Distillers Dried Grain Product Innovation and Its Impact on Adoption, Inclusion, Substitution, and Displacement Rates in a Finishing Hog Ration

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Abstract

This study finds that the use of distillers dried grain with solubles (DDGS) as feed is greatly influenced by the development of DDGS products that are available in the market. We find that newer-generation DDGS products have a higher optimal inclusion rate, reaching the maximum allowable rate of 20% for swine, and they have a higher displacement rate of 0.23 for soymeal and 0.93 for corn. Although both traditional and newer-generation DDGS products are primarily used as a corn substitute for energy, it will take only a relatively small change in the price or matrix *A* (or both) for the newer-generation DDGS to primarily substitute for soymeal for the limiting amino acid, lysine. In contrast, traditional DDGS products have a lower optimal inclusion rate of 7%, and they have a lower displacement rate of 0.75 for corn and 0.08 for soy meal. This product is primarily used as a corn substitute for energy.

When traditional DDGS is introduced in a feed ration, total feed cost declines by 2.64%, or a reduction of $0.29 per cwt of feed. This translates into a $2.17 per head savings in feed cost in a feeder-to-finish operation. Using newer-generation DDGS reduces feed cost by 9.88%, or a reduction of $1.08 per cwt of feed, saving feeder-finisher operations $8.06 per head.

This study suggests that as a substitute product, the price of DDGS will track the price of both corn and soymeal. It will be more of the former until new-generation DDGS can be used as a primary substitute for soymeal and take a dominant share of the market.

Finally, this study clearly points to the critical importance of DDG product innovation to promote widespread and optimal use of DDGS as a feed ingredient, thereby alleviating the food-feed-fuel trade-off.

Keywords: biofuel, DDGS, DG, distillers dried grain with solubles, distillers grain, feeder-finisher, optimal feed ration.

1. Introduction

The recent spike in food prices to historic highs has been attributed to many factors, but the emergence and expansion of the biofuel sector has received the disproportionate blame. The amount of corn used for fuel alcohol jumped from an average of a billion bushels from 2000 to 2005 to three billion bushels in 2007, or an increase of 201% (see table 1). And during the same period, the price of corn doubled, from an average of $2.06 per bushel to $4.25 per bushel, or an increase of 106%. Moreover, almost all the increase in corn production in this period was used to meet the exploding demand for biofuel feedstock, pushing the share of corn used for fuel to more than double, from 10% to 23%,[1] while what used to be the dominant (58%) use of corn—feed use—shrank in share by 11 percentage points.

Facing a 105% increase in the corn price and a 76.93% increase in the soymeal price, livestock, dairy, and poultry producers had to make adjustments in their production plans. Feed cost is a significant item in their cost structure. When all costs are included, feed cost accounts for 33% of cost, feeder pig cost is 44%, other operating expenses (e.g., veterinary expense, repairs, etc.) account for 8%, and overhead cost (e.g., depreciation, insurance, and taxes) is 16%. If the feeder pig cost is excluded, the share of feed cost climbs to more than half of total cost, at 59%. This cost structure makes pork producers very sensitive to changes in grain prices and/or feed cost.

It is the sharp rise in the price of biofuel feedstock and resulting adverse adjustments in the other commodities that have framed the biofuel expansion issue as a food-feed-fuel trade-off. But although it is a competitor in the use of corn, it should not be ignored that

[1] Corn exports also increased slightly, by 0.48%, and part of the corn supplied came from reducing corn stocks.

the biofuel sector also produces a by-product, distillers grain (DG), that can be used as feed. Ethanol production that uses the dry milling process produces DG. 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 lb of DG, this source of feed ingredient can be substantial; it represented 17% of total corn used as feed in 2007. It is for this reason that the use of DG as feed receives significant attention.

The use of DG as feed is affected by three major factors: adoption rate, maximum allowable inclusion rate, and displacement rate. The adoption rate measures the proportion of feed compounders and livestock producers that use DG in their ration. Of those that use DG, the maximum allowable inclusion rate gives the technical limit of how much they can incorporate in their ration. The displacement rate measures the amount of other feed ingredients in a ration that are substituted with the introduction of a unit of DG.

The adoption rate is primarily driven by economic considerations; that is, if it makes economic sense in terms of benefits and costs to incorporate DG in a feed ration, feed compounders and livestock producers will use DG. However, it should be noted that there are other considerations, mostly technical, that may also affect adoption, such as consistency of the DG product in terms of stability of its nutritional composition, storability, and ease of handling and transportation. Akayezu et al. reported significant variation in nutrient composition both within an ethanol production plant and across plants. Also, since DG contains unstable fatty acids, it is subject to rancidity in a short span of time. Mycotoxins from molds can also have adverse repercussions on animal production performance. All these factors can potentially discourage the use of DG as a feed ingredient, even if economic considerations appear favorable.

The maximum allowable inclusion rate of DG in animal feed ration has been examined in many studies, including Noll for poultry, Shurson and Thaler for swine, Trenkle and Tjardes and Wright for cattle, and Schingoethe for dairy. These studies establish inclusion rates that avoid compromising animal production performance (i.e., reduced daily weight gain), as well as final product quality (i.e., meat quality). Beef cattle feed ration has the highest inclusion rate at 40% of wet distillers grain. The maximum distillers dried grain inclusion rate for dairy is 20%, for finishing hogs, 20%, and for broiler, 10% (NCGA). When determining how much DG to use in a ration, in many cases it is simply assumed that users of DG would apply the maximum allowable inclusion rate if some partial budget analysis shows that it makes economic sense to use DG. In this study, we determine whether maximum inclusion rates are limiting factors in the use of DG.

The displacement rate is the main focus of this study. Because major feed ingredients such as corn, soymeal, and DG share common nutrients, there is a conflicting claim as to what feed ingredient DG displaces in a feed ration. Some say it is corn for energy while others claim it is soymeal for protein. Which is which, and can this question be resolved? Moreover, the rate at which these feed ingredients are displaced by DG is not well established either. It is not even clear if apples are compared to apples when displacement rates are compared in the literature. Is it purely technical displacement rates based on the feed ingredients' relative nutritional composition that are compared? For example, one unit of distillers dried grain with solubles (DDGS) can equivalently replace the metabolizable energy from a 0.82 unit of corn. If this is the case, which nutrient is considered: energy, protein, minerals, or vitamins? At first glance the determination of displacement rate appears straightforward, but it is not so for two reasons. First, economic consideration has to be factored in. But more importantly, there are other nutrients that can come into play other than the aggregate energy or crude protein; nutrients such as specific amino acids (e.g., lysine) and their balance may have a stronger influence on final displacement. This is particularly true in the case of monogastric animals in which specific amino acids and their balance are critically important in a feed ration because of the animals' inability to synthesize adequate amounts of these nutrients on their own.

Finally, this study focuses on the impact of product development of DG in adoption, inclusion, and displacement rates. We also want to estimate what savings in feed cost, if any, can be attributed to the use of DG in a finishing hog ration.

2. Model

We use a standard linear programming model to formulate a least-cost feed ration for finishing hogs; that is, we solve the following optimization problem:

[1] Minimize $p'x$

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

where $\boldsymbol{x}$ is an $n \times 1$ 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); $\boldsymbol{p}$ is an $n \times 1$ matrix of feed ingredient prices; $\boldsymbol{A}$ is an $m \times n$ matrix of technological coefficients representing the amount of nutrient from the respective source of feed ingredients, $\boldsymbol{b}$ is an $m \times 1$ matrix of right-hand-side constants such as feed nutrient requirements (e.g., energy, protein, minerals, and vitamins); $\boldsymbol{l}$ is an $n \times 1$ matrix of lower bound such as the non-negativity condition of the decision variables;

and ***u*** is an $n \times 1$ matrix of upper bound such as the maximum inclusion rate of DDGS in the ration.

The model solves for an optimal feed ration mix specifying the amount of each feed ingredient to use that minimizes total feed cost and meets all nutritional requirements, given current prices.

3. Data and Results

This study develops a database and linear program (LP) solver interface with the database in Microsoft Excel and the LP solver in SAS (SAS, 2002). The database in Excel includes data on nutritional requirements for finishing hogs, nutritional composition of commonly used feed ingredients, and feed ingredient prices. 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 is taken from the National Research Council (NRC) (1998) for corn, soymeal, and DDGS. In this paper, the term DDGS is used in a generic sense to refer to all types of DDGS. The earlier form of the product with nutrient profile given by the NRC is referred to as traditional DDGS product, or tDDGS. We use the Dakota Gold brand as the new-generation DDGS product, or nDDGS. Giesemann (personal communication) and Giesemann et al. provided the nutritional composition of nDDGS. Prices of corn, soymeal, and DDGS are from the USDA market news, and prices of mineral and vitamin supplements are from industry sources.

The author developed a link between this database in Excel and an LP problem solver in SAS version 9.1., in which the LP problem reads all the prices, nutritional requirements, and nutritional composition of common feed ingredients from the Excel database. The data is first exported into a file that can be easily imported into SAS, which, when read by SAS, is already in the form given in equation [1]. The LP problem is solved in SAS for the optimal mix of feed ingredients that minimizes feed cost and at the same time meets all the nutritional requirements of a finishing hog ration. The output is then written back into the same Excel file for further analysis or for formatting into tables and charts.

To ensure spatial consistency, we model a representative feed compounder that is located in Kansas City, Missouri. The USDA market news reports a price quoted in Kansas City for the major feed ingredients we consider, including corn, soymeal, and DDGS. This removes the need to adjust the prices to account for transportation cost. We then use prices of minerals and vitamins from industry sources, assuming these products are delivered at a Kansas City location. 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). This is used as the price of the tDDGS. The nDDGS is given a price premium of 2.11% above this price.

Table 2 shows the nutritional requirement of a finishing hog. Our specific example is for finishing hogs in the last weight category. To highlight a few nutrients, a finishing hog requires 1,501 kcal of metabolizable energy per pound of feed, and the feed ration must contain 0.61% lysine, 0.53% calcium, and 121 IU of vitamin D_3 per pound of feed. These nutritional requirements must be satisfied by the optimal feed ration.

Tables 3 and 4 show the nutritional composition of common feed ingredients and supplements for minerals and vitamins. We note that two types of DDGS are considered in this analysis. As shown in the table, with the ever-improving quality of DDGS, newer-generation products coming into the market have very different nutrient profiles. nDDGS has 39.9% higher metabolizable energy, 5.7% more crude protein, and 19% to 58% higher specific amino acids, especially lysine. Moreover, digestibility of these amino acids is much higher in nDDGS than in tDDGS. For example, lysine digestibility in tDDGS is only 47% while it is 74.8% in nDDGS. Threonine is 83.6% compared to 55%, and tryptophan is 86% compared to 50%.

Metabolizable energy contents for the four major sources, corn, soymeal, tDDGS, and nDDGS, are 1,551, 1,533, 1,279, and 1,790 kcal per pound, respectively. Soymeal is the highest source of crude protein at 47.5% compared to only 8.3% in corn. DDGS is much closer to soymeal, at 27.7% for tDDGS and 29.3% for nDDGS. In terms of specific amino acids, soymeal still tops corn and DDGS as a richer source. For example, corn has only 0.26% lysine, tDDGS has 0.62%, and nDDGS has 0.98%, while soymeal has 3%. The same pattern holds for the other amino acids. For minerals and vitamins, DDGS shows higher content of phosphorous, chlorine, iron, zinc, copper, niacin, and riboflavin. nDDGS is low in calcium. Also, specific sources of minerals and vitamins are needed to supplement the main grain feed ingredients in meeting the requirement of hogs.

In the LP problem we adjust the coefficient that enters in the ***A*** matrix, which is the amount of specific amino acids contributed by each source of feed ingredient by their respective digestibility rates, as given in table 5.

We use the price, nutrient requirement, and nutrient composition information in a SAS LP solver to find the least cost mix of feed ingredients that meets all the nutritional requirement of the animal. The optimal feed rations are shown in table 6. To isolate the effect of DDGS in the feed ration, the first ration excludes DDGS in the mix of potential feed ingredients. We implement this by raising the DDGS price to an artificially prohibitive level so it does not enter into the optimal solution. The optimal base feed ration weighing 100 lb contains 78 lb of corn and 19 lb of soymeal. The rest of the ration is supplementary minerals and vitamins. This ration is close to the reference diets for pigs calculated by Lammers et al. (2007) for the weight category 80 to 160 lb, which had 77 lb of corn and 21 lb of soymeal. We then reset the LP problem to reflect the true market price of tDDGS and solve for a new optimal feed ration. The second ration has an optimal mix that contains 73 lb of corn, 18 lb of soymeal, and 7 lb of tDDGS. Even if 20% is allowed for DDGS, the optimal solution only included 7%. The introduction of 7.34 lb of tDDGS reduces corn by 5.47 and soymeal by 0.59. Supplemental sources of minerals also declined: dicalcium phosphate declined by 0.22, limestone by 1.02, and salt by 0.04. The cost of the second feed ration is $0.29 per cwt of feed lower than the base ration, or 2.6% lower. Assuming a feed efficiency of 3.0 and weight gain of 220 lb, a feeder-finisher operation can save $2.17 per head by using tDDGS in its feed ration.

As in the previous step, we repeat to reset the LP problem and solve for a new optimal feed ration using the price and nutrient composition of nDDGS instead of tDDGS.

The resulting optimal feed ration is very different. The amount of nDDGS included in the ration reaches the maximum allowable for swine at 20%, or 20 lb in a 100 lb ration. This displaces 18.54 lb of corn, 4.59 lb of soymeal, 0.56 dicalcium phosphate, and 0.10 of salt. In this ration, however, we needed to add 3.78 of limestone. The cost of this ration is $1.08 per cwt of feed lower than the base ration, or 9.88% lower. Feed cost savings amounts to $8.13 per head in a feeder-finisher operation.

Table 7 shows the nutritional profile of the three feed rations. For the no-DDGS feed ration, several nutrients are at the lower boundary in the optimal solution, including metabolizable energy, threonine, available phosphorous, sodium, iodine, selenium, vitamin A, vitamin D_3, and vitamin B_{12}. The rest of the nutrients are in excess supply. Lysine is usually expected to be the limiting amino acid in a swine ration. However, in our base case ration, it is threonine that is limiting. The reason is the adjustment for digestibility in the coefficient matrix $\boldsymbol{A}$, in which threonine has a lower digestibility of 78% compared to the 85% of lysine for soymeal. With the introduction of tDDGS in the ration, the nutrient profile changes, with lysine now binding while threonine has a surplus, and calcium becomes binding, too. This is because, in the case of tDDGS, threonine has higher digestibility compared to lysine, and calcium is relatively lower, especially in nDDGS. When nDDGS is introduced, three nutrients change status compared to the baseline ration of no-DDGS. That is, amino acid threonine has a surplus while lysine becomes binding. Also, since DDGS has the highest phosphorous content, there is surplus for available phosphorous. We note two things in these feed rations. First, we only consider a corn-soymeal-DDGS ration. This is consistent with avoiding frequent changes in order to maintain the quality of the ration, especially in monogastric animals.

It is, however, quite possible that other feed ingredients can enter into the optimal solution. Second, we did not give specific attention to the fact that some nutrients are in surplus supply since they are not very excessive. Swine nutrition experts claim that providing beyond what is the required nutrient level, as long as it is not too excessive, does not pose a serious toxicity problem for the health and performance of animals, especially when the animals are provided with an ample supply of water.

We now turn to the main focus of the study, that is, understanding the changes in the feed ingredient mix with the introduction of DDGS. Three measures are considered: nutrient technical ratios of replacement, gross displacement rates, and feed ingredient substitution rates. We take particular care in deriving the numbers as well as in providing a clear interpretation to avoid confusion.

Table 8 gives a nutrient-by-nutrient ratio between corn and DDGS, and soymeal and DDGS based on their relative nutritional composition. For example, in terms of metabolizable energy, one unit of tDDGS can replace 0.82 unit of corn. Since tDDGS has more protein content than corn, if tDDGS is used to replace the protein contribution of corn, a unit of tDDGS can replace 1.70 to 3.34 units of corn. In the case of soymeal, if tDDGS is used to replace soymeal for its protein, then it can replace 0.11 to 0.58 unit of soymeal for crude protein and specific amino acids. The most limiting amino acid is lysine, whereby tDDGS can only replace 0.11 of soymeal. If DDGS is used to replace the energy contribution of soymeal, a unit of tDDGS can replace 0.83 unit of soymeal.

We define gross displacement as the rate at which other feed ingredients are replaced with the introduction of a new ingredient, in this case, tDDGS, without breaking down how much of the total DDGS is replacing which specific feed ingredient. What we propose in this study is to estimate the displacement rate based on the actual amounts of corn and soymeal that are replaced by total DDGS by comparing the optimal feed rations. In the cases of no DDGS in the ration and a ration with tDDGS, the rates would be 5.47 of corn and 0.59 of soymeal replaced by 7.34 of tDDGS, which gives a displacement rate of 0.75 and 0.08, respectively. When nDDGS is used, the displacement involves 20 lb of nDDGS replacing 18.54 lb of corn and 4.59 lb of soymeal. This translates into a displacement rate of 0.93 and 0.23 for corn and soymeal, respectively. It is worth noting that with its improved nutritional profile and digestibility, the nDDGS has raised the displacement rates for both corn and soymeal, particularly the latter.

Since the gross displacement rate does not account for specific attribution, it cannot provide guidance as to how much of the 7.34 and 20.00 lb of tDDGS and nDDGS, respectively, is substituting for corn and how much for soybeans. What we need to do is separate the amount of DDGS that is used to replace a specific ingredient. Then we can estimate a substitution rate that accounts for attribution. The substitution rate is important because it is the only way we can determine which feed ingredient DDGS substitutes for, corn or soymeal. Since several nutrients are jointly available from the three major feed ingredients, it is difficult to separate and isolate the attribution of replacement to specific ingredients. The reason is that if DDGS primarily replaces corn for energy, then the joint protein in DDGS can also replace soymeal. If it primarily replaces soymeal for protein, then the joint energy in DDGS can also replace corn. What we propose is to determine which feed ingredient is the primary target for replacement, and which feed ingredient is only substituted as a secondary effect because of the joint availability of common nutrients.

To do this we sort out a proper accounting of the replacement based on the nutrient so the attribution is clear.

Step 1. Estimate the change in nutrient by feedstock between the base (b) and new (n) ration, i.e.,

$$D_{ij} = A_{ij}(x_j^n - x_j^b) .$$

Table 9 shows the D_{ij} values, indicating the changes between the no-DDGS and with-tDDGS optimal feed ration nutrient composition broken down by the feed ingredient source of the respective nutrient. For example, introduction of tDDGS supplies a total of 9,389 kcal of metabolizable energy, which replaces 8,484 kcal of metabolizable energy from corn and 905 kcal from soymeal. A second example is lysine, whereby 0.009 lb of lysine from corn and 0.015 lb of lysine from soymeal are replaced by 0.021 lb of lysine from tDDGS. It should be noted that in this accounting, tDDGS does not have to replace all that was displaced if a nutrient is at a surplus supply situation at the baseline ration of no-DDGS, which is the case in lysine. The numbers balance in energy because they are at the lower boundary in both rations.

Step 2. Estimate the amount of DDGS needed to replace the displaced nutrient from each feed ingredient by dividing the changes in step 1 by the appropriate nutrient contribution from DDGS, say, j=d for DDGS:

$$DDGs_{ij} = \frac{D_{ij}}{A_{id}}$$

Table 10 gives the amount of tDDGS needed to replace each nutrient from a specific feed ingredient source. We suggest a rule that the feed ingredient with the nutrient that requires the highest amount of DDGS and whose level is at the lower boundary is the feed ingredient that is the primary target for replacement for that nutrient, and the rest are only replaced as a secondary effect. The economics behind this rule is very intuitive. That is, since all the numbers are derived from a cost-minimization framework, when at the optimal solution a nutrient from a particular feed ingredient shows the highest DDGS required for its replacement, it must be the case that replacing such nutrient-ingredient reduces the cost of the ration the most. Or equivalently, replacing the nutrient-ingredient provides the highest value (in terms of value of displaced ingredient) of the new entering feed ingredient, which in this case is the DDGS. That is,

$$x_j^i = \max(DDGs_{ij}) \qquad \forall i, j$$

where subscript *j* is for the feed ingredient and superscript *i* is for the nutrient. It turns out that in our specific case, replacing corn (*j*=*c*) as a source of energy (*i*=*e*) requires the highest amount of tDDGS, at 6.63 lb (see table 10). All the other nutrients supplied previously by corn required only 1.63 to 3.22 lb of tDDGS. Moreover, the nutrients from soymeal replaced by tDDGS only required 0.78 to 5.20 lb, much less than the 6.63. For this reason, we can make the claim that tDDGS displaced corn primarily as a source of energy, and the displacement of soymeal is a secondary effect.

Since the maximum amount of tDDGS needed to replace corn as a source of energy is less than the total amount of tDDGS included in the optimal ration (6.63 versus 7.34 lb), we suggest that the remaining balance of 0.708 lb of tDDGS is that which we can attribute to be used to replace soymeal. To identify which nutrient from soymeal was substituted, we subtract from the total change between the two rations compared to the amount of nutrient that can be supplied by the 6.63 lb of tDDGS that already replaces corn. That is,

$$R_i = \sum_j D_{ij} - A_{id}(DDGs_{ec}))\ .$$

We only take values of *R* that are positive, since a negative *R* suggests that that nutrient is already in excess supply. We repeat step 2 by dividing *R* with the appropriate nutrient contribution from DDGS, i.e.,

$$DDGS_{im} = \frac{R_i}{A_{id}}$$

where $j{=}m$ is for soymeal. Again, we choose the nutrient with the highest amount of DDGS needed to replace it. Since we have already excluded all nutrients that are in surplus supply, only two cases are possible. First, the nutrient is binding both in the base ration and in the new ration. Or, it is surplus in supply in the base but binding in the new ration. In the first case (e.g., energy), we find that the amount of tDDGS required to replace soymeal as an energy source ($DDDS_{em}$) is 0.71 lb, which is the same as the balance between the included DDGS (7.34) less the amount used to replace the feed ingredient that was the primary target of substitution (6.63). In the second case (lysine), the same number will be estimated after we remove the excess amount in the base ration. As a double check, if we divide the *R* values by the coefficient of soymeal in the *A* matrix, it will give a number equal to the amount of soymeal replaced from the base to the new ration, or 0.59 lb. So the correct and exact statement is that for a hog finishing ration, tDDGS substitutes 0.82 (5.47/6.63) of corn for energy, and because this tDDGS also contains other nutrients present in soymeal, it also substitutes 0.83 (0.59/0.71) of soymeal for energy and lysine.

We repeat the same analysis in comparing the substitution between the ration with no DDGS and the ration with nDDGS. It is very interesting to note that in this case the maximum amounts of nDDGS needed to replace specific nutrients are very close to each other, 16.07 lb for energy from corn and 15.61 lb[2] for lysine from soymeal. Following the same rule as applied previously, the correct and exact statement in this case is that for a hog finishing ration, nDDGS primarily substitutes for energy from corn at a rate of 1.15 (18.54/16.07) and substitutes for energy and lysine from soymeal at 1.17 (4.59/2.94).

We note with interest that in the case of tDDGS, the ratio of the maximum tDDGS to replace corn and maximum tDDGS to replace soymeal is 0.62. This number is 0.98 for nDDGS, suggesting that only a relatively small change in the prices and or in the matrix *A* (or both) can make nDDGS substitute for soymeal for protein as the direct effect and can make it substitute for corn as the secondary effect.

It is now obvious that the numbers are very different for the technical ratio of replacement, gross displacement, and substitution. For example, the displacement rate of soymeal in the tDDGS (nDDGS) is 0.08 (0.23) while the substitution rate is 0.83 (1.17). The reason the displacement rate is smaller is that we are dealing with a gross number in the denominator of this ratio, without accounting for attribution. In the substitution rates, however, we account for specific attribution. In effect, we are looking at the same number but in a different way. We note, however, that the amount of the real variables in the ration remains the same. What causes confusion in the discussion is when one number is mistaken, and interpreted for the other. This is important because the implications are not trivial, especially when it comes to policy consideration since a higher number means a lesser food-feed-fuel trade-off.

We also note that tDDGS is included at a rate of only 7.3%, while the inclusion of nDDGS is at the maximum allowable rate of 20%.

[2] This is after removing the surplus of lysine from the base ration.

4. Conclusion

This study examined important questions in the use of DDGS in a finishing hog ration. First, what does DDGS primarily substitute for in a feed ration for finishing hogs—corn or soymeal? Second, what are the appropriate optimal displacement and substitution rates? And third, are the maximum inclusion rates limiting in the use of DDGS? We answer this question by deriving the numbers for two types of DDGS products—traditional and new generation—and by comparing them to each other.

Using a standard LP model we solve for three least-cost feed rations for finishing hogs, one with no DDGS, a second with tDDGS, and a third with nDDGS. We found that our answers to the research questions are dependent on the kind of DDGS that are used. In the case of tDDGS, DDGS substitutes for corn as a main source of energy, and the substitution of soymeal is just a secondary effect because of the availability of other nutrients in tDDGS that can replace nutrients found in soymeal. The optimal displacement rate is 0.75 for corn and 0.08 for soymeal. The substitution rates are 0.82 and 0.83, respectively. The optimal amount of tDDGS included in the optimal ration represents only 7.3% of the ration, far below the 20% maximum allowable inclusion rate.

In the case of nDDGS, the DDGS still substitutes for corn as a main source of energy, and the substitution of soymeal is a secondary effect. However, it will take only a relatively small change either in the prices or the matrix A (or both) for the nDDGS to primarily replace soymeal, with the replacement of corn as a secondary effect. The displacement rate is higher for nDDGS at 0.23 for soymeal and 0.93 for corn. The substitution rates are also higher, at 1.17 and 1.15, respectively. The amount of nDDGS included in the ration reaches the maximum allowable rate of 20%.

The price of DDGS will track the price of the feed ingredient that it primarily replaces. The findings of this study suggest that the price of DDGS will track both corn and soymeal prices. It will be more of the former until new-generation DDGS can be used as a primary substitute for soymeal and take a dominant share of the market.

Inclusion of DDGS in a feed ration saves feeder-finisher operations $2.17 per head if tDDGS is used and $8.06 per head if nDDGS is used.

Finally, with their higher substitution and displacement rates, newer-generation DDGS products can better alleviate the trade-off between food, feed, and fuel in the continuing expansion of biofuels.

Table 1. Corn utilization

	Level		Share		Change	
	2000-05	2007	2000-05	2007	Million Bushels	Percentage Points
	Million Bushels		Percent			
Domestic Use	8,321	10,395	81.56	81.08	2,074	-0.48
Feed	5,896	6,050	57.79	47.19	154	-10.60
Fuel Alcohol	1,070	3,000	10.49	23.40	1,930	12.91
HFCS	530	490	5.20	3.82	-40	-1.38
Seed	20	22	0.20	0.17	2	-0.03
Food, Other	804	833	7.88	6.50	29	-1.38
Exports	1,881	2,425	18.44	18.92	544	0.48
Total	10,202	12,820	100.00	100.00	2,618	

SOURCE: USDA, PS&D.

Table 2. Nutritional recommendations for swine

				Growing-Finishing Weight Category			
		Gest.	Lact.	1	2	3	4
Amino acids							
Lysine	%	0.31	0.82	1.06	0.89	0.74	0.61
Threonine	%	0.23	0.51	0.70	0.59	0.51	0.43
Tryptophan	%	0.07	0.16	0.21	0.18	0.15	0.12
Meth. + Cystine	%	0.25	0.40	0.59	0.50	0.44	0.36
Crude protein	%			19.37	17.01	15.01	13.19
Met. Energy	kcal/lb	1480	1488	1488	1494	1498	1501
ME / Lysine				1401	1681	2015	2449
Minerals							
Calcium	%	0.72	0.71	0.72	0.64	0.59	0.53
Phos., total	%			0.58	0.51	0.47	0.43
Phos., available	%	0.38	0.36	0.33	0.26	0.21	0.17
Sodium (Na)	%	0.10	0.15	0.16	0.15	0.14	0.13
Chlorine (Cl)	%	0.15	0.23	0.24	0.22	0.21	0.20
Iron	ppm	61	93	108	94	81	70
Zinc	ppm	52	79	108	94	81	70
Copper	ppm	3.7	5.6	6.8	5.9	5.1	4.5
Manganese	ppm	7	11	3.4	3.0	2.6	2.2
Iodine	ppm	0.10	0.16	0.15	0.14	0.13	0.11
Selenium	ppm	0.11	0.17	0.24	0.21	0.18	0.15
Vitamins							
Vitamin A	IU	973	1494	1638	1465	1296	1209
Vitamin D_3	IU	97	149	164	147	130	121
Vitamin E	IU	11	17	11	10	9	8
Vitamin K	mg	0.24	0.37	0.49	0.44	0.40	0.35
Niacin	mg	4.9	7.5	17	13	10	8
Pant. Acid	mg	5.8	8.9	11	10	8	6
Riboflavin	mg	1.8	2.8	3.9	3.1	2.5	2.0
Vitamin B_{12}	mcg	7.3	11.2	19	15	12	9
Biotin	mg	0.09	0.13				
Folacin	mg	0.21	0.13				
Choline	mg	213	327				

SOURCE: Holden et al., 1996, and NRC, 1998.

Table 3. Nutritional composition of common feed ingredients

	Corn	Soymeal	tDDGS	nDDGS
Price ($/cwt)	7.59	15.19	6.69	6.69
Metabolizable energy (kcal/lb)	1,551	1,533	1,279	1,790
Crude protein (%)	8.300	47.500	27.700	29.300
Lysine (%)	0.260	3.020	0.620	0.980
Threonine (%)	0.290	1.850	0.940	1.120
Tryptophan (%)	0.060	0.650	0.250	0.310
MethCystine (%)	0.360	1.410	1.020	1.390
Calcium (%)	0.030	0.340	0.200	0.040
Phosphorous total (%)	0.280	0.690	0.770	0.870
Phosphorous available (%)	0.040	0.160	0.590	0.739
Sodium (%)	0.020	0.020	0.250	0.210
Chlorine (%)	0.050	0.050	0.200	0.0026
Iron (%)	0.003	0.018	0.026	0.0001
Zinc (%)	0.002	0.006	0.008	0.0001
Copper (%)	0.000	0.002	0.006	0.0000
Manganese (%)	0.001	0.004	0.002	0.0000
Niacin (mg/lb)	0.0000	9.9790	34.0194	34.0194
Pantacid (mg/lb)	2.7215	6.8038	6.3502	6.35029
Riboflavin (mg/lb)	0.5443	1.4061	3.9008	3.90089

SOURCE: NRC, 1998.
Vitamins in nDDGS assumed equivalent to NRC.

Table 4. Nutritional composition of minerals and vitamins as feed ingredients

	Dicalcium Phosphate	Limestone	Salt	GF Mineral	ADEK Premix	GF Vitamins
Price $/cwt	77.60	7.00	11.60	70.15	85.68	56.45
DM %	96.00	98.00				
ME kcal/lb	0.00	0.00				
NE kcal/lb	0.00	0.00				
Protein %	0.00	0.00				
Calcium %	21.30	38.00				
Phosphate (%)	18.70	0.00				
Available Phosphate %	18.70	0.00				
Ether Extract (%)	0.00	0.00				
C. Fiber (%)	0.00	0.00				
Lysine %	0.00	0.00				
Threonine (%)	0.00	0.00				
Tryptophan (%)	0.00	0.00				
Meth. + Cystine (%)	0.00	0.00				
Sodium (Na) (%)			39.30			
Chlorine(Cl) %			60.70			
Iron (%)				7.00		
Zinc (%)				7.00		
Copper (%)				0.44		
Manganese (%)				0.22		
Iodine (%)				0.01		
Selenium (%)				0.01		
Vitamin A (IU/lb)					2,300,000	
Vitamin D_3 (IU/lb)					230,000	
Vitamin E (IU/lb)					16,000	
Vitamin K (mg/lb)					700	
Niacin (mg/lb)						31,000
Pant. acid (mg/lb)						20,000
Riboflavin (mg/lb)						7,000
Vitamin B_{12} mcg/lb						35,000

SOURCE: Iowa Pig Center, Iowa State University.

Table 5. Digestibility of amino acids in common feed ingredients

	Corn	Soymeal	tDDGS	nDDGS
Lysine (%)	66.0	85.0	47.0	74.8
Threonine (%)	69.0	78.0	55.0	83.6
Tryptophan (%)	64.0	81.0	50.0	86.0

SOURCE: NRC, 1998, and Giesemann et al.

Table 6. Optimal hog feed ration with and without DDGS

	No DDGS	tDDGS		nDDGS	
	Qty	Qty	Change	Qty	Change
Feed Ration	lbs				
Corn	78.23	72.76	-5.47	59.69	-18.54
Soymeal	18.78	18.19	-0.59	14.19	-4.59
Dicalcium phosphate	0.56	0.34	-0.22	0.00	-0.56
Limestone	1.96	0.94	-1.02	5.74	3.78
Salt	0.29	0.24	-0.04	0.19	-0.10
Trace minerals	0.11	0.11	0.00	0.11	0.00
Vitamin pre-mix	0.08	0.08	0.00	0.08	0.00
DDG	0.00	7.34	7.34	20.00	20.00
Total Weight	100.00	100.00		100.00	

SOURCE: Model solution.

Table 7. Nutritional profile of the 100 lb feed ration

	Boundary	No DDGS	tDDGS	nDDGS
Metabolizable energy (kcal/lb)	150,143	**Binding**	**Binding**	**Binding**
Crude protein (%)	13.18837	Surplus	Surplus	Surplus
Lysine (%)	0.61319	Surplus	**Binding**	**Binding**
Threonine (%)	0.42753	**Binding**	Surplus	Surplus
Tryptophan (%)	0.12188	Surplus	Surplus	Surplus
MethCystine (%)	0.35753	Surplus	Surplus	Surplus
Calcium (%)	0.52753	Surplus	**Binding**	Surplus
Phosphorous total (%)	0.42565	Surplus	Surplus	Surplus
Phosphorous available (%)	0.16565	**Binding**	**Binding**	Surplus
Sodium (%)	0.13188	**Binding**	**Binding**	**Binding**
Chlorine (%)	0.20188	Surplus	Surplus	Surplus
Iron (%)	0.00701	Surplus	Surplus	Surplus
Zinc (%)	0.00701	Surplus	Surplus	Surplus
Copper (%)	0.00045	Surplus	Surplus	Surplus
Manganese (%)	0.00022	Surplus	Surplus	Surplus
Iodine (%)	0.00001	**Binding**	**Binding**	**Binding**
Selenium (%)	0.00002	**Binding**	**Binding**	**Binding**
Vitamin A (IU)	120,924	**Binding**	**Binding**	**Binding**
Vitamin D_3 (IU)	12,924	**Binding**	**Binding**	**Binding**
Vitamin E (IU)	819	Surplus	Surplus	Surplus
Vitamin K (mg)	35	Surplus	Surplus	Surplus
Niacin (mg)	819	Surplus	Surplus	Surplus
Pantacid (mg)	619	Surplus	Surplus	Surplus
Riboflavin (mg)	196	Surplus	Surplus	Surplus
Vitamin B_{12} (mcg)	919	**Binding**	**Binding**	**Binding**

SOURCE: Model solution.

Table 8. Technical ratio of corn and soymeal replacement

	Corn		Soymeal	
Nutrient	tDDGS	nDDGS	tDDGS	nDDGS
Met. energy	0.82	1.15	0.83	1.17
Crude protein	3.34	3.53	0.58	0.62
Lysine	1.70	4.27	0.11	0.29
Threonine	2.58	4.68	0.36	0.65
Tryptophan	3.26	6.94	0.24	0.51
Meth. + Cystine	2.23	3.88	0.57	0.98

SOURCE: Computed from NRC, 1998.

Table 9. Total nutrient and source replacement

	tDDGS			nDDGS		
Change in Nutrient	Corn	Soymeal	DDG	Corn	Soymeal	DDG
Met. energy (kcal)	8,484	905	-9,389	28,755	7,045	-35,800
Crude protein (lb)	0.454	0.280	-2.033	1.539	2.183	-5.860
Lysine (lb)	0.009	0.015	-0.021	0.032	0.118	-0.147
Threonine (lb)	0.011	0.009	-0.038	0.037	0.066	-0.187
Tryptophan (lb)	0.002	0.003	-0.009	0.007	0.024	-0.053
Meth. + Cystine (lb)	0.016	0.007	-0.048	0.055	0.053	-0.229

SOURCE: Model solution.

Table 10. Required DDGS to replace nutrients by source (lb)

	tDDGS		nDDGS	
	Corn	Soymeal	Corn	Soymeal
Metabolizable energy	6.633	0.708	16.065	3.935
Crude protein	1.639	1.012	5.251	7.449
Lysine	3.221	5.201	4.339	16.090
Threonine	2.117	1.648	3.961	7.081
Tryptophan	1.680	2.487	2.670	9.074
Meth. + Cystine	2.454	1.044	4.783	4.672

SOURCE: Model solution.

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