineral	0.25	0.25	0.25	0.25
L-lysine HCl	0.15	0.15	0.15	0.15
Phase III				
Corn	76.35	69.15	61.75	54.55
SBM, 46%	18.00	15.75	13.75	11.50
Soybean oil	3.00	2.55	2.10	1.65
DDGS	0.00	10.00	20.00	30.00
Dicalcium phosphate	1.15	0.85	0.55	0.25
Limestone	0.80	1.00	1.15	1.35
Salt	0.30	0.30	0.30	0.30
Vitamin/Trace Mineral	0.25	0.25	0.25	0.25
L-lysine HCl	0.15	0.15	0.15	0.15
Phase IV				
Corn	82.60	75.40	68.05	60.95
SBM, 46%	13.25	11.00	9.00	6.75
Soybean oil	1.50	1.05	0.55	0.05
DDGS	0.00	10.00	20.00	30.00
Dicalcium phosphate	1.20	0.90	0.55	0.25
Limestone	0.75	0.95	1.15	1.30
Salt	0.30	0.30	0.30	0.30
Vitamin/Trace Mineral	0.25	0.25	0.25	0.25
L-lysine HCl	0.15	0.15	0.15	0.15
Phase V				
Corn	85.60	78.15	71.05	63.95
SBM, 46%	10.25	8.25	6.00	3.75
Soybean oil	1.50	1.05	0.55	0.05
DDGS	0.00	10.00	20.00	30.00
Dicalcium phosphate	1.20	0.90	0.55	0.25
Limestone	0.75	0.95	0.60	1.30
Salt	0.30	0.30	0.30	0.30
Vitamin/Trace Mineral	0.25	0.25	0.25	0.25
L-lysine HCl	0.15	0.15	0.15	0.15

Table 2. Nutrient composition of experimental diets.

	Control		10% DDGS		20% DDGS		30% DDGS	
	Form.	*Anal.*	*Form.*	*Anal.*	*Form.*	*Anal.*	*Form.*	*Anal.*
Phase I								
ME (kcal/lb)	1562	*1530*	1562	*1551*	1562	*1512*	1562	*1520*
Ca, %	0.66	*0.70*	0.65	*0.76*	0.65	*0.68*	0.66	*0.90*
P, %	0.55	*0.59*	0.55	*0.61*	0.55	*0.58*	0.55	*0.49*
Fat, %	6.65	*6.39*	6.94	*7.76*	7.14	*6.94*	7.40	*8.40*
CP, %	18.5	*17.7*	19.9	*18.2*	21.3	*19.6*	22.7	*19.8*
Lys, %	1.10	*0.90*	1.10	*1.06*	1.10	*1.01*	1.10	*0.98*
M + C, %	0.62	*0.51*	0.68	*0.64*	0.73	*0.70*	0.79	*0.73*
Thr, %	0.70	*0.58*	0.75	*0.69*	0.80	*0.74*	0.85	*0.76*
Trp, %	0.23	*0.20*	0.24	*0.18*	0.24	*0.21*	0.24	*0.20*
Phase II								
ME (kcal/lb)	1566	*1527*	1566	*1543*	1566	*1509*	1566	*1507*
Ca, %	0.62	*0.76*	0.62	*0.80*	0.63	*0.87*	0.62	*0.80*
P, %	0.54	*0.62*	0.54	*0.61*	0.54	*0.58*	0.54	*0.50*
Fat, %	6.75	*6.54*	7.06	*7.51*	7.33	*7.09*	7.55	*7.85*
CP, %	17.1	*17.1*	18.6	*17.8*	19.9	*19.2*	21.4	*20.2*
Lys, %	1.00	*1.06*	1.00	*1.04*	1.00	*1.02*	1.00	*1.04*
M + C, %	0.58	*0.59*	0.64	*0.65*	0.70	*0.67*	0.75	*0.74*
Thr, %	0.64	*0.64*	0.70	*0.68*	0.75	*0.74*	0.80	*0.79*
Trp, %	0.21	*0.18*	0.22	*0.22*	0.22	*0.20*	0.22	*0.20*
Phase III								
ME (kcal/lb)	1551	*1514*	1551	*1501*	1551	*1496*	1551	*1488*
Ca, %	0.62	*0.7*	0.63	*0.87*	0.62	*0.81*	0.63	*0.74*
P, %	0.52	*0.56*	0.52	*0.63*	0.52	*0.6*	0.52	*0.55*
Fat, %	5.93	*5.46*	6.2	*6.27*	6.46	*6.76*	6.73	*7.2*
CP, %	15.2	*13.28*	16.5	*15.22*	18	*16.49*	19.3	*17.38*
Lys, %	0.85	*0.82*	0.85	*0.86*	0.85	*0.88*	0.85	*0.94*
M + C, %	0.53	*0.5*	0.59	*0.55*	0.64	*0.64*	0.7	*0.71*
Thr, %	0.56	*0.49*	0.61	*0.56*	0.67	*0.64*	0.72	*0.71*
Trp, %	0.18	*0.16*	0.18	*0.17*	0.19	*0.16*	0.19	*0.18*
Phase IV								
ME (kcal/lb)	1527	*1509*	1527	*1500*	1527	*1494*	1527	*1493*
Ca, %	0.60	*0.88*	0.61	*0.77*	0.61	*0.91*	0.60	*0.79*
P, %	0.51	*0.65*	0.51	*0.59*	0.51	*0.55*	0.51	*0.57*
Fat, %	4.61	*5.50*	4.87	*5.35*	5.09	*5.67*	5.31	*5.84*
CP, %	13.50	*12.58*	14.90	*13.30*	16.40	*14.70*	17.70	*15.60*
Lys, %	0.72	*0.72*	0.72	*0.73*	0.72	*0.75*	0.72	*0.70*
M + C, %	0.49	*0.46*	0.54	*0.49*	0.60	*0.58*	0.66	*0.63*
Thr, %	0.50	*0.47*	0.55	*0.48*	0.60	*0.58*	0.65	*0.64*
Trp, %	0.15	*0.14*	0.16	*0.15*	0.16	*0.16*	0.17	*0.17*
Phase V								
ME (kcal/lb)	1529	*1476*	1529	*1529*	1529	*1510*	1529	*1506*
Ca, %	0.59	*0.74*	0.60	*0.72*	0.60	*0.67*	0.59	*0.78*
P, %	0.50	*0.59*	0.50	*0.52*	0.50	*0.49*	0.50	*0.48*
Fat, %	4.68	*3.35*	4.95	*5.37*	5.17	*5.22*	5.39	*5.60*
CP, %	12.40	*12.26*	13.90	*11.65*	15.30	*13.05*	16.60	*13.95*
Lys, %	0.64	*0.74*	0.64	*0.62*	0.64	*0.62*	0.64	*0.57*
M + C, %	0.46	*0.44*	0.52	*0.45*	0.57	*0.53*	0.63	*0.57*
Thr, %	0.46	*0.45*	0.51	*0.45*	0.56	*0.53*	0.61	*0.55*
Trp, %	0.14	*0.13*	0.14	*0.13*	0.14	*0.14*	0.15	*0.13*

Growth performance
Pigs initially weighed 62.5 lbs at the beginning of the experiment, and did not differ between treatments (P > .10). Initial weight groups averaged 51.0 (Low), 61.9 (Medium), and 74.5 lbs (High). The first group of pigs marketed occurred on day 91 of the trial. Growth performance data were collected for day 91 and overall, and are presented in Figures 1 – 8. Pigs fed the 20 or 30% DDGS diets had reduced ADG (1.80 and 1.78 lb/d) (P < .10) compared to 0 or 10% DDGS (1.90 and 1.89 lb/d), but ADFI was unaffected by dietary treatment (P > .10). Feed conversion (G/F) decreased when pigs were fed 30% DDGS (0.360) ((P < .10) compared to 0 and 10% DDGS inclusion levels (0.377 and 0.377). Overall, a similar effect on growth performance with dietary treatment was noted, with decreased ADG at the 20 and 30% DDGS levels without a difference in feed intake. Feed conversion did decrease when pigs were fed the 20 or 30% DDGS diets compared to 0 or 10% levels. Initial weight group significantly affected growth performance on day 91 and overall, with increased initial weight resulting in improved ADG, ADFI, and day 91 weight (P < .01) and decreased G/F (P < .06). No significant treatment x group interactions were detected (P > .10).

Figure 1. Day 91 weight, by treatment

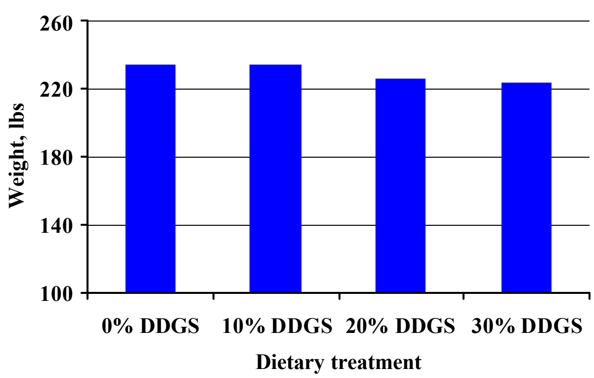


Figure 2. Day 91 weight, by wt group

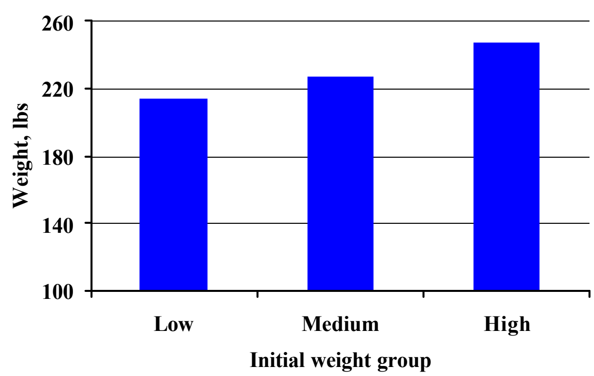


Figure 3. ADG, day 91, by treatment

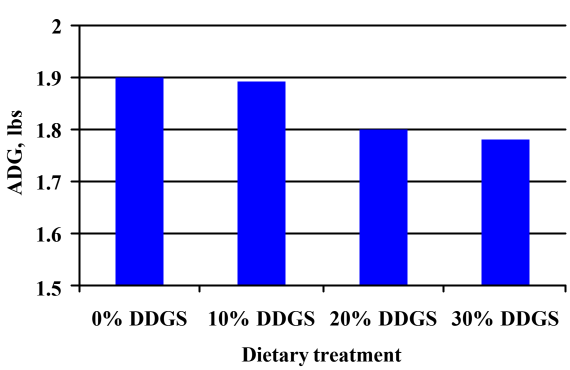


Figure 4. ADG, overall, by treatment

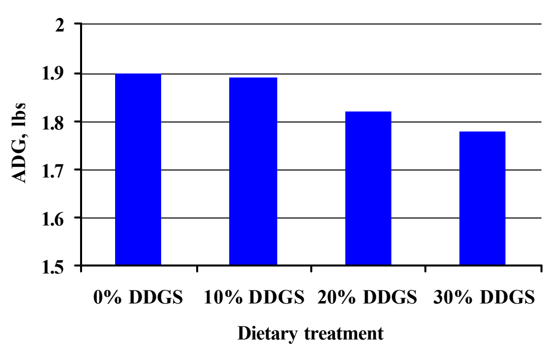


Figure 5. ADFI, day 91, by treatment

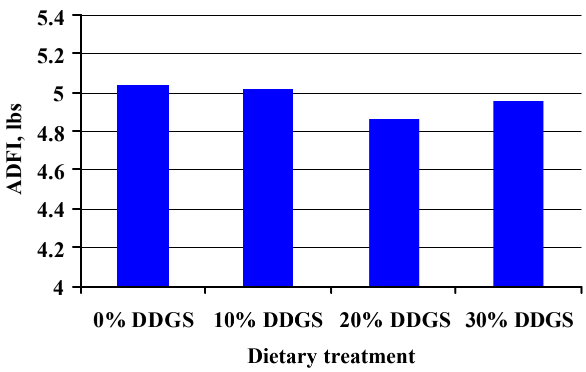


Figure 6. ADFI, overall, by treatment

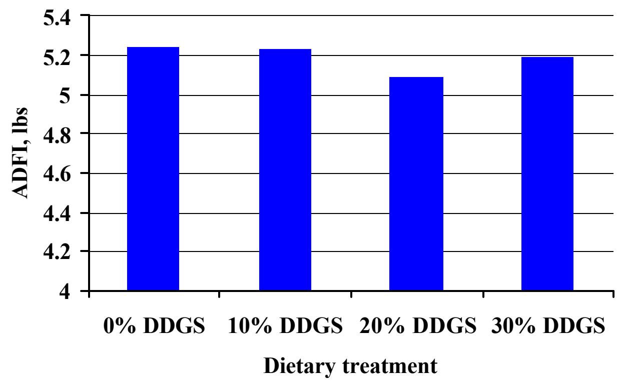


Figure 7. G/F, d 91, by treatment

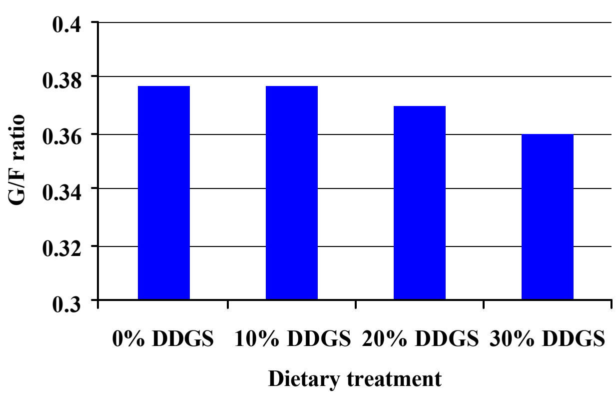
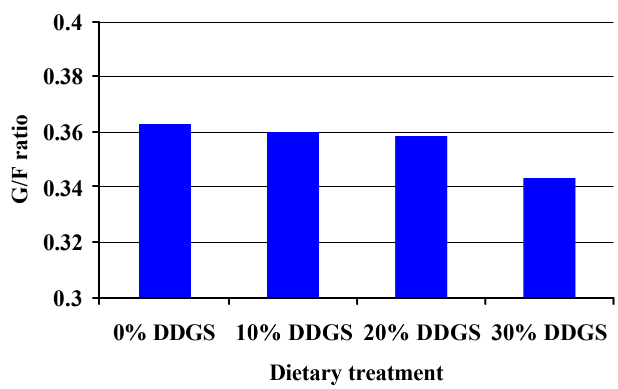


Figure 8. G/F, overall, by treatment



Carcass data

Although all pigs in a pen were marketed when the weekly pen weight average was within 5 lbs of the goal, a linear decrease in market weight with increased DDGS level of the diet was observed (P < .03). Figures 9 – 14 present the market weight and carcass data by dietary treatment. Carcass weight was lower for pigs fed the 20 or 30% DDGS diets (177.5 and 177.2 lbs) compared to the 0 and 10% DDGS treatments (189.0 and 191.1 lbs) (P < .01), but this is at least partially due to the differences in market weight at time of slaughter. Due to the differences in carcass weight, dressing % was also lower for the 20 and 30% DDGS treatments (71.50 and 71.74%) compared to the 0 and 10% treatments (73.37 and 73.03%) (P < .01). Lean % was unaffected by dietary treatment (P > .10), although loin depth tended to decrease linearly (P < .02) with increasing DDGS level in the diet. Fat depth did not differ between treatment groups (P < .10). Carcass weight, fat depth, and % lean differed among weight groups (P < .01), but other carcass traits measured were unaffected by initial weight group (P > .10).

Figure 9. Weight at market, by treatment

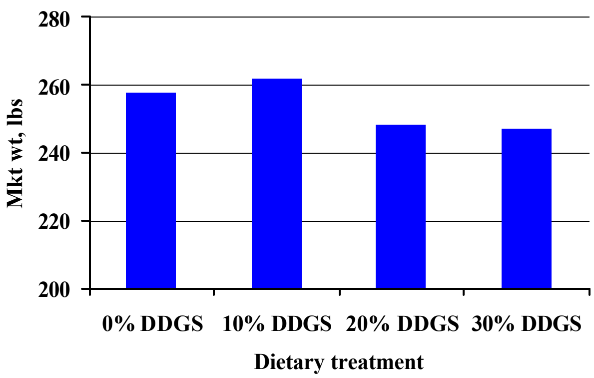


Figure 10. Carcass weight, by treatment

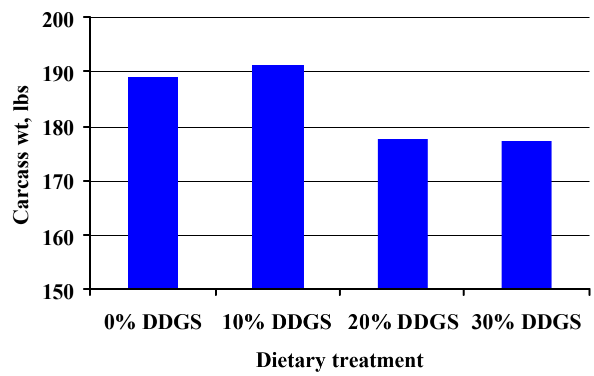


Figure 11. Dressing % at market, by treatment

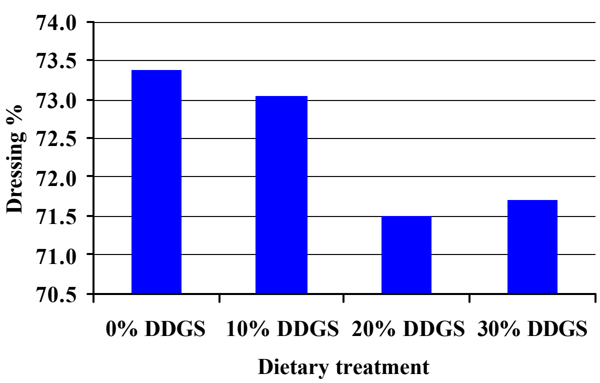


Figure 12. Lean % (market), by treatment

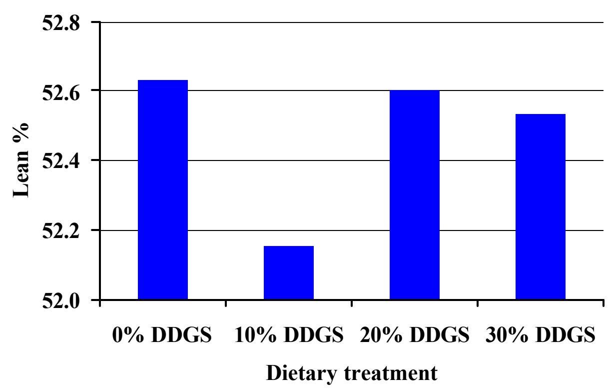


Figure 13. Loin depth (mm), by treatment

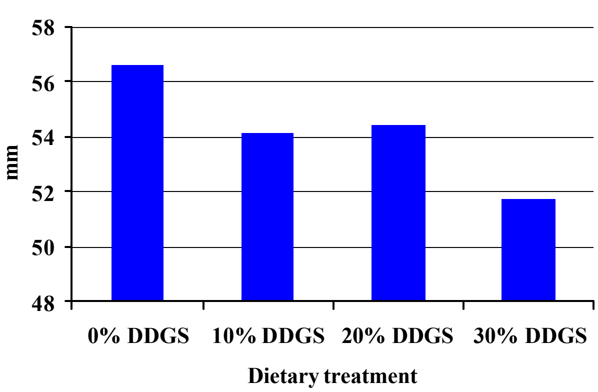
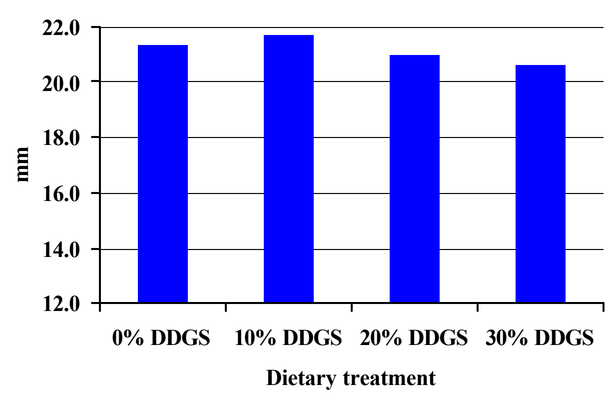


Figure 14. Fat depth (mm), by treatment



Carcass quality
Iodine number increased linearly (P < .05), and thus carcass fat became more unsaturated, as the level of DDGS was increased in the diet (Table 3). It has been well established that feeding diets that contain an unsaturated fat source can alter the level of saturation in pork fat. Lea et al. (1970) characterized quality pork fat as having an iodine number below 70. In our study, iodine values were greater than 70 for diets containing 20 and 30% DDGS. Overall, our values were within the upper range (50 to 72) of iodine numbers reported for pork belly fat in swine fed raw soybeans (Pontif et al., 1987) or barley- and maize-based diets (Lucas et al., 1960; Lawrence, 1974). The effect of DDGS feeding on iodine number was reflected in the analysis of belly firmness score (Table 3). Lower belly firmness scores indicated that bellies from pigs that were fed 30% DDGS were softer (P < .05) than bellies from pigs fed 0 or 20% DDGS. Softer bellies were most likely a consequence of elevated levels of unsaturated lipids.

Table 3. Fat quality characteristics of swine fed differing levels of DDGS.

	Treatment				
	Control	***10%***	***20%***	***30%***	***RMSE***
Belly thickness, cm	3.15[c]	3.00[cd]	2.84[cd]	2.71[d]	0.56
Belly firmness score[a], degrees	27.3[c]	24.4[cd]	25.1[c]	21.3[d]	6.3
Adjusted belly firmness score[b], degrees	25.9[c]	23.8[cd]	25.4[c]	22.4[d]	5.4
Iodine number	66.8[c]	68.6[d]	70.6[e]	72.0[e]	3.4

[a]Belly firmness score = $\cos^{-1}[(0.5(L^2) - D^2)/(0.5(L^2))]$, where L = belly length measured on a flat surface and D = the distance between the two ends of a suspended belly; higher belly firmness scores indicate firmer bellies.
[b]Belly firmness score adjusted for belly thickness.
[c,d,e]Means within a row lacking a common superscript letter differ (*P* < 0.05).

Based on curvilinear regression analysis, iodine number and belly thickness explained 14% and 33% of the observed variation in belly firmness score, respectively, and together iodine number and belly thickness explained 37% of the observed variation in belly firmness score (data not presented in tabular form). Thus, carcass fatness had a larger effect on belly firmness than did fat composition.
Color measurements of L* were not different (P > .05) among dietary treatments (Table 4). Likewise, visual evaluations of the longissimus muscle did not differ between treatments for color score, firmness score, or marbling score. Moreover, ultimate pH was not different (P > .05) between treatments. Most water holding capacity traits, including 24-h drip loss, cooking loss, and total moisture loss, were not different (P > .05) between treatments. However, differences were detected between 0 and 20% DDGS treatments for 11-d purge loss. Dietary treatment did not affect (P > .05) Warner-Bratzler shear force values of cooked loin chops. Therefore, feeding DDGS in swine finishing diets did not have any meaningful effects on pork muscle quality.

Table 4. Muscle quality characteristics of swine fed differing levels of DDGS.

	Treatment				
Trait	***Control***	***10%***	***20%***	***30%***	***RMSE***
L*[a]	54.28	55.10	55.81	55.51	2.87
Color score[b]	3.17	3.15	3.05	3.12	0.81
Firmness score[c]	2.21	2.04	2.06	2.08	0.52
Marbling score[d]	1.89	1.85	1.72	1.91	0.61
Ultimate pH	5.61	5.56	5.60	5.61	0.16
11-d purge loss, %	2.06[f]	2.37[fg]	2.84[g]	2.54[fg]	1.15
24-h drip loss, %	0.70	0.67	0.71	0.74	0.17
Cooking loss, %	18.66	18.50	18.26	18.77	2.58
Total moisture loss[e], %	21.42	21.54	21.81	22.05	3.13
Warner-Bratzler shear force, kg	3.40	3.44	3.33	3.30	0.53

[a]0 = black to 100 = white.
[b]1 = pale pinkish gray to white; 2 = grayish pink; 3 = reddish pink; 4 = dark reddish pink; 5 = purplish red; 6 = dark purplish red (NPPC, 1999).
[c]1 = soft; 2 = firm; 3 = very firm (NPPC, 1999).
[d]Visual scale approximates percent intramuscular fat content (NPPC, 1999).
[e]Total moisture loss = 11-d purge loss + 24-h drip loss + cooking loss.
[f,g]Means within a row lacking a common superscript letter differ ($P < 0.05$).

Conclusion

Results from this study suggest that when grow-finish diets are formulated on a total amino acid basis, less than 20% DDGS should be included in the diet for optimal performance and carcass composition. Inclusion of DDGS in diets for growing swine does not appear to appreciably affect pork muscle quality, at least up to the 30% inclusion levels tested in this study. Dietary inclusion levels of 20% or greater may provide satisfactory performance and carcass composition if diets are formulated on a digestible amino acid basis, but further trials are necessary to determine this.

Literature Cited

Al-Kanani, T., E. Akochi, A.F. MacKenzie, I. Alli, and S. Barrington. 1992. Odor control in liquid hog manure by added amendments and aeration. J. Environ. Qual. 21:704-708.

Canh, T.T., M.W.A. Verstegen, A.J.A. Aarnink, and J.W. Schrama. 1997. Influence of dietary Factors on Nitrogen Partitioning and Composition of Urine and Feces of Fattening Pig. J. Anim. Sci. 75:700-706.

Canh, T.T., J.W. Schrama, A.J.A. Aarnink, M.W.A. Verstegen, C.E. van't Klooster, and M.J. W. Heetkamp. 1998a. Effect of dietary fermentable fibre from pressed sugar-beet pulp silage on ammonia emission from slurry of growing-finishing pigs. Anim. Sci. 67:583-590.

Canh, T.T., A.L. Sutton, A.J.A. Aarnink, M.W.A. Verstegen, J.W. Schrama and G.C.M. Bakker. 1998b. Dietary carbohydrates alter the fecal composition and pH and the ammonia emission from slurry of growing pigs. J. Anim. Sci. 76:1887-1895.

Carpenter, L.E. 1970. Nutrient composition of distillers feeds. Proc. Distillers Feed Res. Council. 25:54-61.

Cromwell, G.L., T.S. Stahly, H.J. Monegue, and J.R. Overfield. 1983. Distillers dried grains with solubles for growing-finishing swine. Kentucky Agric. Expt. Station. Progress Report 274. p. 30-32. Lexington, KY.

Cromwell, G.L. and T.S. Stahly. 1986. Distillers dried grains with solubles for growing finishing swine. Proc. Distillers Feed Conf. 41:77-87.

Cromwell, G.L., K.L. Herkelman, and T.S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J. Anim. Sci. 71:679-686.

Distillers Grains. 2000. Distillers Grains Technology Council. Louisville, KY.

Feedstuffs Reference Issue. 1999. Ingredient analysis table. Miller Publishing Co., Minnetonka, MN, 71:24-31.

Heartland Lysine, Inc. 1998. Digestibility of essential amino acids for poultry and swine. Version 3.51, Heartland Lysine, Inc., Chicago, IL.

Hobbs, P.J., T.H. Misselbrook, and B.F. Pain. 1995. Assessment of odours from livestock wastes by a photoionization detector, an electronic nose, olfactometry and gas chromatography-mass spectrometry. J. Agric. Engng. Res. 60:137-144.

Kirchgessner, M., M. Kreuzer, A, Machmuller, and D.A. Roth-Maier. 1994. Evidence for a high efficiency of bacterial protein synthesis in the digestive tract of adult sows fed supplements of fibrous feedstuffs. Anim. Feed Sci. and Technol. 46:293-306.

Kreuzer, M. and A. Machmuller. 1993. Reduction of gaseous nitrogen emission from pig manure by increasing the level of bacterially fermentable substrate in the ration. Proceedings of the First International Symposium on Nitrogen Flow in Pig Production and Environmental Consequences. Wageningen, The Netherlands 8-11 June 1993. EAAP Publ. No. 69:151-156.

Lawrence, T. L. J. 1974. Short note: The effect on bacon pig backfat iodine number and caloric value of feeding barley or maize based diets to give different growth rates. J. Agric. Sci. Camb. 82:177-179.

Lea, C. H., P. A. T. Swoboda, and D. P. Gatherum. 1970. A chemical study of soft fat in cross-bred pigs. J. Agric. Sci. Camb. 74:1-11.

Lucas, I. A. M., I. McDonald, and A. F. C. Calder. 1960. Some further observations upon the effects of varying the plane of feeding for pigs between weaning and bacon weight. J. Agric. Sci. Camb. 54:81-99.

Mroz, Z., A.W. Jongbloed, S. Beers, P.A. Kemme, L. de Jonge, A.K. van Berkum and R.A. van der Lee. 1993. Preliminary studies on excretory patterns of nitrogen and anaerobic deterioration of faecal protein from pigs fed various carbohydrates. Proceedings of the First International Symposium on Nitrogen Flow in Pig Production and Environmental Consequences. Wageningen, The Netherlands 8-11 June 1993. EAAP Publ. No. 69:247-251.

National Research Council. 1998. Nutrient Requirements of Swine. 10th ed. National Academy Press, Washington, D.C., pp. 124-142.

Olentine, C. 1986. Ingredient profile: distillers feeds. Proc. Distillers Feed Conf. 41:13-24..

Pontif, J. E., L. L. Southern, D. F. Coombs, K. W. McMillin, T. D. Bidner, and K. L. Watkins. 1987. Gain, feed efficiency, and carcass quality of finishing swine fed raw soybeans. J. Anim. Sci. 64:177-181

Riskowski, G.L., A.C. Chang, M.P. Steinberg, and D.L. Day. 1991. Methods for evaluating odor from swine manure. Appl. Engng. Agric. 7 (2):248-253.

Sauer, W.C., H. Jorgensen, and R. Berzins. 1983. A modified nylon bag technique for determining apparent digestibilities of protein in feedstufs for pigs. Can. J. Anim. Sci. 63:233-237.

Wahlstrom, R.C., C.S. German, and G.W. Libal. 1970. Corn distillers dried grains with solubles in growing-finishing swine rations. J. Anim. Sci. 30:532-535.

Weigel, J.C., D. Loy, and L. Kilmer. 1997. Feeding Co-Products of the Dry Corn Milling Process. p. 2-4. Renewable Fuels Association and National Corn Growers Association. Washington, D.C. and St. Louis, MO.

DDGS Publications (1999-2001)

Scientific Abstracts Presented - Midwest or National American Society of Animal Science Meetings

Whitney, M.H., M.J. Spiehs, and G.C. Shurson. 1999. A nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 77:188 (Suppl. 1).

Spiehs, M.J., G.C. Shurson, and M.H. Whitney. 1999. Energy, nitrogen, and phosphorus digestibility of growing and finishing swine diets containing distiller's dried grains with solubles. J. Anim. Sci. 77:188 (Suppl. 1).

Spiehs, M.J., M.H. Whitney, G.C. Shurson, and R.E. Nicolai. 2000. Odor characteristics of swine manure and nutrient balance of grow-finish pigs fed diets with and without distillers dried grains with solubles. J. Anim. Sci. 78:69 (Suppl. 2).

Whitney, M.H., M.J. Spiehs, G.C. Shurson, and S.K. Baidoo. 2000. Apparent ileal amino acids digestibilities of corn distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 78:185 (Suppl. 1).

Scientific Abstracts Submitted - National American Society of Animal Science Meetings

Whitney, M.H., M.J. Spiehs, and G.C. Shurson. 2001. Phosphorus availability of distiller's dried grains with solubles in swine diets. J. Anim. Sci. (submitted for National ASAS meetings, July, 2001)

Whitney, M.H, G.C. Shurson, L.J. Johnston, D. Wulf, and B. Shanks. 2001. Growth performance and carcass characteristics of pigs fed increasing levels of distiller's dried grains with solubles. J. Anim. Sci. (submitted for National ASAS meetings, July, 2001).

B. Shanks, D. Wulf, M.H. Whitney, L.J. Johnston, and G.C. Shurson. 2001. Pork quality characteristics of grow-finish pigs fed increasing dietary levels of distiller's dried grains with solubles. J. Anim. Sci. (submitted for National ASAS meetings, July, 2001)

M.S. Thesis

Evaluation of the Feeding Value of Distillers Dried Grains with Solubles for Swine. 2001. Mindy Spiehs, University of Minnesota.

Papers Published and Presented at Nutrition Conferences

Whitney, M.H., M.J. Spiehs, and G.C. Shurson. 1999. Use of Minnesota-South Dakota regional Distillers Dried Grains with Solubles in swine diets. 60th Minnesota Nutrition Conference & Zinpro Technical Symposium. September 20-22, 1999, Bloomington, MN. pp. 171-186.

Shurson, G.C., M.H. Whitney, M.J. Spiehs, S.K. Baidoo, and A. Renteria. 2000. The Value of Distillers Dried Grains with Solubles in Pig Diets. Concepts in Pig Science 2000, 2nd Annual Turtle Lake Pig Science Conference, May 3-5, 2000, Stillwater, MN, pp. 47-62.

Presentations at Ethanol Conferences

Shurson, G.C., M.H. Whitney, M.J. Spiehs, S.K. Baidoo, and A. Renteria. 2000. The Value of Distillers Dried Grains with Solubles in Pig Diets. Distiller's Grains Technology Council's Fourth Symposium, May 24-25, 2000, Louisville, KY.

Shurson, G.C. 2000. Increasing the Use of Distillers Dried Grains with Solubles in Pig Diets. 16th Annual International Fuel Ethanol Workshop and Trade Show, June 20-23, 2000, Windsor, Ontario.

Whitney, M.H. 2000. Research results on using distiller's dried grains with solubles in swine diets. ACE Conference, July 24-28, 2000, Fargo, ND.

Articles Published in National Industry Magazines

Dried distillers grains nutrient database may promote use in swine diets. Feedstuffs, October, 25, 1999.

"P" is for "Profit" and "Pigs". Article written by Wendy Fernstrom, freelance writer for the MN Corn Growers Association. January 5, 2001.

DDGS
Opportunity Cost

*** Developed by John Goihl & Dean Koehler**
Agri-Nutrition Services

Additions:

+ DDGS	200 lb	x	Cost/lb	=	$ ________
+ Limestone	3 lb	x	Cost/lb	=	$ ________
			Total (A)		$ ________

Deletions:

Corn	177 lb	x	Cost/lb	=	$ ________
Soybean meal, 44%	20 lb	x	Cost/lb	=	$ ________
Dicalcium phosphate, 18.5%	6 lb	x	Cost/lb	=	$ ________
			Total (D)		$ ________

Opportunity Cost:

Total (D) - Total (A) - Goal [$] = Opportunity Cost of DDGS $ ________/200 lb.

DDGS
Opportunity Cost

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Agri-Nutrition Services

Additions:

+ DDGS	200	lb	x	Cost/lb	=	$________
+ Limestone	3	lb	x	Cost/lb	=	$________
				Total (A)		$________

Deletions:

Corn	178	lb	x	Cost/lb	=	$________
Soybean meal, 46%	19	lb	x	Cost/lb	=	$________
Dicalcium phosphate, 18.5%	6	lb	x	Cost/lb	=	$________
				Total (D)		$________

Opportunity Cost:

Total (D) - Total (A) - Goal [$] = Opportunity Cost of DDGS $________/200 lb.