Not All DDGS Are Created Equal: Nutrient-Profile-Based Pricing to Incentivize Quality

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Abstract

This study finds that distillers dried grains with solubles (DDGS) is a dominant feed ingredient in hog finishing rations, despite variability in the product's nutritional content. The optimal inclusion rate has remained at the maximum allowable limit of 20%, suggesting that when a particular DDGS product has low nutrient content, feed compounders simply supplement with corn and soymeal, whatever deficits in nutrients are created as a result.

The study examines DDGS products from 40 different ethanol plants and finds that, relative to the DDGS product with the lowest feed ration cost, the optimal feed ration costs of DDGS products from the other 39 ethanol plants are $0.002 to $0.42 more per cwt of feed. The implied price discount from this cost differential ranges from a low of 0.10% to a high of 25.55%. For an ethanol plant with 50 million gallons in capacity, this price discount amounts to revenue losses of $0.03 million to $6.27 million per year.

The study also found that feed compounders generate $7.51 per ton more in DDGS feed cost savings when they eliminate inter-plant variability and face only intra-plant sources of variability. By including nutritional content variability information in the pricing of DDGS, proper price signals are communicated to ethanol plants so that they can make their own assessments on quality control initiatives to reduce variability in their DDGS products. When the market does not reward better DDGS quality or penalize low product quality, stakeholders do not have any incentive to improve product quality.

Keywords: biofuel, DDGS, DDGS quality, hog feeder-finisher, optimal feed ration, stochastic LP.

1. Introduction

The use of corn for fuel is expanding, more than doubling in share in the recent period, and this is creating a tight supply of feed grains both in the United States and around the world. As a result, feed use, which used to be the dominant (58%) use of corn in the U.S., shrank in share by 11 percentage points. Biofuel co-products such as distillers grains (DG) are alternative feed ingredients that can alleviate this tight supply situation. Considering that 81.5% of ethanol in the U.S. is produced using the dry milling process, and that each bushel of corn feedstock produces 17 pounds of DG, the quantity of this feed ingredient can be substantial. In 2007, DG represented 17% by weight of total corn used as feed.

However, using distillers dried grains with solubles (DDGS)[1] in animal feed rations presents its own challenges. One problem often raised by feed compounders is the lack of consistency in the nutritional composition of DDGS. As Giesemann, Gibson, and Karges (n.d.) reported, unlike ground corn and soybean meal, which are physically and/or chemically processed in a continuous flow system, fermentation in ethanol production depends on batched biological processes and is inherently subject to variability. Several studies have documented the variability of the nutritional composition of DDGS. For example, Noll, Abe, and Brannon (2003) reported that DDGS fat content varied from 9.4% to 11.1% while crude protein content varied from 26.2% to 30%. Lysine, which is the most limiting amino acid for a hog ration, is also the most variable amino acid, with a coefficient of variation of 11.2%, and even has a within-plant coefficient of variation of 4.6%. Akayezu et al. (1998) reported an even wider range in fat, from 4.3% to 18.7%, and crude protein from 25.9% to 36.3%. His study concluded that there is considerable

[1] Of all the biofuel co-products, we focus on DDGS in this study.

variation of DDGS composition even within production facilities. Since it is recommended that ileal digestible amino acids be used to formulate diets, the variability of both the nutrient composition and the digestibility of these nutrients are important in feed formulation, especially in monogastric animals that are unable to metabolize some amino acids in adequate amounts. Stein (2007) states that the more important amino acids in a hog ration—including lysine, methionine, threonine, and tryptohan—are among the highest in their coefficient of variation. Moreover, with the exception of glycine and proline, the digestibility of lysine has the highest coefficient of variation. Variability in the nutritional content of DDGS is introduced at several points in the production process. One source is the variability originating from the feedstock used in ethanol production. Geisseman states that definition of the Association of American Feed Control Officials (AAFCO) of DG requires that the grain of majority inclusion be listed as the source. Thus, what is labeled as corn DG could have as much as 49% sourced from some other grain, such as sorghum or wheat. But according to Stein (2007), even if the same grain is used to produce the ethanol, variability in the nutritional composition of DDGS may still be observed. For example, even if corn is the only feedstock used, the production process is such that any variability in the nutritional content of the corn input is magnified in the variability of the nutritional content of the final DDGS product by a magnitude of three. In the fermentation stage of the production process, sulfuric acid may be added to control the pH. After distillation and centrifuge, wet DG has 65% to 70% moisture and needs to be dried to reduce the moisture content to 10% to produce dried distillers grains (DDG). The heating process itself could potentially accelerate a reaction called Maillard reaction whereby sugars and carbohydrates react with proteins, primarily lysine, reducing the digestiblity of lysine and some have found even the digestibility of energy is compromised. Another source of variability is the amount of soluble that is added back to make DDGS. The AAFCO simply requires that after removal of ethyl alcohol by distillation from the yeast fermentation of a grain or grain mixture, at least three-fourths of the solids of the resultant whole stillage is condensed and dried to produce DDGS. The amount of solubles added back may vary since the syrup can be sold separately. Also, new processes that are increasingly introduced in the industry can also be a contributing factor. For example, extracting oil at the front end of the ethanol production process produces DDGS with 4% to 6% fat while removing the fat from the syrup toward the end of the process produces DDGS with 7% to 8% fat.

Faced with this type of feed ingredient, it is very important that feed compounders properly account for this variability of the nutrient composition of DDGS in their feed formulation. If they are too conservative and oversupply the nutrients then they are paying unnecessarily for redundant nutrients and may even compromise the growth performance of animals by expending energy to excrete surplus nutrients. On the other hand, if the nutrients are inadequate to the requirements of the animal then the growth performance of the animal is equally compromised. The most ideal situation is for feed compounders to secure their supply of DDGS from a single source with dependable DDGS products to eliminate inter-plant sources of variability. But even with this strategy, feed compounders still face intra-plant variability, which can be substantial.

The general aim of this study is to examine the impact of nutrient composition quality and variability in the use of DDGS in a finishing hog feed ration. Specifically, we want to answer the following questions:

- Does DDGS nutrient composition variability reduce their optimal inclusion rate below the maximum allowable rate of 20% (National Corn Growers Association)?
- By how much does DDGS nutrient composition variability compromise feed cost savings of feed compounders?
- What is the potential value to feed compounders of minimizing the variability of nutrient composition in DDGS?
- By how much should DDGS products with more variable nutrient composition be discounted in their price?
- How should price premium and or discount incentives be structured so that stakeholders in the DDGS market produce DDGS products with better and more stable nutrient composition?

We propose a methodology to answer these questions using two different cases. Since no primary data was collected, we simply illustrate the usefulness of the methodology and provide plausible results. The first case illustrates a methodology of estimating price discounts on DDGS products from several ethanol plants. The second case illustrates a methodology of valuing reductions in the variability of nutrient composition of DDGS, either from the point of view of an ethanol plant exploring alternative process interventions to improve nutrient composition stability of its DDGS products, or from the point of view of a feed compounder exploring procurement strategies to reduce nutrient composition variability of its DDGS supply.

2. Model

The basic model is a standard linear programming (LP) model to formulate a least-cost feed ration for finishing hogs used in Fabiosa (2008). The optimization problem is to

[1] Minimize $p'x$

$$\text{subject to } \begin{array}{c} Ax\{\geq = \leq\}b \\ l \leq x \leq u \end{array}$$

where ***x*** is an *n x 1* matrix of structural decision variables, which in this case are the levels of feed ingredients to include in a feed hog ration (e.g., corn, soymeal, DDGS, and supplements for minerals and vitamins); ***p*** is an *n x 1* matrix of feed ingredient prices; ***A*** is an *m x n* matrix of technological coefficients representing the amount of nutrient from the respective source of feed ingredients, ***b*** is an *m x 1* matrix of right-hand-side constants such as feed nutrient requirements (e.g., energy, protein, minerals, and vitamins); ***l*** is an *n x 1* matrix of lower bound such as the non-negativity condition of the decision variables; and ***u*** is an *n x 1* matrix of upper bound such as the maximum inclusion rate of DDGS in the ration.

Because of the variability in the nutritional content of DDGS, we augment the LP program in [1] to be stochastic to account for the random elements in the ***A*** matrix. For this purpose we use a multivariate normal distribution to characterize the random nutritional content of DDGS, i.e.,

[2] $$n(a;\mu,\Sigma) = \frac{1}{(2\pi)^{N/2}|\Sigma|^{1/2}} e^{\left(-\frac{1}{2}(x-\mu)'\Sigma^{-1}(x-\mu)\right)}$$

where a is a matrix of random coefficient elements of the ***A*** matrix, μ is a vector of their mean values, and Σ is a variance-covariance matrix.

3. Data and Results

This study uses the same model and database developed in Fabiosa (2008). The nutritional requirement is taken from the recommendations of the Swine Nutrition, Growth, and Behavior Section of the Iowa Agriculture and Home Economics Experiment

Station and the Animal Science Extension Section of Iowa State University, published in "Life Cycle Swine Nutrition" (Holden et al., 1996). The nutrient composition data of DDGS products from 40 ethanol plants were taken from the University of Minnesota Web site on DDGS at http://www.ddgs.umn.edu/. The data include 40 ethanol plants from 11 states. The nutrient composition data of the rest of the feed ingredients are taken from the National Research Council (NRC, 1998). Prices of corn, soymeal, and DDGS are from the USDA Market News, and prices of mineral and vitamin supplements are from industry sources.

To ensure spatial consistency, we model a representative feed compounder located in Kansas City, Missouri. The prices of feed ingredients were updated from a USDA source on market prices for the month of August 2008. During this period, the price of #2 yellow corn is $189.64 per ton, $353.18 per ton for high-protein soymeal, and $166.25 per ton for DDG (27% crude protein, 10% fat, and 10% moisture).

The nutrient levels and their respective variabilities in the 40 plant samples are given in tables 1 and 2.[2] Metabolizable energy ranges from 1,589 to 1,836 kcal per lb or a coefficient of variation of 3.35%. Crude protein ranges from 27.30% to 33.92% or a coefficient of variation of 5%. Of the five specific amino acids considered, the level of lysine and tryptophan have the highest coefficient of variation, almost double compared to the rest of the amino acids, at 13.14% and 13.20%, respectively. Moreover, lysine has the highest coefficient of variation for digestibility of all the amino acids at 9.63%. We note that the digestibility rates for the selected amino acids are not significantly different from that of corn. In fact, the mean lysine digestibility of DDGS is lower than the digestibility of corn. For the minerals, sodium and calcium have standard errors that are

[2] Mean values from available data are used for missing nutrient values.

larger than their respective means, giving a coefficient of variation of 221.84% and 124.09%, respectively. Phosphorous has the lowest coefficient of variation at 16.58%. The rest of the minerals have coefficient of variation in the range of 27.27% to 39.12%.

In the first part of the study we solve equation [1] using SAS (2002) for an optimal feed ration using the DDGS from the 40 ethanol plants to examine the impact of the varying nutritional content on the use of DDGS in a finishing hog ration and the resulting feed cost savings, if any. Then the DDGS with the lowest feed ration cost is considered as the reference DDGS product, and a forgone feed cost savings is computed for the other 39 ethanol plants with higher feed ration cost. Table 3 presents the results. The feed ration cost of other sources of DDGS are higher by $0.002 to $0.42 per cwt of feed compared to the reference DDGS. Around a third (or nine) of the DDGS products had feed ration costs that were higher by $0.14 per cwt of feed compared to the reference DDGS. Another way of looking at these result is to express them in terms of equivalent price discounts on DDGS products with higher feed ration cost relative to the reference DDGS. This is computed by multiplying the forgone feed cost savings by the ratio of 2,000 and the optimal inclusion rate, which in all these cases is at the maximum allowable inclusion of 20%. Table 4 shows that the price discount is in the range of 0.10% to 25.55%, with a third of all ethanol plants incurring a discount that is greater than 8.59%. For an ethanol plant with a capacity of 50 million gallons a year, these price discounts can easily translate to revenue losses of $0.03 million to $6.27 million, or an average of $1.80 million a year.

These results strongly suggest that not all DDGS are created equal. Their nutrient profiles are very different and can have substantial feed cost savings implications. Since

DDGS product quality is very important, a pricing discount mechanism is needed to reflect the value of quality and incentivize the production of quality DDGS products in the market. Without a pricing mechanism that can reflect product quality differentials, above-average (in terms of nutrient profile quality) DDGS products will not gain any premium, and below-average DDGS products will not be discounted, so there is no incentive to improve quality. However, if this price signal can be communicated to individual ethanol plants, then they can assess their respective DDGS quality control production process and calculate how much it would cost to improve the quality of their DDGS products and implement changes whose benefits exceed costs. The benefit in this case is the removal of any quality-related price discount. The informational requirement to implement this pricing discount mechanism is not prohibitive. First, the nutrient profile of a reference DDGS must be agreed upon and used to map the current market price and discounts. Then, both users and suppliers of DDGS must have access to an analytical tool (e.g., Internet based) that can estimate how much lower or higher is the feed cost of their DDGS products relative to the reference DDGS product for a given animal type. This difference in cost can then be used to determine the discount or premium on the DDGS price in the same way it is computed in the 39 ethanol plants in our earlier example. In our specific example, if the current DDGS market price of $166.13 per ton maps to the reference DDGS product, then the DDGS from ethanol plant number 20[3] with a feed ration cost $0.10 per cwt of feed higher than the reference DDGS product will have to be priced at $155.82 per ton. Furthermore, the DDGS product from ethanol plant number 40

[3] We sorted the DDGS from the 40 ethanol plants by the cost of their optimal feed ration, in ascending order, and then assigned a number to the plants consecutively. The intent was to make the plants anonymous.

with a feed ration cost \$0.42 per cwt of feed higher should be priced at \$123.77 per ton only.

The second part of the study is similar to the first but gives a more hypothetical example of DDGS nutrient composition variability and its effect on feed cost savings. It can be interpreted from the point of view of a feed compounder reducing the variability of its DDGS supply through procurement strategies, or from the point of view of an ethanol plant reducing the variability of its DDGS through quality control interventions in its plant. Since this study did not collect actual primary data on the nutritional content of DDGS, we estimate the parameters to characterize the multivariate normal distribution of the random component of the ***A*** matrix from the 40 ethanol plants and consider this distribution as descriptive of the full variance case (that is, inclusive of both intra- and inter-plant sources of variability). Given the available data, this study considers 15 nutrients as random, including metabolizable energy, crude protein, five specific amino acids (lysine, threonine, tryptophan, methionine, and cystine), and eight minerals (calcium, phosphorous, sodium, chlorine, iron, zinc, copper, and manganese). All the other nutrients, including vitamins are assumed nonrandom. In addition, the digestibility rates of crude protein and the five selected amino acids are also considered as random.[4] The correlation matrix of these random nutrients is presented in tables 5a to 5c. Metabolizable energy and crude protein have a negative correlation of -0.155, while lysine and tryptophan are positively correlated with metabolizable energy at 0.261 and 0.095, respectively. Phosphorous is positively correlated with metabolizable energy but at a low level of 0.01, while correlation with lysine is higher at 0.251.

[4] If data are available, extending this model to include all nutrients important in a finishing hog feed formulation is as easy as increasing the dimension of the vector of mean values of the nutrients and the variance-covariance matrix.

Feed compounders can deal with the problem of variability in the nutrient content of DDGS by instituting procurement procedures that reduce variability in their supply. An example is by securing a DDGS supply only from ethanol plants with somewhat homogenous DDGS products. One approach may be for feed compounders to group potential DDGS suppliers into close geographic units hoping that their proximity will make their DDGS products more homogenous. A potential source of variability that can likely be controlled in the grouping of plants into smaller geographic units is the variability originating from the feedstock—corn. This procurement strategy increases the likelihood that the ethanol plants secured their corn feedstock from somewhat similar sources, as varieties of corn used may be similar and the agronomic conditions surrounding corn production may be comparable. The extreme limit of this approach is to secure DDGS only from a single supplier. However, even this approach may still leave a substantial magnitude of variability from intra-plant sources.

To examine the effects of variability in the nutritional content of DDGS in a finishing hog feed ration, we first assume that feed compounders have enough information to characterize fully the distribution of the nutrient content of DDGS products from their suppliers. Second, we assume that they are able to choose a certain safety level. This safety level is defined in this case as the probability that feed compounders set when choosing a critical value of the nutrient level used to formulate feed rations such that the realized nutrient content is equal to or greater than the critical value at a probability equal to the safety level. In our example we arbitrarily set the safety level.

Next we examine the economic impact of reducing the variability of the nutrient composition of DDGS either by grouping ethanol plants that are potential suppliers of

DDGS or even in the limiting case by securing the DDGS supply from only one source. We implement this by comparing the distribution of feed cost savings under two cases. The first case uses the full variability of DDGS products with the variance-covariance matrix derived from the 40 ethanol plants (tables 5a to 5c), while the second case assumes that feed compounders are successful in reducing inter-plant sources of variability such that only intra-plant variance remains. We use two variance-covariance matrices and solve for two sets of optimal feed formulation. With no intra-plant variability data, we simply scale down the variance-covariance matrix from the first case. Noll, Abe, and Brannon (2003) report a coefficient of variation for lysine for both inter-plant and intra-plant-only variation. Assuming that the mean is the same for samples from all sources and from within the sample source, then the ratio of the within-source and across-all-sources coefficient of variation will give a factor that can be used in scaling down the variance of lysine, which in this case is equal to 0.41. We use the same factor in scaling down all the other elements of the variance-covariance matrix. To generate the distribution of the feed cost savings in these two cases, we make 1,000 draws from the multivariate normal distribution to get new realizations of the random elements of the $\boldsymbol{A}$ matrix. Then we reset the LP program with these new elements and solve for a new optimal feed ration for each draw. The feed cost savings is the difference between the feed cost of each optimal feed ration in each draw and the cost of the optimal feed ration with no DDGS from Fabiosa (2008).

The adjustment in the ration for each draw comes from two sources: the change in the inclusion rate of the DDGS, if any, and the change in the nutrient composition at each draw. That is, any shortfall in energy, protein, and minerals previously supplied by

DDGS is replaced by corn and soymeal when the realized values of the random elements of the ***A*** matrix happen to be low.

Figure 1 shows the distribution of feed cost savings in the case with full variance and the case in which there is only intra-plant variability. We note that DDGS is included at the maximum allowable level of 20% in all of the 1,000 optimal feed ration generated in the experiment, except for two draws in which it was 12.45% and 13.78%. Table 6 shows that the mean value of the feed cost savings differed between the two cases because of the change in maximum inclusion rate requirement, $0.94 per cwt feed in the full variance case and $0.96 per cwt in the intra-variance-only case. As expected and as clearly shown in figure 1, the distribution of the feed cost savings has a tighter spread when intra-plant factors are the only sources of DDGS nutrient variability. The coefficient of variation in the full variance case is 9.63%% while it is only 5.21% in the intra-variance case. The economic impacts of the reduction in nutrient composition variability can be interpreted in two ways. First, given the distribution of the two cases examined, feed compounders that set a target of generating a feed cost savings that is equal to or greater than $0.84 per cwt[5] have a probability of success of only 84.14% under the full variance case and a much higher success probability of 98.85% in the intra-plant-only variance case. Or, equivalently, the amount of feed cost savings generated with a certainty of 90% is only $0.82 per cwt of feed under the full variance case but is a higher $0.90 in the intra-plant-only variance case, giving an advantage of $0.08 per cwt of feed when the only source of variability is coming from intra-plant factors. This differential in savings is equivalent to $7.51 per ton of DDGS, representing 4.52% of the price of DDGS. This means that a feed compounder that is successful in minimizing the inter-plant sources of variability so that

[5] This is one standard deviation away from the mean of the full variance case.

it faces only intra-plant variability can increase feed cost savings by $7.51 per ton of DDGS compared to a feed compounder who is facing the full variance. Or, equivalently, when DDGS with only intra-plant variability is considered as the initial DDGS reference supply, then when there is any change in the source of supply that increases the variability to the full variance case, that DDGS product can be discounted in price by 4.52%. For an ethanol plant with a 50-million-gallon capacity, a $7.51 DDGS price discount translates into revenue losses of $1.11 million per year. Again, if this price signal can be communicated to individual ethanol plants, then they can assess their respective DDGS quality control production process and calculate how much it would cost to narrow the spread of the DDGS nutritional composition to approach the DDGS with only intra-plant variability, and implement changes whose benefits exceed costs. The benefit in this case is the removal of any price discount when the improvement in the consistency of DDGS nutritional content is achieved.

Finally, the cost of testing for nutritional content is around $500 per test which includes proximate analysis, minerals, amino acids, and mycotoxins. An ethanol plant with a 50-million-gallon capacity produces 400 tons of DDGS each day, which may come from four separate fermenters. Assuming that testing is done at the end of each batch of fermentation, then that requires testing for every 100 tons. That amounts to a testing cost of $5 per ton. Does it pay to test DDGS? If at the given distribution and safety level used by feed compounders DDGS suppliers have a high likelihood that the actual level of the nutrient from the test is high enough to produce a feed cost savings greater than $5 per ton, then testing DDGS is worthwhile. For the 40 ethanol plants examined in the first case, the break-even volume of a test ranges from 14 to 2,500 tons.

For the second case in which the DDGS variability was significantly reduced, it takes only 67 tons to cover the testing cost with the savings in feed cost.

4. Conclusion

The expansion of ethanol production in the United States has also increased the availability of co-products such as DDGS for feed use. A reported major drawback in the use of DDGS in feed rations, especially for monogastric animals such as hogs, is the variation of the grains' nutritional content. Although corn and soymeal have variability in their nutritional content also, it is not as unstable as DDGS because the latter is subjected to a biological process by batch method, which introduces many sources of variability. For example, inherent in the conversion process, any variability in the feedstock is magnified by a factor of three when it reaches the final DDGS product. Moreover, the drying process also enhances chemical reactions that may compromise the digestibility of amino acids and energy.

We examined the impact of variable nutrient composition in DDGS in two ways. First, we compared the cost of an optimal feed ration using the DDGS products from 40 ethanol plants and found that the range in their feed cost is substantial, from $0.002 to $0.42 per cwt feed. Another way of looking at these result is to express them in terms of equivalent price discounts on DDGS products with higher feed ration cost relative to the reference DDGS, the one with the lowest cost. The price discount is in the range of 0.10% to 25.55%. With this magnitude of discounts, the revenue loses to ethanol plants with a capacity of 50 million gallons would be $0.03 million to $6.27 million annually.

The second analysis characterizes the multivariate normal distribution of 15 random nutrients in DDGS using parameters estimated from 40 ethanol plants. We then scale down this distribution to represent a decrease in variability from a full variance case to an intra-plant-only variability. Our analysis shows that DDGS is a dominant feed ingredient, making it a good candidate to enter into the optimal ration solution. Even with its variability, of the 1,000 draws from the multivariate normal distribution of its nutrients, DDGS still enters into the optimal ration at the maximum allowable rate of 20%, except for two cases in which it was 12.45% and 13.78%. Hence, the adjustment in these draws was simply to supplement with corn and soymeal whatever deficit is created when a particular realization of the draws happens to have a lower nutritional content level.

Assuming a 90% safety level, feed compounders that are able to minimize inter-plant sources of variability such that they only face intra-plant variation save $7.51 per ton of DDGS compared to feed compounders who are facing the full variability of DDGS. This number can also be interpreted as the rate of discount on the price of DDGS (4.52%) that can be imposed on DDGS suppliers with the full variance by feed compounders whose DDGS inputs have only intra-plant variability. For an ethanol plant with a 50-million-gallon capacity, this price discount can amount to a loss of $1.11 million.

This discount information can be useful when communicated to ethanol plants so they can assess the potential of improving their plant quality control to reduce variability in their DDGS products. The costs would be the costs to implement better quality control procedures, and the benefit would be the avoided discount.

Table 1. Nutrient level and digestibility

	Content			Digestibility		
	Min	Mean	Max	Min	Mean	Max
Met Energy (kcal/lb)	1,589	1,732	1,836			
Crude protein (%)	27.30	30.80	33.92	66.99	74.81	82.01
Lysine (%)	0.61	0.94	1.17	55.75	63.73	77.88
Threonine (%)	1.01	1.14	1.28	63.59	70.78	77.47
Tryptophan (%)	0.18	0.24	0.34	56.20	65.82	71.98
Methionine (%)	0.54	0.63	0.76	78.89	83.30	89.20
Cystine (%)	0.55	0.65	0.76	68.94	73.71	81.24
Calcium (%)	0.02	0.06	0.51			
Phosphorous (%)	0.42	0.78	1.06			
Sodium (%)	0.01	0.28	3.97			
Chlorine (%)	0.12	0.19	0.36			
Iron (ppm)	68.00	118.63	295.00			
Zinc (ppm)	38.00	58.50	105.00			
Copper (ppm)	3.00	6.28	13.00			
Maganese (ppm)	9.00	17.50	27.00			

SOURCE: http://www.ddgs.umn.edu/profiles/CSC%20Comparison%20Table.pdf\

Table 2. Nutrient variability

	Content			Digestibility		
	Mean	Std Dev	Coef Var	Mean	Std Dev	Coef Var
Met Energy (kcal/lb)	1,732	58.007	3.349			
Crude protein (%)	30.80	1.539	4.996	74.81	4.98	6.66
Lysine (%)	0.94	0.124	13.138	63.73	6.14	9.63
Threonine (%)	1.14	0.066	5.792	70.78	4.38	6.19
Tryptophan (%)	0.24	0.032	13.202	65.82	5.51	8.38
Methionine (%)	0.63	0.056	8.833	83.30	3.09	3.71
Cystine (%)	0.65	0.052	7.915	73.71	4.25	5.77
Calcium (%)	0.06	0.078	124.098			
Phosphorous (%)	0.78	0.129	16.575			
Sodium (%)	0.28	0.610	221.837			
Chlorine (%)	0.19	0.055	29.404			
Iron (ppm)	118.63	46.407	39.120			
Zinc (ppm)	58.50	15.952	27.268			
Copper (ppm)	6.28	1.881	29.975			
Manganese (ppm)	17.50	4.946	28.262			

SOURCE: http://www.ddgs.umn.edu/profiles/CSC%20Comparison%20Table.pdf\

Table 3. Distribution of forgone feed cost savings

Forgone Saving	Count	Cum Count	Frequency	Cum Frequency
$/cwt feed	Number	Number	Percent	Percent
0.002	1	1	2.56	2.56
0.072	12	13	30.77	33.33
0.143	17	30	43.59	76.92
0.213	2	32	5.13	82.05
0.284	4	36	10.26	92.31
0.354	1	37	2.56	94.87
More	2	39	5.13	100.00
	39		100.00	

SOURCE: Model results.

Table 4. Distribution of price discounts

Discount	Count	Cum Count	Frequency	Cum Frequency
Percent	Number	Number	Percent	Percent
0.10	1	1	2.56	2.56
4.34	12	13	30.77	33.33
8.59	17	30	43.59	76.92
12.83	2	32	5.13	82.05
17.07	4	36	10.26	92.31
21.31	1	37	2.56	94.87
More	2	39	5.13	100.00
	39		100.00	

SOURCE: Model results.

Table 5a. Nutrient correlation matrix

	Energy	C Protein	Lys	Thr	Try	Met	Cys
Energy	1.000	-0.155	0.261	-0.108	0.095	-0.064	-0.330
C Protein	-0.155	1.000	0.109	0.562	0.166	0.182	0.203
Lys	0.261	0.109	1.000	0.354	0.309	-0.230	-0.291
Thr	-0.108	0.562	0.354	1.000	0.616	0.458	0.354
Try	0.095	0.166	0.309	0.616	1.000	0.368	0.407
Met	-0.064	0.182	-0.230	0.458	0.368	1.000	0.629
Cys	-0.330	0.203	-0.291	0.354	0.407	0.629	1.000

Table 5b. Nutrient correlation matrix, continued

	Cal	Pho	Sod	Chl	Iro	Zin	Cop	Man
Energy	-0.475	0.010	-0.162	-0.387	-0.501	0.097	0.104	-0.325
Protein	-0.035	0.114	-0.089	-0.149	0.020	0.245	0.130	0.049
Lys	-0.303	0.251	0.205	-0.362	-0.444	-0.044	0.147	-0.366
Thr	-0.025	0.026	-0.051	-0.209	0.010	0.044	-0.370	0.010
Try	0.078	-0.067	-0.080	-0.133	0.065	-0.243	-0.287	-0.038
Met	0.119	-0.288	-0.176	-0.100	0.163	0.024	-0.293	0.031
Cys	0.207	-0.162	-0.172	-0.057	0.170	0.097	-0.183	0.188

Table 5c. Nutrient correlation matrix, continued

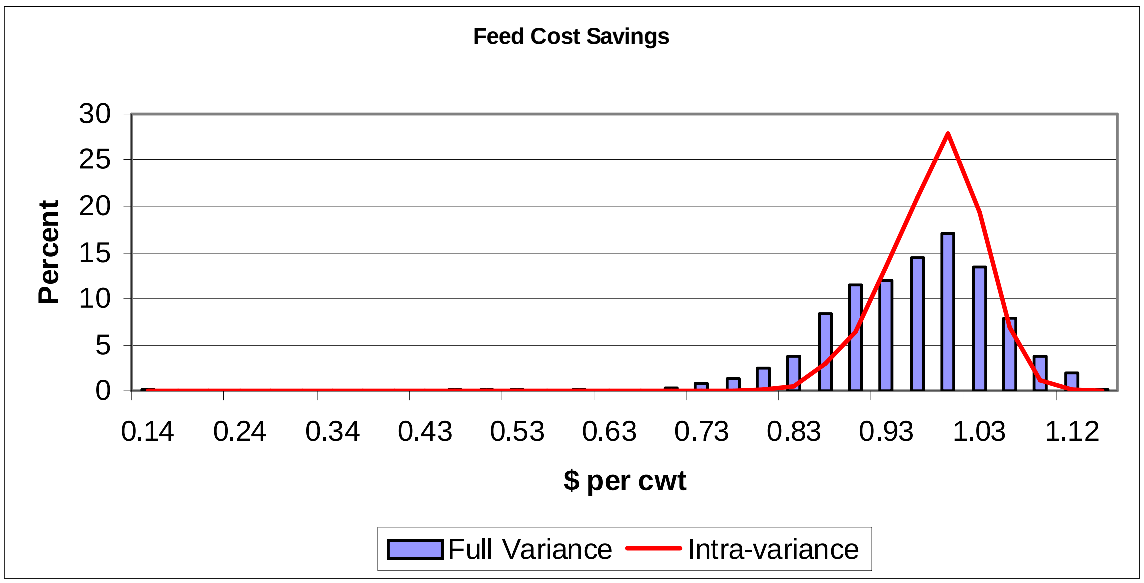
	Cal	Pho	Sod	Chl	Iro	Zin	Cop	Man
Cal	1.000	-0.185	0.017	0.785	0.842	-0.250	-0.167	0.411
Pho	-0.185	1.000	0.078	-0.050	-0.119	0.425	0.333	0.407
Sod	0.017	0.078	1.000	0.044	-0.027	-0.008	0.051	-0.105
Chl	0.785	-0.050	0.044	1.000	0.762	-0.184	-0.111	0.324
Iro	0.842	-0.119	-0.027	0.762	1.000	-0.173	-0.200	0.497
Zin	-0.250	0.425	-0.008	-0.184	-0.173	1.000	0.334	0.321
Cop	-0.167	0.333	0.051	-0.111	-0.200	0.334	1.000	0.159
Man	0.411	0.407	-0.105	0.324	0.497	0.321	0.159	1.000

SOURCE: Computed from
http://www.ddgs.umn.edu/profiles/CSC%20Comparison%20Table.pdf\

Table 6. Feed cost savings distribution

		Full Variance	Intra Variance
Mean feed cost savings	$/cwt feed	0.94	0.96
Coefficient of variation	percent	9.63	5.21
Probability of savings >= $0.84/cwt feed	percent	84.14	98.85
Savings probability of 90%	$/cwt feed	0.82	0.90

SOURCE: Model results.



SOURCE: Model results.

Figure 1. Distribution of feed cost savings

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