# The Value of Distiller's Dried Grains with Solubles in Swine Diets

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## Background

Distiller's Dried Grains with Solubles (DDGS) is a co-product of the distillery industries. Most (~98%) of the DDGS in North America comes from plants that produce ethanol for oxygenated fuels. The remaining 1 to 2% of DDGS is produced by the alcohol beverage industry.

Approximately 3.2 to 3.5 million metric tonnes of DDGS are produced annually in North America (Markham, 2000; personal communication). According to the Minnesota Department of Agriculture (Groschen, 2001), Minnesota has 14 ethanol plants that produce over 240 million gallons of ethanol per year and 1 million tons of DDGS from 130 million bushels of corn (13% of MN corn crop). Thus, ethanol plants in Minnesota produce approximately 30% of the total DDGS production in North America annually. Most of the ethanol plants in Minnesota are small (13 to 34 million gallon capacity per year), farmer owned (8,945 farmer members), and relatively new (1 to 10 years old).

The Minnesota Ethanol Industry is growing at a rapid pace. In 1994, 24 million gallons of ethanol were produced in Minnesota (Groschen, 2001). In 2000, 220 million gallons of ethanol were produced, an increase of over 900 %. This trend is expected to continue.

In North America, over 80% of DDGS are used in ruminant diets (Markham, 2000;personal communication). Minnesota is the only state in the U.S. where a significant amount of DDGS (40,000 to 50,000 tonnes annually) is fed to turkeys. Less than 1% of the total annual production is fed to swine.

Traditionally, most of the DDGS in the U.S. has been fed to ruminants because of low protein quality, reduced amino acid digestibility, increased fiber, and lower DE and ME content compared to corn. In addition, cattle feeding systems are much more capable of utilizing high moisture feedstuffs than swine feeding systems. Variability in nutrient content and cost competitiveness relative to corn and soybean meal have also limited the use of DDGS in swine diets in the Midwestern states of the U.S. As a result, many swine nutritionists have considered DDGS to be a less desirable nutrient source compared to other energy and amino acid sources. However, due to the increasing quantities of DDGS being produced and the potential improvement in nutritional value resulting from using newer technology and quality control in the Minnesota plants, the application of DDGS in swine diets needed to be re-evaluated.

The primary goals of the Minnesota and South Dakota ethanol industry, which has provided the majority of funding for this research effort, are:

- to determine if the DDGS is of higher nutritional value than other industry sources in order to potentially differentiate MN produced DDGS from other sources

- to determine if it can be used as a cost effective partial replacement for corn, soybean meal and dicalcium phosphate in practical swine diets in order to increase its usage in the pork and poultry industries

- identify nutritional features that give DDGS higher value compared to other ingredients used in swine/livestock feeds

The purpose of this paper is to describe and compare the nutritional value of Minnesota produced DDGS among other industry sources and published values, provide new data on the nutritional value of DDGS for swine, and describe the application of DDGS in practical swine diets.

## Nutrient Content and Variability Among and Within MN and SD Ethanol Plants

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 co-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.

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.

Very little research has been conducted on distiller's co-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 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, we conducted a study to determine the nutrient composition and variability of DDGS from new ethanol plants in Minnesota and South Dakota (MNSD). These nutrient values were compared to those that have been published (NRC, 1998; Feedstuffs Reference Issue, 1999; and Heartland Lysine, 1998), as well as to nutrient values for DDGS produced by an older Midwestern plant (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 Minnesota and South Dakota. 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 plant, 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 the OMP sample was much darker in color.

All samples were sent to the University of Missouri (Columbia, MO) for amino acid analysis and to 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 nutrient values obtained from the DDGS sample obtained from an older Midwestern plant (Tables 1, 2, and 3).

MNSD DDGS had higher crude fat content than OMP DDGS, which contributed to the higher DE and ME values by minimizing the energy dilution effect of the high fiber content of DDGS. All 11 essential amino acids were higher in Minnesota-South Dakota DDGS than the sample of DDGS from OMP, potentially making MNSD DDGS a more valuable nutrient source than other DDGS sources because 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 among 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.

**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 (%) | NDG (%) | 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 No. 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) | .25 (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] 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 No. 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)
Feedstuffs Reference Issue, Vol. 71 No. 31, July 30, 1999. (FRI)

*Results from this study show that DDGS produced by MNSD ethanol plants is generally higher in energy, amino acids, and phosphorus than the OMP DDGS and values listed in NRC (1998). This study also showed significant differences in nutrient variability, particularly for lysine, within and among ethanol plants, even though these plants are using similar fermentation and processing technology.*

*A study is currently underway to compare quality and consistency of DDGS among MNSD ethanol plants. Minimum standards are being established for particle size, moisture, bulk density, and color of MNSD DDGS in order to differentiate MNSD DDGS with other sources in the industry.*

## DE and ME Values of MN DDGS

We conducted two trials 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).

Sixteen grower pigs weighing 28.6 ± 2.2 kg and 31.2 ± 7.3 kg during the Trial 1 and Trial 2, respectively, and 16 finisher pigs weighing 84.4 ± 6.2 kg and 76 ± 10.6 kg during Trial 1 and Trial 2, 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 Trial 1 and Trial 2, respectively and 1767 g/d and 1814 g/d during the finisher phases of Trial 1 and Trial 2, respectively. Urine and feces were collected on day 8 to 10 of the 10-day period. Feed, feces, and urine were analyzed for gross energy content. Digestible and metabolizable energy values were determined.

*Digestible and metabolizable energy concentrations for the MNSD DDGS were variable making it difficult to assign a specific value for the DE and ME content of MNSD DDGS (Tables 4 and 5). However, even the lowest estimates of energy density in MNSD DDGS suggests that the MNSD DDGS is at least equal to 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 is most likely higher (Figures 1 and 2). 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 also when 30% DDGS was added to finisher diets.*

*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.*

**Table 4. Digestible and metabolizable energy estimates of MNSD DDGS in Trial 1 (dry-matter basis).**

| Variable | Control | 10% DDGS | 20% DDGS | 30% DDGS | CV (%) |
|---|---|---|---|---|---|
| Grower | | | | | |
| 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 |
| Finisher | | | | | |
| 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 5. Digestible and metabolizable energy estimates of MNSD DDGS in Trial 2 (dry-matter basis).**

| Variable | Control | 10% DDGS | 20% DDGS | 30% DDGS | CV (%) |
|---|---|---|---|---|---|
| Grower | | | | | |
| 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 |
| Finisher | | | | | |
| 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 Trial 1 with NRC (1998), Feedstuffs Reference Issue (1999), Feed Co-Products of the Dry Corn Milling Process (1997), and Distillers Grains (2000).**

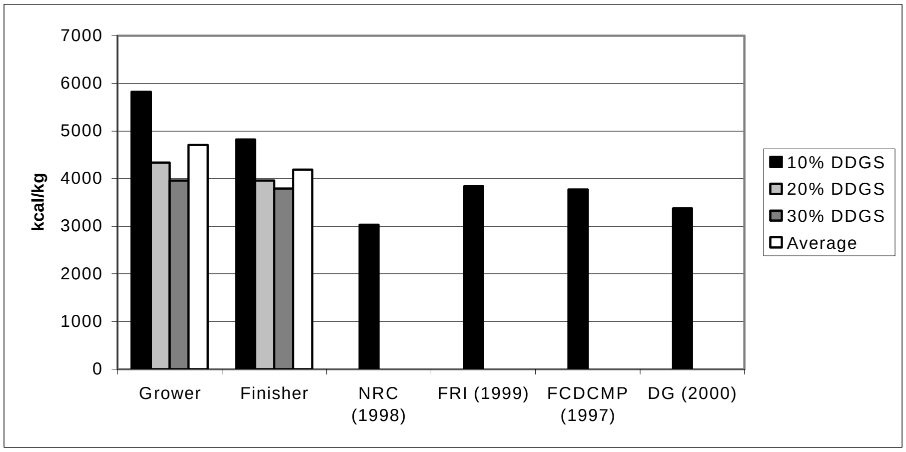
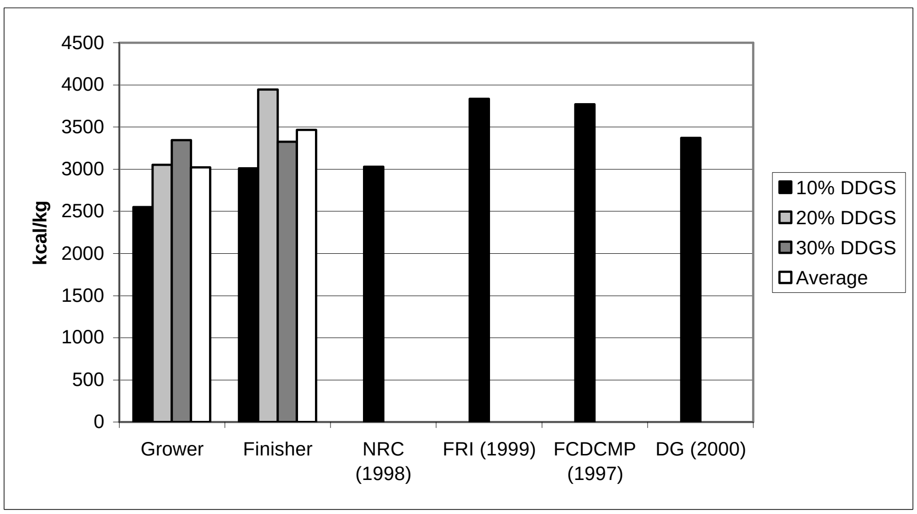



**Figure 2. Comparison of ME values (dry-matter basis) for DDGS from Trial 2 with NRC (1998) Feedstuffs Reference Issue (1999) Feed Co-Products of the Dry Corn Milling Process (1997) and Distillers Grains (2000). Basis for DDGS from Trial 2 with NRC (1998) Feedstuffs Reference Issue (1999) Feed Co-Products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




## Apparent Ileal Amino Acid Digestibility Values of MN DDGS

Apparent ileal amino acid digestibility values for DDGS from a new ethanol plant in Minnesota have been determined. We also compared these values with values from current reference publications (NRC, 1998; Heartland Lysine, 1998; Feedstuffs Reference Issue, 1999) and a sample of DDGS from an older Midwestern plant (OMP).

The study utilized 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 power washed 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 (Table 6). 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 (Table 6). 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 7. Coefficients of variation are shown in parenthesis next to the value represented. Apparent ileal digestible amino acid levels for DDGS produced in the Minnesota ethanol plant generally 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 (Table 9). 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 (Table 8). Methionine and phenylalanine appeared to be lower in MNSD DDGS compared to Heartland Lysine (1998) values. 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 (Table 8). Total lysine content was the most variable (CV=10.1%) of the amino acids measured.

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 (Table 9). 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 (Table 10). 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 (Tables 7 and 8).

**Table 6. Composition and nutrient content of dietary treatments in Experiment 1.**

| Ingredient | Experiment 1 | | | | Experiment 2 | |
|---|---|---|---|---|---|---|
| | 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 7. Amino acid composition, apparent ileal and total tract digestible levels of MNSD and OMP DDGS (dry).**

| | 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 8. 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 |

**Table 9. 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 10. 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).*

*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.*

## Phosphorus Availability of MN DDGS

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 availability in MNSD DDGS were determined.

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 availability. Pigs were randomly allotted by weight and ancestry to one of seven dietary treatments (Table 11). 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 availability). 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 12. 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.

**Table 11. 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 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.

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 3 and 4. 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 5) increased linearly (P < .01) with increasing P intake. However, P retention (% of intake) (Figure 6) did not differ between dietary treatments (P > .10).

**Figure 3. Phosphorus intake level (mg/d).**

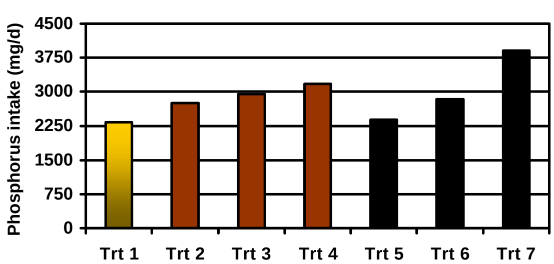



**Figure 4. Phosphorus excreted (mg/d).**

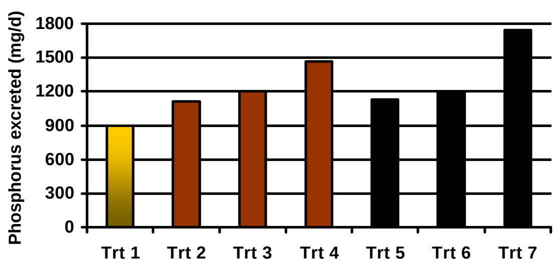



**Figure 5. Phosphorus retained (mg/d).**

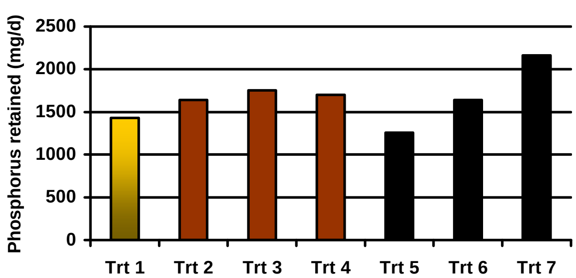
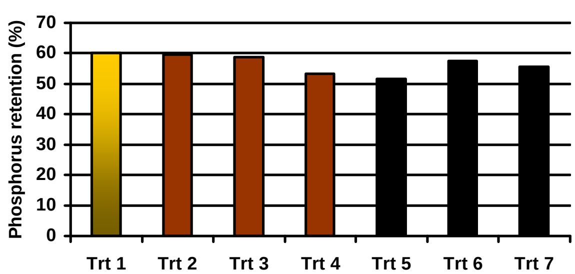



**Figure 6. Phosphorus retention (% of intake).**



A linear regression analysis was conducted for P excreted and P retained relative to P intake for dicalcium phosphate and DDGS separately (Figures 7 and 8). 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 dicalcium, was 87.5% (excretion data) and 92.2% (retention data).

**Figure 7. Regression analysis: P excreted.**

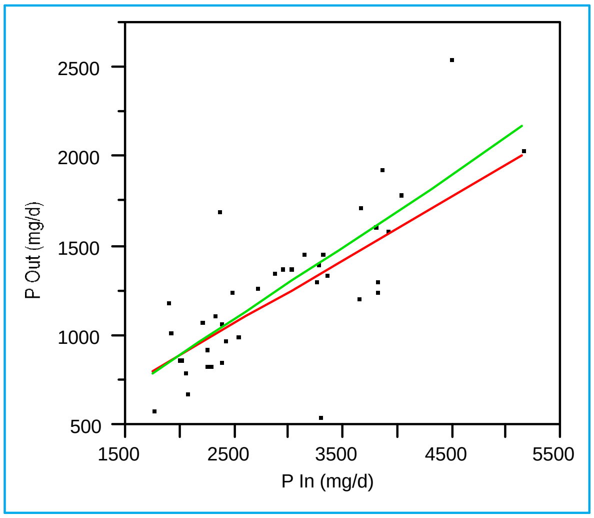
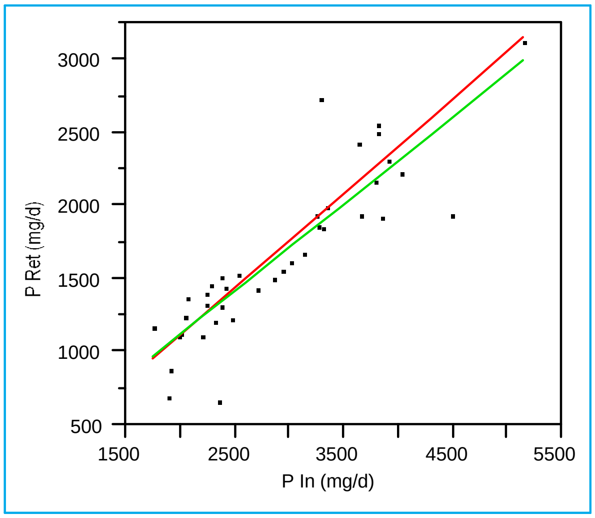



**Figure 8. Regression analysis: P intake.**




*These results suggest that DDGS produced from the MNSD region ethanol plants is an excellent source of available phosphorus (~ 90% available) 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.*

## Evaluating the Cost Effectiveness of Adding DDGS to Grow-Finish Swine Dets

The following tables provide a quick method for evaluating the cost effectiveness of partially replacing corn, soybean meal (44% or 46%), and dicalcium phosphate with 10% DDGS in grow-finish diets. These tables were developed by John Goihl and Dean Koehler, Agri-Nutrition Services, Shakopee, MN.

**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.

**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.

## Performance Limitations When Formulating Grow-Finish Swine Diets Containing DDGS on a Total Amino Acid Basis

Poor amino acid balance and digestibility have resulted in conservative and somewhat variable recommendations involving maximum inclusion rates of 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.

Our research results have shown that total and apparent digestible lysine in DDGS from Minnesota and South Dakota (MNSD) ethanol plants are 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. We conducted an informal survey of feed industry nutritionists who suggested 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.

We conducted a study 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. 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 12 and 13. 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.

**Table 12. 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 |

Pigs were weighed and feed disappearance was 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 re-weighed. 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 13. 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 |

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 9-16. 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 9. Day 91 weight, by treatment.**

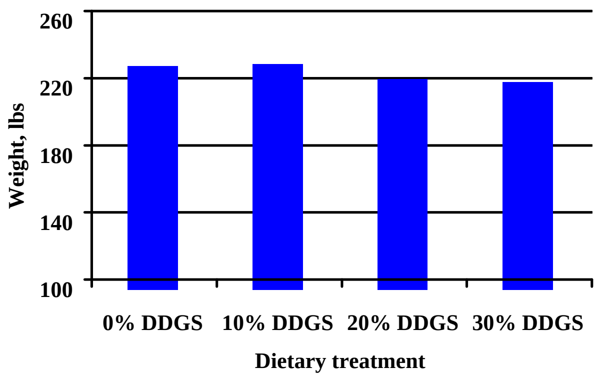



**Figure 10. Day 91 weight, by wt group.**

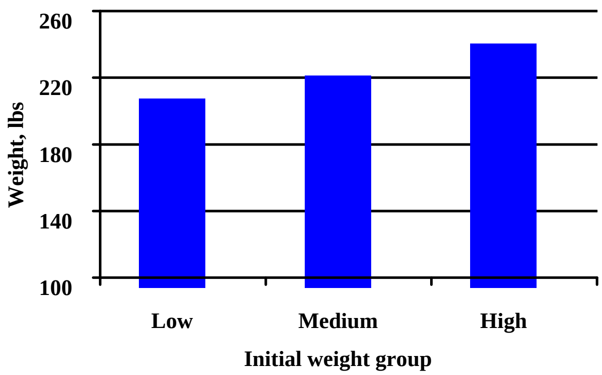



**Figure 11. ADG, day 91, by treatment.**

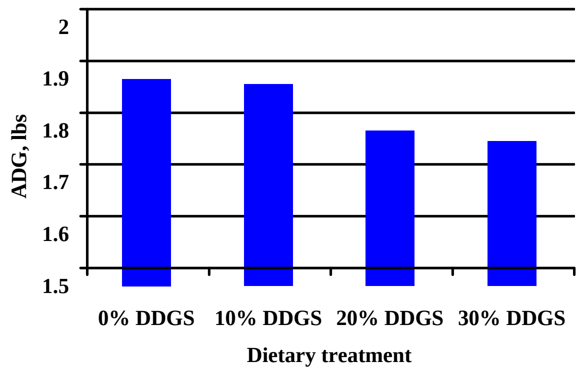



**Figure 12. ADG, overall, by treatment.**

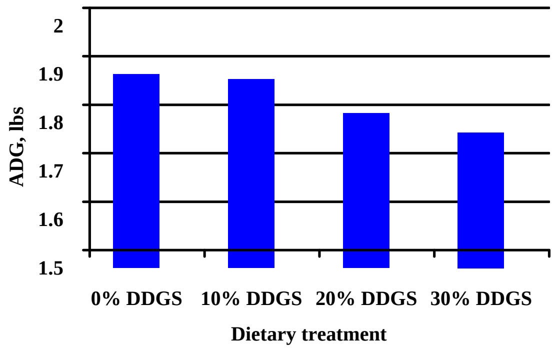


Figure 13. ADFI, day 91, by treatment.

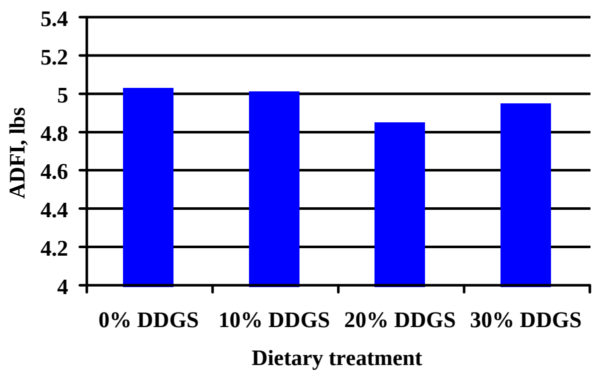



Figure 14. ADFI, overall, by treatment.

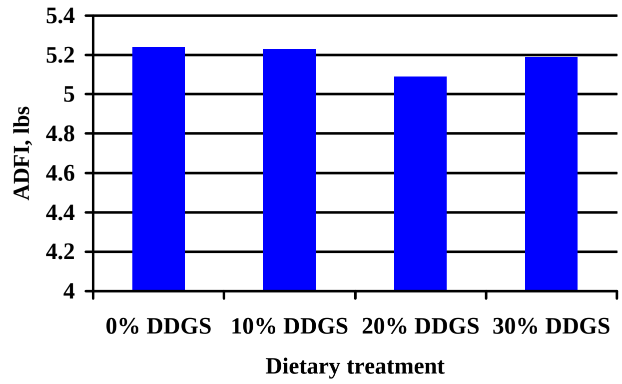



Figure 15. G/F, d 91, by treatment.

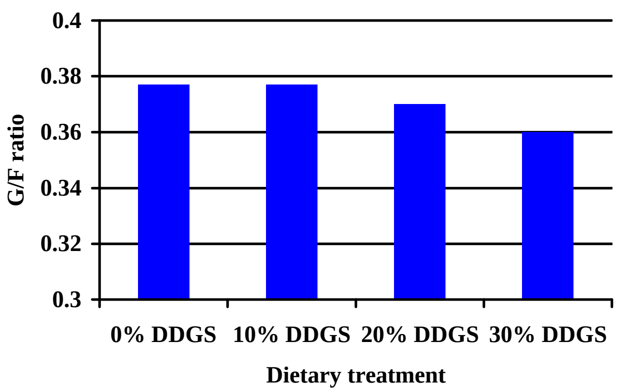
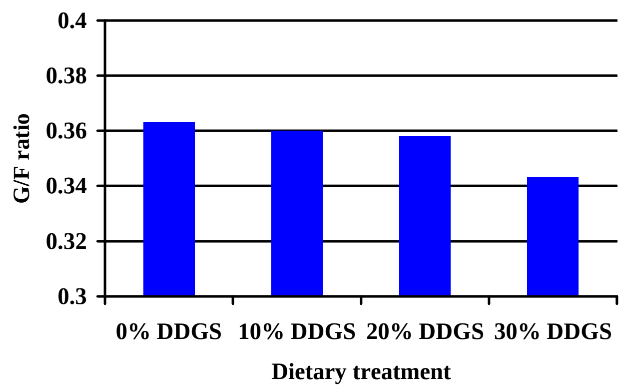



Figure 16. G/F, overall, by treatment.




## Pork and Carcass Quality Considerations when Adding DDGS to Swine Diets

Diet composition and nutrient levels can affect 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.

In the grow-finish study previously described, all pigs in a pen were marketed when the weekly pen weight average was within 5 lbs of the goal. This resulted in a linear decrease in market weight with increased DDGS level of the diet was observed ($P < .03$). Figures 17-22 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 17. Weight at market, by treatment.**

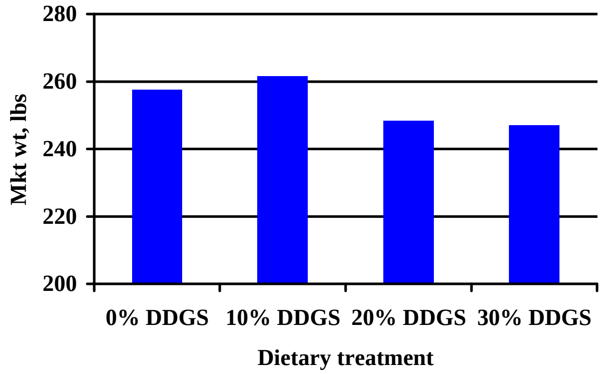



**Figure 18. Carcass weight, by treatment.**

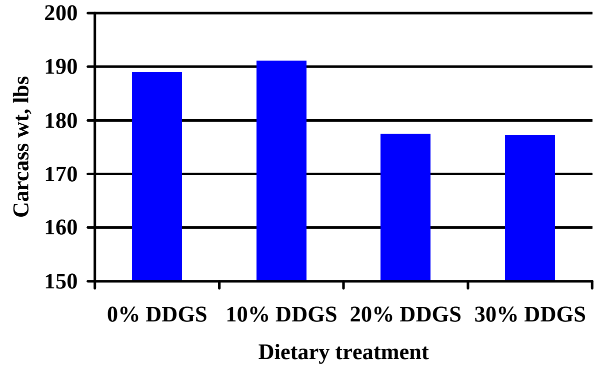



**Figure 19. Dressing % at market, by treatment.**

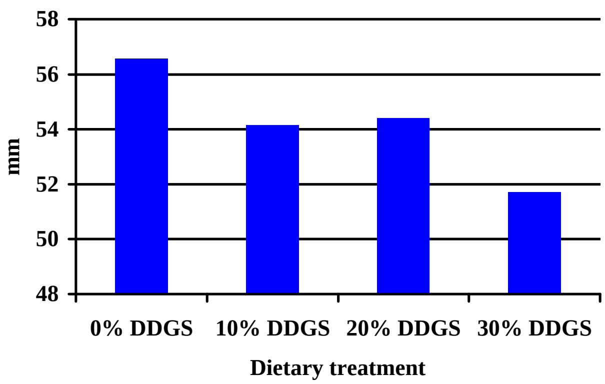



**Figure 20. Lean % (market), by treatment.**

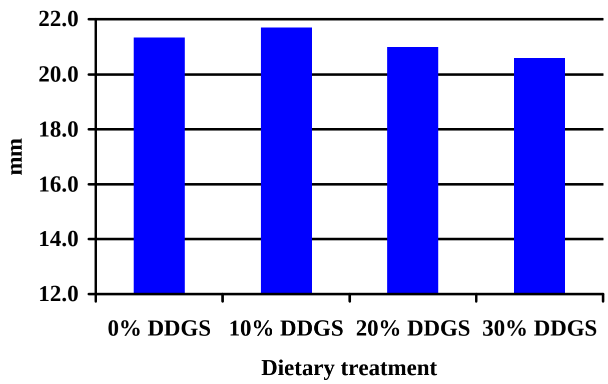



**Figure 21. Loin depth (mm), by treatment.**

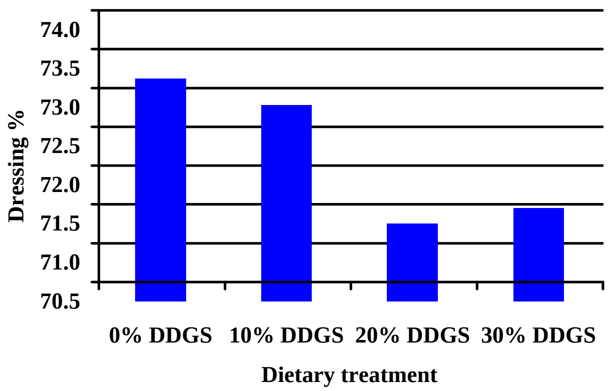
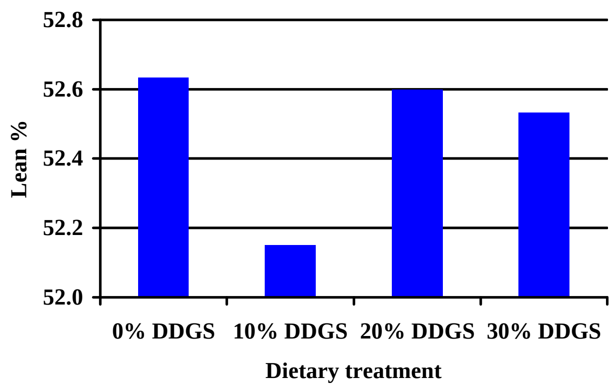



**Figure 22. Fat depth (mm), by treatment.**



Iodine number increased linearly (P < .05), and thus carcass fat became more unsaturated, as the level of DDGS was increased in the diet (Table 14). 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 14. 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 15). 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 15. 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.
[f g] Means within a row lacking a common superscript letter differ ($P < 0.05$).

*These results 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. Higher DDGS inclusion rates could likely be used without affecting performance if diets are formulated on a digestible amino acid basis, but additional studies are needed to determine this.*

*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 evaluated in this study. However, pork fat quality is reduced when 30% DDGS is added to the diet which may be the most significant factor limiting the maximum inclusion rate of DDGS in grow-finish diets.*

## Recommended Inclusion Rates for MN Produced DDGS in Practical Swine Diets

Maximum recommended inclusion rates for DDGS in swine diets are variable (Table 16).

**Table 16. Maximum recommended inclusion rates for DDGS in swine diets.**

| Production Phase | Feed Co-Products Handbook (1997) | Pork Industry Handbook | Newland and Mahan (1990) |
|---|---|---|---|
| Nursery pigs > 25 lbs | Up to 5% | Up to 5% | Up to 5% |
| Growing pigs (40-120 lbs) | Up to 7.5% | Up to 10% | Up to 20% |
| Finishing pigs (120 lbs – mkt) | Up to 10% | Up to 10% | Up to 20% |
| Gestating sows | Up to 50% | Up to 40% | Up to 40% |
| Lactating sows | Up to 20% | Up to 10% | No recommendation |
| Breeding boars | Up to 30% | No recommendation | No recommendation |
| Replacement gilts | Up to 20% | No recommendation | No recommendation |

All of the recommended maximum inclusion rates listed by the three references in Table 16 are based on old research data evaluating DDGS from older ethanol plants, and are based on formulating diets on a crude protein or total amino acid basis. The recommendations from

Newland and Mahan (1990) are the most liberal of the three references. They indicate that if more than 20% DDGS is used in grow-finish diets, the addition of synthetic lysine and tryptophan are necessary to achieve optimal performance. We believe that the maximum recommended inclusion rates for MNSD produced DDGS are the same as those listed by Newland and Mahan (1990). However, we have studies on going that are designed to further evaluate these recommendations using MNSD DDGS. Although Newland and Mahan (1990) had no recommendation on maximum inclusion rates for lactating sows, boars, or replacement gilts due to lack of studies conducted in these production phases, we believe that the recommendations listed by the Feed Co-Products Handbook (1997) for these production phases are satisfactory.

## Effect of Using DDGS on Manure Management and the Environment

Pork producers have several challenges related to manure management in order to be in compliance with environmental regulations. Reducing the nutrient content of manure and gas and odor emissions are the primary concerns that can be partially managed through diet manipulation.

Some 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 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).

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. Our studies have demonstrated that DDGS originating from ethanol plants in the

Minnesota and South Dakota region contains higher levels of total phosphorus (0.89%) and higher phosphorus availability (90%) compared to NRC (1998) levels.

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 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 plant. Additionally, a balance trial was conducted to determine nitrogen and phosphorus balance. Twenty barrows with average initial weight of 57.6 ± 3.8 kg were used for the 10-week trial. Pigs were allotted by weight and ancestry to one of two dietary treatments (10 pigs/treatment) in a three-phase feeding program (Table 17). 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).

**Table 17. 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, copper 1.36 mg, manganese 6.17 mg.

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.

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 during the 10-week trial. 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 study (Table 18). 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 (Table 18).

**Table 18. 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 |

*MNSD DDGS 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 is needed to reduce excess N intake and excretion. 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.*

**Figure 23. 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

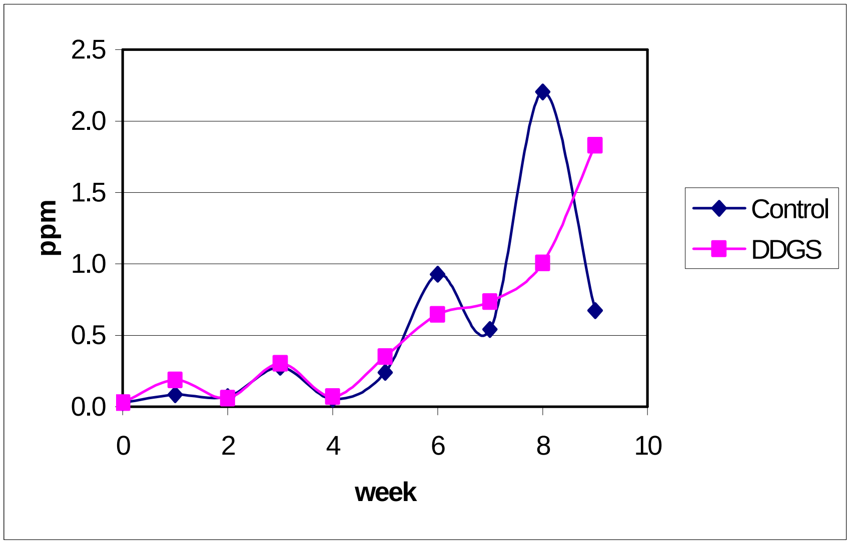



**Figure 24. Ammonia levels obtained from air space of DPSM containing manure from pigs fed diets with and without 20% MNSD DDGS.**

CV = 18.21 MSE ± .0876 P = 0.17

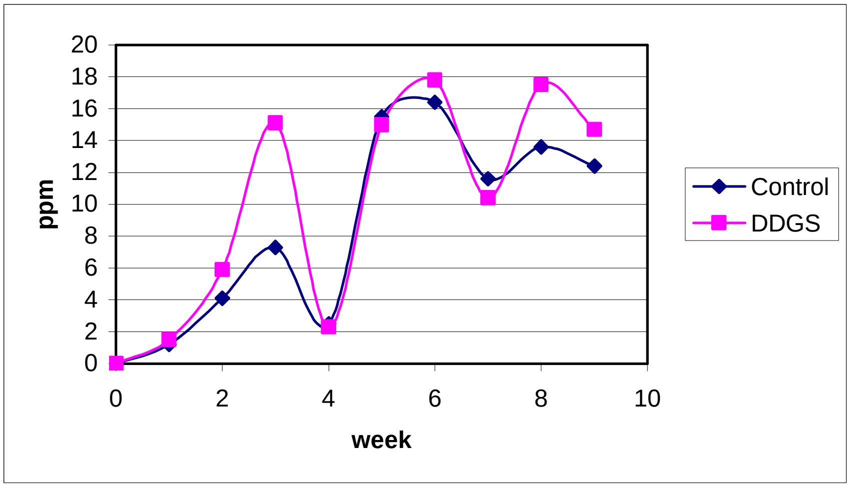
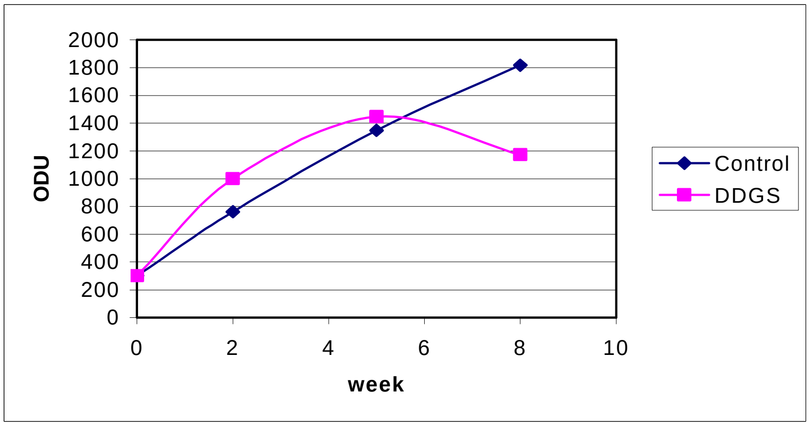


**Figure 25. Odor detection threshold of air samples collected from DPSM containing manure from pigs fed diets with and without 20% MNSD DDGS.**

CV = 8.11 MSE ± .1152 P = 0.99




## Potential Benefits of DDGS on Gut Health

Ileitis and gut edema are significant problems in the pork industry. These are widespread gut health problems that reduce growth performance of finishing pigs, increase mortality rates, and require the use of antibiotics when the industry is desperately trying to reduce its dependence of these compounds.

Many Minnesota pork producers have begun adding 5 to 10% DDGS in grow-finish diets to reduce diet costs. However, in doing so the majority of these producers have observed marked reductions in mortality rates, improved performance, and less usage of antibiotics. We are initiating a series of controlled studies to determine if adding DDGS to corn-soybean meal diets actually results in this potential benefit, and explore possible modes of action. We believe that the fiber fraction found in DDGS may favorably alter the gut microflora to alleviate the adverse effects of ileitis and gut edema.

## Summary

In general, results of our MNSD DDGS 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 (e.g. NRC, 1998)
- No detrimental effects on ammonia, hydrogen sulfide or odor emissions from swine manure

- A significant reduction in phosphorus content in manure due to the high phosphorus availability (90%) in DDGS.

- 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 unsaturated fat and reduced fat firmness with increasing dietary inclusion rates (this may limit the use of DDGS in grow-finish diets to no more than 20%).

- Can be effectively used as a partial replacement for corn, soybean meal and dicalcium phosphate and be an economical addition to practical swine diets depending on the price relationship between DDGS and the ingredients it partially replaces.

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