Chapter 22

Use of Reduced-Oil DDGS in Swine Diets

Introduction

Traditionally, corn DDGS has contained 10 to 11% crude fat and has a metabolizable energy (ME) content similar to corn for swine (Stein and Shurson, 2009). However, over the past 2 years, an increasing number of ethanol plants have invested in centrifugation technology to extract some of the oil from the thin stillage before removing water to make condensed distillers solubles and blending with the coarse grains fraction and drying to make DDGS. Currently, approximately 50% of the U.S. ethanol industry is removing a portion of the oil from thin stillage prior to producing DDGS. Industry experts are predicting that 80% of the ethanol industry will be extracting oil by the end of the year 2012.

The rapid adoption of oil extraction technology is driven by high economic returns. For example, a 100 million gallon ethanol plant can invest $3 million in capital (i.e. building, two centrifuges, tubing) and operating expenses (electricity) to extract 9.07 million kg of oil/year. Current market price for crude corn oil is $0.88/kg resulting in $8 million in gross revenue/year. Therefore, the initial capital investment for implementing this technology can be recovered in less than 5 months of operation. Approximately 90% of this crude oil is marketed to the biodiesel industry whereas the remaining 10% is sold for use in poultry feed.

Therefore, the implementation of oil extraction technology has led to a wider range of crude fat content in DDGS (5 to 12%) than in previous years. Since oil contains 2.25 times more energy than carbohydrate (i.e. starch), corn oil removal reduces the ME content in DDGS. This reduction in energy content will affect the economic value and usage rates of DDGS in all animal feeds to varying degrees. The question is, how much? Knowing this, DDGS end-users are demanding price discounts on reduced-oil DDGS (RO-DDGS) because of expected reductions in energy value. This reduces the market price for DDGS and ethanol plant revenue from DDGS sales, but this reduction is more than offset by the increase in revenue from the sale of crude corn oil. Nutritionists want to know the extent of reduction in energy content due to partial removal of corn oil in order to make appropriate adjustments in diet formulations (e.g. diet inclusion rates, adding other sources of energy) to meet desired dietary energy levels.

DE and ME estimates and variability among “typical” DDGS sources

Dried distillers grains with solubles is primarily an energy source, but also supplies significant amounts of digestible amino acids and available phosphorus to swine diets. Recent studies have been conducted to determine DE and ME content of various sources of DDGS and develop prediction equations using chemical analysis measures to estimate actual energy content (Stein et al., 2006; Pedersen et al. 2007; Anderson et al. 2011; Stein et al., 2009; Mendoza et al., 2010). The average and ranges of GE, DE, and ME content of DDGS sources evaluated in these studies are shown in **Table 1**, and are compared to the energy values for corn.

As shown in **Table 1**, average GE of DDGS samples was relatively consistent across the five studies (5,311 to 5,593 kcal/kg DM), but the overall range in GE was more variable (5,177 to 5,691 kcal/kg DM). Average DE estimates among the five studies was 3,950 kcal DE/kg DM, but ranged from 3,382 to 4,593 kcal/kg DM. Average ME of DDGS samples from 4 of the 5 studies reporting ME values was 3,784 kcal ME/kg DM, but like DE values, ranged from 3,381 to 4,336 kcal ME/kg DM. This range of 955 kcal/kg DM among DDGS sources is problematic when attempting to manage dietary energy values with high inclusion rates of DDGS. For comparison purposes, corn ME averaged 3,928 kcal/kg DM (range was from 3,805 to 4,103 kcal/kg DM) among the 4 studies that reported ME values (**Table 1**), and was higher than the value published (3,843 kcal/kg DM) in NRC (1998). Therefore, the average ME value of DDGS is approximately 96% of the value of corn, but can range from 88.9 to 105.7% of the value of corn.

Table 1. Comparison of GE, DE, and ME estimates among DDGS sources and corn, and CP, NDF, and crude fat levels from 5 studies.

	Stein et al. (2006)	Pedersen et al. (2007)	Anderson et al. (2011)	Stein et al. (2009)	Mendoza et al. (2010)
No. samples	10	10	6	4	17
Avg. GE, kcal/kg	5,426	5,434	5,420	5,593	5,311
Range GE, kcal/kg	5,372-5,500	5,272-5,592	5,314-5,550	5,483-5,691	5,177-5,421
Avg. DE, kcal/kg	3,556	4,140	4,072	4,029	3,954
Range DE, kcal/kg	3,382-3,811	3,947-4,593	3,705-4,332	3,920-4,252	3,663-4,107
Avg. ME, kcal/kg	ND	3,897	3,750	3,790	3,700
Range ME, kcal/kg	ND	3,674-4,336	3,414-4,141	3,575-3,976	3,381-3,876
ME/DE, %	ND	94.1	92.1	94.1	93.6
Avg. CP, %	30.9	32.2	31.3	31.8	30.3
Range CP, %	28.2-32.7	29.8-36.1	29.5-34.1	30.5-33.1	27.3-33.3
Avg. NDF, %	45.2	27.6	40.4	40.1	34.6
Range NDF, %	41.8-49.1	23.1-29.7	33.4-49.1	35.1-45.2	25.3-43.1
Avg. Crude fat, %	ND	11.7	11.4	13.2	11.7
Range Crude fat, %	ND	9.6-14.3	10.2-12.1	10.9-14.1	8.7-14.6
Corn DE, kcal/kg	3,845	4,088	3,885	4,181	3,893
Corn ME, kcal/kg	ND	3,989	3,805	4,103	3,813

Crude protein levels of DDGS sources used in these studies were relatively consistent, but the range in crude fat and NDF content (two primary contributing factors to DE and ME content) among sources within studies, and among studies, was highly variable (**Table 1**). Although, the variation in DE and ME estimates among DDGS sources can largely be attributed to nutrient composition differences among sources, it is also likely that different methodologies used for conducting metabolism studies, different laboratory procedures used to measure nutrients, and lab to lab variation among studies had significant contributions to this variability. For example, the average and range in NDF values in the Pedersen et al. (2007) study were much lower than those reported in the other 4 studies. It is unclear if NDF composition was actually lower in these samples evaluated by Pedersen et al. (2007), or if a different analytical method was used compared to NDF procedures used in other studies. Urriola et al. (2010) reported that apparent total tract digestibility (ATTD) of NDF among 8 corn DDGS sources averaged 59.3%, but ranged from 51.6 to 65.8%, and ATTD of total dietary fiber ranged from 39.4 to 56.4%. These results indicate that considerable variability in fiber digestibility exists among DDGS sources, which is likely a significant contributing factor to the variability in DE and ME content among DDGS sources. Recent unpublished data from Pomerenke et al. (2011) showed that fecal digestibility values of fatty acids are higher than ileal fatty acid digestibility values, MUFA and SFA digestibilities are higher when growing pigs are fed DDGS compared to a corn-soybean meal diet, but PUFA digestibility was lower (66.5% vs. 77.3% for a 30% DDGS diet compared to corn-soybean meal diet). Because corn oil in DDGS is predominantly PUFA, and because the crude fat content of DDGS can vary substantially, these factors also contribute to differences in ME variability among DDGS sources.

Several researchers have shown that apparent fat digestibility is significantly reduced when dietary fiber increases (Dierick et al., 1989; Noblet and Shi, 1993; Shi and Noblet, 1993). Just (1982a,b) showed that apparent fat digestibility decreases by 1.3 to 1.5 percentage units for each additional 1 percentage unit of crude fiber in the diet, and the depressive influence of crude fiber depends to some degree on the source of a feedstuff. Noblet and Shi (1993) demonstrated that apparent digestibility of fat decreased linearly with increasing dietary NDF content, and at the same time, the fat digestibility increased with increasing dietary fat level. These research results indicate that there are many factors that contribute to our ability to obtain accurate estimates of ME in various sources of DDGS. Because of the need to obtain source specific ME estimates among DDGS sources, we need to develop, validate, and implement rapid, accurate, and inexpensive “nutritional tools” to estimate actual energy values among DDGS sources.

Research results on reduced-oil DDGS

Results from 3 recent studies have been published that estimated the effect of reduced oil on ME content for growing pigs (Dahlen et al., 2011, Jacela et al., 2011, Anderson et al., 2011). In the studies by Jacela et al. (2011) and Anderson et al. (2011), oil was removed by hexane extraction, whereas Dahlen et al. (2011) compared the DE and ME content of DDG (with no solubles) with DDGS, which was slightly higher in oil content (10.02% DM basis), and produced by the same ethanol plant. It is important to realize that the processes used to produced reduced fat DDGS in these studies are different than the centrifugation technologies used to extract oil in ethanol plants currently. Therefore, these data are not applicable for predicting the ME content of reduced fat DDGS, but have been erroneously used by some industry professionals to obtain initial estimates. The nutrient content of the reduced fat sources evaluated in these studies is shown in **Table 2**.

The results from these studies are problematic for estimating the impact of oil extraction on ME content because of the wide disparity in DE and ME estimates based on crude fat content. For example, the de-oiled DDGS evaluated in the Anderson et al. (2011) study contained the lowest crude fat content (3.15%) and the highest NDF content (50.96%), but had the highest DE content (3,868 kcal/kg ME) of the 3 sources. Like the de-oiled DDGS source evaluated by Anderson et al. (2011), the de-oiled source evaluated by Jacela et al. (2011) was also obtained from a VeraSun ethanol plant using similar production technology. However, it had slightly higher crude fat (4.56%), much lower NDF (35.58%), and had the lowest DE content (3,100 kcal/kg), despite having similar GE content as the sample evaluated in the Anderson et al. (2011) study. This large discrepancy indicates significant differences in DE methodologies, analytical methods, and laboratory error between these 2 studies. Furthermore, the ME and NE estimates for the de-oiled DDGS in the Jacela et al. (2011) study were calculated using equations developed for complete feeds, which were not specifically developed for use in corn distillers co-products, making these estimates highly questionable. The estimates of impact from a 1% reduction in crude fat on ME content from the Dahlen et al. (2011) study are also problematic. First, comparing the ME content of DDGS with DDG from the same source is not valid in this context because the nutrient in condensed solubles component is absent in DDG resulting in a lower ash and higher fiber content, which biases the estimate of ME from a 1 percentage unit reduction in crude fat.

In the Anderson et al. (2011) study, crude fat among 6 DDGS sources ranged from 10.16 to 12.10% and ME content ranged from 3,414 to 4,141 kcal/kg. Calculating the impact of a 1 percentage unit reduction in crude fat using the de-oiled DDGS as the reference point, individual values were 59, 1, 41, -28, 25, and 1 kcal/kg DM. The wide disparity in ME estimates, and even a negative value, indicates that relating ME content only to crude fat content results in erroneous ME estimates.

Kil et al. (2010) conducted a study to determine the effect of extracted versus intact corn oil and dietary NDF on endogenous fat losses and ileal and total tract digestibility of fat in growing pigs. They showed that extracted corn oil has greater apparent and true digestibility than intact corn oil at the terminal ileum and over the entire intestinal tract, but purified NDF had little effect on apparent and true digestibility of corn oil. They also showed that apparent ileal and total tract digestibility of corn oil increased curvilinearly as dietary fat concentration increased regardless of the form of fat. Endogenous fat losses contribute more to the total output of fat, and therefore have a greater effect on apparent digestibility of fat at smaller amounts of dietary fat than greater amounts. These results provide additional insight into why we cannot simply assume that a linear reduction in crude fat content in DDGS will result in a linear reduction in ME content.

Table 2. Comparison of nutrient composition and energy values of reduced-oil DDGS (RO-DDGS) and DDG (DM basis).

Item	DDG – Dahlen et al., 2011	De-oiled DDGS – Jacela et al. 2011[1]	De-oiled DDGS – Anderson et al., 2011
DM,	90.33	87.69	87.36
GE, kcal/kg DM	5,536	5,098	5,076
DE, kcal/kg DM	3,232	3,100	3,868
DE/GE	58.38	60.80	76.20
ME, kcal/kg DM	2,959	2,858[2]	3,650
ME/GE	53.45	56.06	71.91
ME/DE	91.55	92.19	94.36
ME kcal/1% fat reduction	5.0	ND	17.0[4]
NE, kcal/kg DM	ND	2,045[3]	ND
CP	34.98	35.58	34.74
Crude fat	8.80	4.56	3.15
NDF	ND	39.46	50.96
ADF	20.37	18.36	15.82
Ash	2.57	5.29	5.16
Arg	ND	1.50 (82.7)	1.44
Cys	0.60	ND	0.61
His	ND	0.93 (74.6)	0.89
Ile	ND	1.38 (74.5)	1.25
Leu	ND	4.15 (83.8)	4.12
Lys	1.04	0.99 (50.4)	1.00
Met	0.65	0.67 (80.4)	0.64
Phe	ND	1.92 (80.8)	1.51
Thr	1.22	1.26 (68.9)	1.26
Trp	0.20	0.22 (78.0)	0.18
Val	ND	1.75 (73.8)	1.76
Ca	0.03	0.06	0.07
P	0.61	0.87	0.84

[1]Values in ( ) are standardized ileal digestibilities of amino acids.
[2]ME value was calculated as ME = 1 x DE – 0.68 x CP (R^2 = 0.99; Noblet and Perez, 1993).
[3]NE value was calculated as NE = (0.87 x ME) – 442 (R^2 – 0.99; Noblet et al., 1994).

[4]Average reduction compared to the average fat and ME content of 6 DDGS sources. Individual values were 59, 1, 41, -28, 25, an 1 kcal ME/1% reduction in crude fat among 6 DDGS sources with crude fat content ranging from 10.16 to 12.10% and ME content ranged from 3,414 to 4,141 kcal/kg.

DE and ME Impact of Reduced-Oil in DDGS

In order to directly determine the impact of RO-DDGS on ME content for swine, the University of Minnesota and USDA-ARS conducted a study (unpublished) to determine the relationship between crude fat and ME content, as well as develop prediction equations to accurately estimate these effects. A total of 11 DDGS samples from different sources ranging in crude fat content from 8.6 to 13.2% were fed to finishing pigs to determine actual DE and ME content. Samples were also analyzed for gross energy and nutrient composition (**Table 3**) to determine changes and correlations in nutrient content as oil is extracted from DDGS.

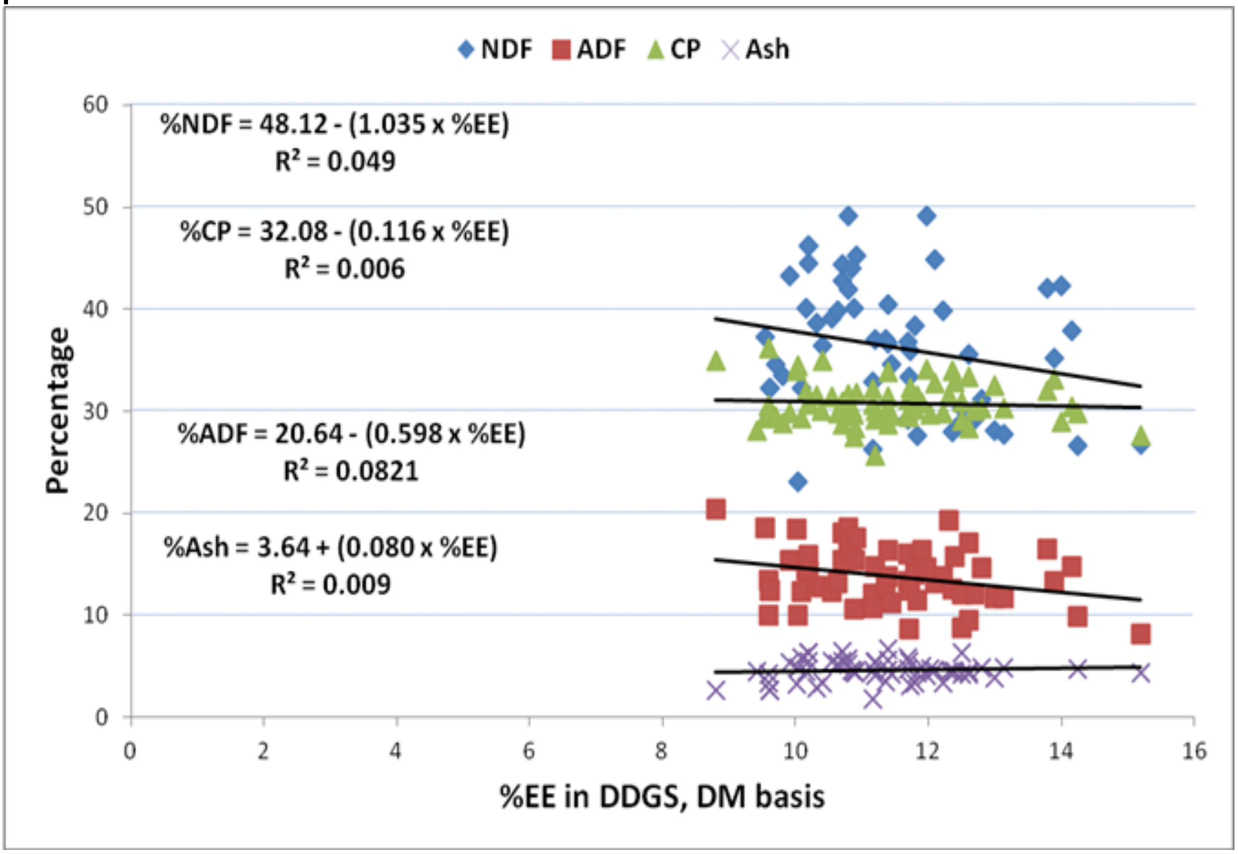
Table 3. Energy and nutrient composition of 11 DDGS sources (DM basis)

DDGS Source	GE, kcal/kg	ME/GE	ME, kcal/kg	Crude fat, %	NDF, %	Crude protein, %	Starch, %	Ash, %
8	5,167	69.57	3,603	13.2	34.0	30.6	1.3	5.3
11	5,130	69.26	3,553	11.8	38.9	32.1	1.1	4.9
9	4,963	71.83	3,550	9.7	28.8	29.8	2.8	5.0
6	4,963	70.68	3,513	9.6	33.0	30.1	3.4	4.9
7	4,938	69.36	3,423	10.1	38.2	30.3	2.2	5.0
2	5,075	67.01	3,400	11.1	36.5	29.7	3.9	4.3
4	4,897	68.69	3,362	8.6	35.7	32.9	0.8	5.1
3	5,066	66.04	3,360	10.8	38.6	29.7	1.6	4.6
10	4,948	67.46	3,327	10.0	35.9	32.7	1.0	5.3
1	5,077	65.06	3,302	11.2	44.0	27.7	1.8	4.4
5	5,043	64.70	3,277	11.1	39.7	31.6	0.9	5.0

By comparing the ME and crude fat content of DDGS sources 11 and 9, there was a 2.1 percentage unit difference in crude fat content, but only reduced ME by 3 kcal/kg DM. However, comparing DDGS sources 8 and 5, there was also a 2.1 percentage unit difference in crude fat content, but the ME content was 326 kcal/kg DM lower in source 5 compared to source 8. This indicates that relating ME content to crude fat concentration alone will not provide an accurate estimated of ME content among reduced-oil DDGS sources. Theoretically, as oil is removed from DDGS, all other nutrients should increase in concentration and ME content will decrease. However, it is not as simple as calories lost for each percentage of oil extracted from DDGS. As shown in **Figure 1**, there is a very high correlation between gross energy (GE) and crude fat content indicating that accurate ME prediction equations will require using GE since the correlations with neutral detergent fiber (NDF), total dietary fiber (TDF), crude protein (CP), and ash are low. As crude fat content decreases, crude protein and ash increase slightly, but TDF and NDF also decrease. It is surprising and unclear why TDF and NDF decrease when crude fat is removed from DDGS. However, other studies reported in the scientific literature have shown the same relationship between NDF, ADF, and crude fat content of DDGS, and NDF and ADF values are highly variable among DDGS sources (**Figure 2**). Therefore, the theory that NDF increases as fat is extracted is incorrect, and due to the high variability in NDF content among reduced oil DDGS samples, it must be taken into account when estimating ME content.

Figure 1. Effect of oil extraction (EE) from DDGS on GE (gross energy), NDF (neutral detergent fiber), TDF (total dietary fiber), CP (crude protein), and ash content.

Figure 2. Effect of corn oil content (ether extract = EE) from DDGS on NDF (neutral detergent fiber), CP (crude protein), ADF (acid detergent fiber) and ash content from the published scientific literature.



As shown in **Figure 3**, there is NO significant impact of reduced oil on DE and ME content of DDGS (R^2 = 0.05 to 0.11). In other words, if we force the prediction of ME content from a 1% reduction in oil the prediction is very poor (R^2 = 0.11), but the average ME content would be reduced by 30 kcal/kg DM (**Figure 3**). Therefore, in order to achieve accurate ME estimates for RF-DDGS, we must use more accurate prediction equations. The most predictive equation derived from using multiple regression analysis was:

ME kcal/kg DM = 1,352 + (0.757 x GE kcal/kg) – (51.4 x % TDF) SE = 50 R^2 = 0.84

However, it is difficult to obtain GE and TDF estimates from most commercial laboratories to use in this equation. As a result, the following equations can be used to estimate ME content of RF-DDGS for swine with a reasonable degree of accuracy:

ME kcal/kg DM = 4,440 – (68.3 x % ADF) SE = 58 R^2 = 0.76

ME kcal/kg DM = 3,711 – (21.9 x % NDF) + (48.7 x % Crude fat) SE = 75 R^2 = 0.65

Figure 3. Relationship between DDGS crude fat content and DE and ME content prediction of 11 DDGS sources.

What Are the Implications of Reduced-oil DDGS for Swine and Other Animal Market Sectors?

•The impact of RO-DDGS on ME content for swine is low.

•Crude fat content of DDGS should not be used to estimate ME content for swine.

•The most accurate predictions equation to estimate ME in RO-DDGS requires determinations for gross energy and total dietary fiber (TDF). These measurements are difficult to obtain from commercial laboratories and the cost of TDF determinations is expensive.

•Alternatively, the following 2 equations can be used with less accuracy, but still reasonably predict ME content of RF-DDGS using more common laboratory nutrient content determinations:
○ME kcal/kg DM = 4,440 – (68.3 x % ADF)
○ME kcal/kg DM = 3,711 – (21.9 x % NDF) + (48.7 x % Crude fat)

•It is likely that pigs are able to utilize a significant portion of fiber in RO-DDGS for energy. However, poultry have less ability to obtain energy from fiber due to limited lower gut fermentation, and as a result, would be expected to be impacted more by RO-DDGS than swine.

•Due to the large quantities of DDGS containing varying amounts of crude fat, marketing or purchasing DDGS on a "Pro-fat" basis is not advised because of the disproportionate changes in fat and crude protein content resulting from oil extraction and their relative impacts on nutritional value for swine. End-users should specify and negotiate price based on a minimum crude protein and minimum crude fat content.

•Removal of oil from DDGS reduces its energy value. Since DDGS is used primarily as an energy source in swine diets, the estimated price discount should be based on the estimated reduction in ME content of the DDGS source being considered, relative to the ME content of "typical", normal fat (10 to 11% on an as-fed basis) DDGS.

•It is likely, based on the number of ethanol plants implementing oil extraction technology, and the extent of oil extraction from DDGS within a source, that the relative consumption rates among livestock and poultry market segments will change. It is expected that more RO-DDGS will be used in the dairy industry because higher dietary inclusion rates can be used without as much risk of milk fat depression. Beef feedlot cattle will continue to use it at relatively high inclusion rates with price adjustments based on estimated reductions in energy value. Swine will also continue to use it with minor price discounts for energy, and may use increasing amounts depending on oil content in order to minimize negative effects on pork fat quality. Of all food animal species, poultry will likely be impacted the most by reduced-oil DDGS, and depending on the extent of reduction in energy value, diet inclusion rates may be dramatically reduced.

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