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Economically Optimal Distiller Grain Inclusion

in Beef Feedlot Rations:

Recognition of Omitted Factors

by

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Abstract

With the rapid expansion of the ethanol industry, the feeding landscape familiar to the feedlot industry is changing. While concerns regarding rising corn prices persist, many within the industry are looking at distiller's grains, a by-product of ethanol production, to serve as a feed substitute. The question remains as to what extent these two feed sources are substitutable. The purpose of this study is to identify the economically optimal inclusion rate of distiller's grains in beef feedlot rations, considering an array of often omitted factors. Most currently prevailing recommendation rates are strictly biologically based and frequently reference only one feeding trial. Unique economic factors considered in this research include the impact of by-product inclusion rates on animal performance (utilizing recently conducted meta-analysis from 17 relevant feeding trials), enhanced likelihood of death loss from heightened sulfur content, and manure disposal costs. Results indicate that excluding these factors can significantly impact optimal inclusion levels and that reliance on a single or few feeding trials may greatly bias results.

Keywords: distiller's grains, livestock rations, manure disposal cost

Introduction

The rapid expansion of the ethanol industry over the past few decades has raised many concerns across livestock and poultry industries regarding future feed costs. Corn, an important feed source for many animal industries, is commonly used as the primary input in ethanol production. As the demand for corn increases, livestock and poultry producers face rising feed costs. However, the by-product of ethanol production known as distiller's grains (DG) can be incorporated into many livestock and poultry rations as a partial substitute for the corn, soybean meal, and urea currently being fed.

This article focuses on the substitution between corn and DG within beef feedlot rations. The beef industry is considered by industry experts to be the leading animal industry in terms of its utilization potential for this alternative feed ingredient. The beef industry accounted for 42% of the DG consumption in 2006 (a 5% increase from 2005) (RFA, 2007). This was the 2nd highest consumption rate (in terms of total tons consumed), following consumption by the dairy industry.

While there have been numerous nutritional investigations that have explored the impact of alternative DG inclusion rates within beef feedlot rations (including a limited number of economic analyses), a comprehensive approach is needed that encompasses the range of important results identified within this body of literature. This improved understanding will better equip producers in determining the appropriate degree of economic substitutability between traditional feed ingredients and DG in their feedlot rations.

The remainder of this article is organized as follows. First a general overview of the literature pertaining to this topic will be presented, followed by the identification of gaps in the research. Then, the objectives of the research presented within this article will be outlined, followed by the conceptual framework, methodology and data, and finally, the research results and conclusions.

Literature Review
There is a vast amount of literature available regarding DG inclusion into beef feedlot diets, as well as livestock and poultry diets in general. There are two main types of distiller's grains fed and studied within the feedlot industry: wet distiller's grains with solubles (WDGS), which generally consists of approximately 30% dry matter (DM); and dry distiller's grains with solubles (DDGS), consisting of about 90% DM. While there have been studies which evaluate other types of DG, such as modified wet (50% DM) and distiller's grains without solubles, the primary focus has been on WDGS and DDGS, and so will remain the focus of our analysis.

Nutritional Content of Distiller's Grains
The nutrient density of distiller's grain with solubles (DGS), a category that includes both wet and dry, is generally three times the composition of the grain source used within the ethanol production process. Distiller grain nutrient composition values found within the literature are typically cited from a National Research Council (NRC) Nutrient Requirement publication. However, given that many ethanol processing technologies have changed since many of these values were collected, there have been efforts by researchers to obtain updated nutrient content data (Belyea, Raush, and Tumbleson, 2004; Spiehs et al., 2002; and University of Minnesota, 2006). These studies find that calcium contents may be much lower than those reported by increasingly dated NRC publications, suggesting a DGS calcium composition of approximately 0.06% of DM (Spiehs et al., 2002; University of Minnesoty, 2006) while NRC reports suggest 0.22% DM (*Nutrient Requirements of Beef Cattle*, 1996; *Nutrient Requirements of Dairy Cattle*, 2001).

Low calcium (Ca) content, in combination with high phosphorus (P) content, have led many animal nutritionist to caution producers regarding the importance of monitoring their Ca:P ratios in order to avoid urinary calculi (water belly). Tjardes and Wright (2002) recommend that the Ca:P ratio be greater than 1.2:1. Additionally, the high sulfur content causes alarm when fed in excess of 0.40% DM as poliocenphalomalacia may result, which can lead to death (Sexten, 2006; Tjardes and Wright, 2002). This concern is particularly true in areas where there are high levels of sulfur within the water.

The Impact of Incorporating DGS on Animal Performance
In an effort to gain perspective regarding the numerous studies that have evaluated the affect of distiller grain inclusion[1] on animal performance, Dr. Steven Rust, beef nutritionist at Michigan State University, collected data from 17 yearling feeding trials conducted since 1990[2] with WDGS and DDGS treatments[3]. Only those studies for which a control, corn based diet with no distiller's grains, were included in the analysis.

Inferences regarding the impact of DGS inclusion on animal performance (average daily gain and dry matter intake) vary across trials. Figures A and B illustrate this variability by plotting feed to gain against DDGS and WDGS inclusion levels, respectively. We see that changing

DDGS inclusion has a rather ambiguous impact on feed to gain. For some DDGS trials a positive relationship is found and for others either a negative relationship or no relationship is suggested. In contrast, figure B suggests a general downward trend between feed to gain and WDGS inclusion, indicating that on average there is a gain in feed efficiency resulting from higher WDGS inclusion levels. Collectively, the impact of DDGS and WDGS on feed to gain is varied. This further documents the need and value of the meta-analysis underlying this project. That is, reliance on a sole trial may lead to unrepresentative results. Also note that very few trials examined both WDGS and DDGS, which would allow for direct comparison under a controlled experiment environment.

The next question that has been raised is how the inclusion of distiller's grains impacts carcass quality. A small subset of the trials in our meta-analysis report measures of carcass quality, more specifically they report marbling scores (figure C). As with the feed to gain discussion above, carcass quality impacts are not as conclusive as one might desire.

Determining DGS Dietary Inclusion Levels
Given the potential of distiller's grains to serve as a lower cost feed source, extension literature has published a great deal of information regarding maximum DGS inclusion recommendations, as well as general guidance with regard to this feed ingredient. While the exact recommendation rate varies slightly throughout the literature, a commonly reported limit for inclusion within feedlot diets is between 30% and 40% (Benson et al., 2005; Buckner et al., 2007; Tjardes and Wright, 2002; and Vander Pol et al., 2006b).

Additionally, there are a variety of economic considerations that have been addressed within the literature as being relevant when determining appropriate distiller grain inclusion levels. In addition to the price of the grain and competing feeds; reliable supply, storage, transportation, and waste management factors must also be taken into account (Loy et al., 2005). Research also suggests that the higher moisture content in WDGS make transportation, handling, and storage of this feed on a dry matter basis more costly (Loy et al., 2005 and Vander Pol et al., 2006a). Additionally, the high phosphorous content in DGS directly affects the nutrient density of the manure (Meyer et al., 2006 and Benson et al., 2005). This alteration in nutrient density impacts manure disposal costs (Hadrich, 2007).

In order to incorporate some economic considerations into DGS inclusion recommendations, Vander Pol et al. (2006a) conducted an economic analysis of feeding WDGS in feedlots using animal performance information, feed prices, transportation costs, and yardage costs at five dietary inclusion levels. Using eleven published research trials, the authors formulated an energy function where energy value relative to corn (*y*) was a function of the % of WDGS (*x*) included within the diet ($y = -0.84x + 164.2; R^2 = 0.28$). They then used their own research trial to formulate a quadratic average daily gain response equation ($a = 3.66 + 0.04x - 0.0007x^2; R^2 = .0.98$), where a= predicted average daily gain (Vander Pol et al., 2006b)[4]. Utilizing each of these estimated functions, the economically optimal WDGS inclusion rate was calculated for feedlot operations located 0, 30, 60, and 100 miles from the ethanol facility under three different corn price scenarios. The authors conclude that 40% WDGS diets can economically be fed for operations located up to 100 miles from the plant.

Research Gaps
There are several areas in which our understanding of optimal DGS inclusion into beef feedlot rations can be enhanced. First, the commonly stated recommendation rate of 30%-40% as a maximum inclusion recommendation (which is based largely off of nutritional research alone) does not take many important economic factors into consideration. Consequently, while break-even analysis that is based off of this 40% inclusion level (or any other inclusion level) may provide producers with decision rules regarding the break-even price of distiller's given a particular inclusion level, it does not provide any information regarding the appropriate inclusion given a set of feed prices, taking both animal response as a function of inclusion and increases in manure disposal costs into account.

Secondly, most existing economic studies on optimal inclusion rates that incorporate animal response functions (e.g., feed to gain, dry matter intake) focus on a single or small sample of research trials. As previously noted, corresponding plots of trials in our meta-analysis (figures A and B) reveal a great deal of variability regarding the degree or even general direction of impact. As such, research is needed to account for this uncertainty that currently faces livestock producers. Additionally, traditional methods for estimating these animal response functions have not treated them as a system, where unobservable (or non-recorded) factors which may vary within a trial are likely to influence both *ADG* and DMI are taken into account.

Thirdly, a wide range of price relationships between corn and distiller's, as well as between distiller grain types (WDGS vs. DDGS), has not been fully examined. Most existing research was conducted using a narrow range of examined prices. The new input price environment presents a need for examination of a wider set of price scenarios. Furthermore, most studies have focused on either wet or dry inclusion. Such an approach does not allow for the trade-off between wet and dry at various transportation distances to be analyzed.

Finally, while nutrient management cost concerns have been addressed throughout the literature, these costs have not yet, to the best of our knowledge, been incorporated into an economic study designed to identify the optimal inclusion of DGS into beef feedlot rations. Collectively, these identified research needs have shaped the objectives of this project.

Objectives
The purpose of this study is to develop a model in which the economically optimal inclusion rate of distiller's grains (WDGS and DDGS) in beef feedlot rations can be identified in the most appropriate and comprehensive manner currently feasible. This analysis will incorporate standard ration formulation factors such as relative feed ingredient prices, nutritional requirements, and mean nutrient composition values. In addition, an array of often omitted factors will be incorporated including estimated animal response functions and manure disposal costs. The sensitivity of baseline results will be examined, including assessments of changes in relative prices, transportation scenarios, nutrient composition (e.g., sulfur), estimated animal response function parameters, and the exclusion of the manure disposal cost component.

Conceptual Framework
Historically, ration formulation models have been built around the notion of cost minimization given a target performance level. However, this approach does not allow the target level to

become a choice variable and the profit maximizing combination of inputs to be reached. One of the basic economic assumptions underlying many behavioral models states that producers are profit maximizing agents. While it may be true that other factors influence their decisions, we will initially assume that profits are the sole measure of utility. Therefore, analyzing how the incorporation of an additional feed ingredient (DGS) impacts profit maximizing decisions is the first step in identifying the economically optimal rate of DGS inclusion into beef feedlot rations.

In its most simplified form, profit (Π) equals total revenue (R) minus total costs. Feed ration decisions not only affect feed costs, but are also related to other cost and revenue components. Profit can be specified as

$$(1)\,\Pi = R - FC - VC - MDC - C_{fs} - \overline{K}\,,$$

where feed costs (FC), other variable costs (VC), manure disposal costs (MDC), the cost of the feeder steer (C_{fs}), and fixed costs (K) collectively comprise total costs[5].

Revenue
The revenue component of equation (1) can be re-specified as

$$(2)\,R = P_y Y\,,$$

where P_y denotes the price of output and *Y* denotes the quantity of output (finished weight in this case). Typically, in the feedlot industry the output price is based off of a measure of carcass quality (*Q*). While there can be many factors that affect this quality, it has been indicated through various research trials that quality may be affected by the inclusion level of DGS in the diet (X_{DGS}). As such, we specify price to be a function of diet composition: $P_y = a(Q) = a(b(X_{DGS}))$.

For all technical purposes, finished weight is a choice variable, as the weight of the animal is easily measurable and observable, and the producer has a choice regarding sell weight. However, the number of days on feed (*DOF*) required for the animal to reach final weight (*Y*) depends on the animal's starting weight (*SW*) and average daily gain (*ADG*). This can be more succinctly expressed as

$$(3a)\,Y = SW + (ADG * DOF)\ \text{ or }\ (3b)\,DOF = (Y - SW)/ADG\,.$$

ADG, as previously mentioned, has been found to be affected by the level of DGS included in the diet. Therefore, we allow ADG in equations (3a) and (3b) to be identified as $ADG = f(X_{DGS})$.While it is acknowledged that there are many other environmental and dietary factors that may impact ADG, how the level of DGS inclusion in the diet impacts ADG is of primary concern. It is assumed that DGS inclusion does not impact these other factors, and therefore, all other factors can be held constant.

Feed Costs
The feed cost component of equation (1) can be further decomposed. Feed costs are a summation of the percent of each feed ingredient in the ration (X_i) multiplied by the cost of each feed ingredient (V_i), the estimated quantity of feed (in terms of dry matter consumed per day (*DMI*)), and by the number of days on feed (*DOF*). Included in the cost of each feed (V_i) is the price of the feed, the cost of transporting the feed ingredient from its source to the feed bunk, as well as any additional handling costs associated with that feed. This allows feed costs to be defined by

$$(4)\ FC = [\sum (X_i V_i)] * DMI * DOF]$$

As with *ADG*, *DMI* can be estimated as a function of distiller grain inclusion, holding all other factors constant. This allows *DMI* in equation (4) to be identified as $DMI = f(X_{DGS})$.

Additionally, this feed cost equation is subject to a variety of nutritional constraints which ensure that the animal's nutritional requirements/limits are met:

$$(5)\ \sum_{i=1}^{n} A_{ji} X_i \geq (\leq, =) K_j$$

where; $j = 1,....,m$; $i = 1,....,n$, ; A_{ji} is the amount of nutrient *j* in feed *i*, and K_j is the amount of nutrient *j* required or limited within the diet. While a complete list of nutritional requirements and constraints may be quite extensive, these requirements can be limited to only those for which the decision of whether or not to include DGS into feedlot rations may be affected or found to be typically constraining.

It is likely that many of these feed costs will be a function of firm size. A larger firm may face lower transportation costs on a per unit basis than a smaller firm, which may need to organize with other small producers in order justify weekly transport of the feed. Additionally, the larger firm is more likely to have the capital needed for any additional storage required for the distiller's grains. The larger firm may also have greater access to the feed via more viable contracting options, and thereby, they may also face lower feed prices than the smaller firm.

Other Variable Costs
The other variable costs (*VC*) component of profit (equation 1) includes yardage costs (*YC*) and daily interest charges (*I*) incurred from any operational loans the producer may have. We utilize a common approach in estimating a feedlot's typical operational loan, which is to use the sum of the cost of the feeder steer and half of the anticipated feed costs. This leads other variable costs to be identified as

$$(6)\ VC = (YC + I) * DOF = [YC + i * (C_{fs} + 0.5 * FC)] * DOF,$$

where i = the daily interest rate and the other variables are as previously specified.

Other costs, typically considered variable costs within the industry (e.g. health costs) are assumed to be fixed. They are fixed in the sense that they are assumed to be not affected by the inclusion of distiller's grains into the ration and are therefore not included within out cost calculations.

Manure Disposal Costs
Manure disposal costs (*MDC*) are a function of not only the total quantity of manure (*TM*) and its nutrient density (in terms of total grams of phosphorus (*Pe*) and nitrogen (*Ne*) excreted per gallon of manure), but other factors (*Z*) as well. These other factors may include the crops available for manure application, the nutrient requirements of these crops, the nutrient content of the soil, the location of the available field, the equipment and manure management system utilized (e.g. liquid or solid), the regulatory guidelines for manure management (which may effect larger firms, those greater than 1,000 head, differently than smaller operations), as well as the facilities and manure storage capacity of the operation.
In order to account for the value of the nutrients within the manure as a source of crop nutrients, the cost of commercial fertilizer (*CF*) per pound of nutrient required by the crop must be subtracted from the cost of manure disposal in order to adequately reflect the cost/value of the manure. Collectively, this allows for the following calculation of manure disposal costs:

$$(7)\ MDC = e(TM, P_e, N_e, Z) - CF^{\,6}$$

The total quantity and nutrient density of the manure is directly affected by the nutrient content of the diet, the number of animals, and the number of days on feed. This is where the amount of DGS included in the diet affects manure disposal costs. Given that DGS are high in both protein and phosphorus and its inclusion into the diet impacts ADG and thus DOF, DGS inclusion directly affects both the quantity and nutrient density of the manure excreted.

Methods and Data
One common approach to ration formulation modeling is the use of linear programming to minimize feed costs given a certain set of available feedstuffs and output level. This approach has been used continually since it was first introduced by Waugh in 1951. However, due to the non-linearity of the problem presented above, a non-linear mathematical optimization model was developed. Our optimization model directly incorporates the above relationships. This section will describe the direct implementation of the conceptual framework along with the base case assumptions used within our optimization model.

Animal Response Function Estimation
After diagnostic analysis of the meta-analysis data, which revealed significant leverage within individual trials, all observations where DGS inclusion was greater than 50% were eliminated. The animal response functions (*ADG* and *DMI*) were estimated using the meta-analysis data from the feeding trials collected by Dr. Steven Rust. A function for marbling was also estimated from the dataset; however, none of the variables were found to be statistically significant[7]. Seemingly unrelated regression procedures were used to account for any correlation in the error terms across the *ADG* and *DMI* equations. Using a systems approach has not to the best of our knowledge ever been applied to animal response function estimations; however, unobservable (or non-recorded) factors which may vary within a trial are likely to influence both *ADG* and

DMI. Therefore, *SURE* regression was deemed appropriate. Furthermore, theoretically consistent recovery of feed to gain estimates (via. adding up restrictions) are easily obtainable from a system of estimated equations.

Regression results are shown in equations 2a and 2b below, where X_{DDGS} is the % DDGS in the diet and X_{WDGS} is the WDGS inclusion level. P-values are reported in parentheses below each equation. Regressions incorporated trial dummy variables (not shown) in order to account for any differences across trials. Given that no a priori reason suggests selecting a particular trial dummy variable to represent the intercept term, the average *ADG* and DMI from all control treatments within the regressed data set was used. This is why there is no p-value shown for the constant. Additionally, both WDGS and DDGS were included within the same equation. However, it is important to note that this does not mean that both WDGS and DDGS were included within the same treatment, nor that we can say anything about animal response in the case of both DGS types included in a yearling diet.

$$(2a)\ ADG = 3.724 + 0.0176 * X_{DDGS} - 0.0003 * X^2_{DDGS} + 0.0312 * X_{WDGS} - 0.0006 * X^2_{WDGS}$$
$$R^2=0.9182 \qquad (0.0130) \qquad (0.0560) \qquad (0.0000) \qquad (0.0000)$$

$$(2b)\ DMI = 22.59 + 0.0627 * X_{DDGS} - 0.0012 * X^2_{DDGS} + 0.0860 * X_{WDGS} - 0.0026 * X^2_{WDGS}$$
$$R^2=0.9302 \qquad (0.0430) \qquad (0.1180) \qquad (0.0030) \qquad (0.0000)$$

The above estimations indicate a quadratic relationship between DGS and both ADG and DMI; however, notice that the squared term on DDGS inclusion is only significant at the 12% level. These equations suggest that WDGS inclusion has a negative impact on feed to gain (increases feed efficiency), while DDGS inclusion has very little impact on feed to gain. The derived relationship between DGS and feed to gain is shown in figure D. The feed to gain relationships derived from these equations were then compared with those regressed directly from the data set. Figure D illustrates a story which is consistent with the trial plots, where increasing WDGS is found to have a negative impact on feed to gain and DDGS is found to have little to no affect.

Given the variability in parameter estimates across various feeding trials, and to assess sensitivity to animal response function estimates, the model was also evaluated using alternative parameter estimates. Alternative parameter estimates were obtained using a Krinsky-Robb bootstrapping approach. More specifically, by utilizing the estimated parameter vector and covariance matrix, 1,000 animal response function estimates were generated from 1,000 randomly drawn parameter vectors. The resulting series of 1,000 animal response function estimates were then sorted from "best" to "worst." More specifically, the set of *ADG* and *DMI* function estimates were sorted in descending and ascending order, respectively as producers are "better off" with higher *ADG* and lower *DMI* impacts of increased DGS inclusion. The sorted series of estimates is then utilized to identify sensitivity of model results to animal response function estimates. In particular, the model is evaluated under alternative scenarios ranging from a "best" case scenario (where a producer is likely to experience the estimated function or better only 5% of the time and 95% of the time is likely to experience worse than the estimated function) to a "worst case" scenario

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(where a producer is likely to experience the estimated function or worse only 5% of the time and 95% of the time is likely to experience better than the estimated function).

These evaluations can also be considered parameterizations of the model for producers of alternative risk aversion levels. For instance, a feedlot operator who is overly risk averse may utilize the "worst case" scenario in making decisions where a purely risk neutral producer may ignore these scenarios and rely solely on models utilizing SURE point estimated functions.

Manure Disposal Costs
There are many assumptions that drive this component of the model as the type, condition, and distance of the available crop acres undoubtedly is different for each individual operation, as well as the specifics of the equipment and system utilized. The main approach used to determine the manure disposal costs followed that presented by Hadrich (2007), while the excretion functions employed were found within the American Society of Agricultural Engineer's publication on "Manure Production and Characteristics" (2005). Hadrich (2007), Harrigan (1997), and the *Manure Distribution Cost Analyzer* developed by Dr. Raymond Massey of the University of Missouri (1998) calculate manure disposal costs based on the amount of time required to load, haul, unload, and incorporate the manure onto available crop acres.

The amount of manure that can be applied to a particular acre of land depends on the agronomic nutrient removal rates of the crop grown on those acres as well as regulatory guidelines for manure application. The "Right to Farm" law, adapted by many states, dictates that manure can be applied using the nitrogen removal rate if the soils contain less than 150 lbs of phosphorus (P) per acre (ac), the phosphorus removal rate if the soil contains between 150 and 300 lbs of P/ac, and that it may not be applied if the soils exceed 300 lbs of P/ac (Hadrich, 2007).   Crop removal rates (lbs/acre) as identified by Warncke et al. (2004) are used along with crop acre and potential yield information in order to obtain an estimate of the quantity of nitrogen and phosphorus removed by a given field at a given distance from the feedlot.

Hypothetical Manure Disposal Scenario
For purposes of this paper, which aims to illustrate the affect of including manure disposal costs into a ration formulation model, the liquid system and the equipment employed within the Hadrich (2007) thesis was utilized, along with the author's estimated crop yields, loading, unloading, traveling speed, and incorporation time assumptions. Available type, condition, and distance of crop acres were obtained from a sample feedlot. We are assuming a liquid manure management system with a 6,000 gallon tank applying to corn (75%), soybean (10%), and corn silage (15%) acres. Within our base case farm, 500 acres of land (within the above proportions) is available every mile. However, the percent of these acres in which the operator must apply at the nitrogen removal rate, the phosphorus removal rate, or which exceed soil phosphorus limits and are unavailable for manure disposal, changes as hauling distance increases. Within our hypothetical model, as the operator is forced to travel further away from the feedlot, the percentage of total acres in which manure can be applied shifts from the no application rate category where the total lbs of P/ac exceed 300 to the nitrogen removal rate category where total lbs of P/ac is less than 150.

The final assumption needed in order to employ the Hadrich (2007) approach was to identify the size of our base case operation in order to calculate the total volume of manure in which to dispose. In our base case, an operation running 1,000 head of cattle was used. However, it is important to note that within many states additional requirements are placed on operations of 1,000 head or more, and these implications on optimal DGS inclusion are not explored within the scope of this article.

Prices and Feed Ingredients
All base case feed ingredient prices are listed in table 2 (base case model results). The listed corn price is the average price for corn (2/9/06-3/16/07, Chicago, IL) as reported on a weekly basis by the Livestock Marketing Information Center (LMIC). Both DDGS and WDGS were then priced using the average DGS to corn price ratio[8] (2/7/06-3/13/07, Springfield, IL), as reported on a weekly basis by the LMIC. Corn silage was priced using the following formula: 7*Price of corn + 7 {Black, 2007}. Hay and Soybean meal were priced using the monthly average price as reported within the Feed Grains Database (Jan 06-Mar 07) (ERS). Limestone was priced by a local feed dealer and personal communication with experts familiar with the industry. Urea was priced at its weekly average (2/6/06-3/19/07, Minneapolis, MN) as reported on a weekly basis by *Feedstuffs Magazine*.

Additional Assumptions and Base Case Parameters
The average starting weight of 778lbs from the feeding trial data (after observations where DGS inclusion was greater than or equal to 50%) was used as the starting weight within our model, and the average finished weight was used as our target weight (1,250 lbs). Using our model starting weight, the average reported price of a medium and large 2 framed feeder steer based out of Springfield, IL on May 11, 2007 was used to calculate the purchase price of the feeder steer ($93.49/cwt) (AMS). 8% was the yearly interest rate used, $0.33/day was the yardage cost, and $100/cwt was the base output price. We began with a transportation distance of zero; however when we added transport into our model, a quoted cost of $2.50 per loaded mile (1 load = 25 tons) was incorporated (Vander Pol et al., 2006a). [9]

Nutrient and Feed Ingredient Constraints
The nutritional constraints imposed in the model, as identified and defined by beef nutrition specialist, Dr. Steven Rust, are listed in table 1. However, there is one conditional constraint within the model that is not shown in table 1. Due to the low quality of protein in DGS, urea is forced in at 0.3% when WDGS inclusion is less than 20% after which point the assumption is made that the quantity makes up for the poor quality. However, in the DDGS model the problem is not only the quality of the protein, but also the availability of the protein; therefore, urea is forced into the model at 0.3% at every inclusion level as a safeguard.

Nutrient composition values for all feed ingredients except for DGS were as reported by the National Research Council (NRC) *Nutrient Requirements of Beef Cattle* publication (1996). As research has indicated that the nutrient composition of DGS has changed since the NRC report values were collected, average values from the 34 U.S. ethanol plants collected by the University of Minnesota (2006) were used.

Results
Model results under base case assumptions are presented within table 2. Optimal DDGS
inclusion under these base case assumptions and prices is 22%, while optimal WDGS inclusion
is 39%. To contrast this with common feed recommendations in the range of 30-40% we see that
WDGS is indeed within this range; however, feeding within this range may not be an optimal
DDGS inclusion when economic factors and animal response functions are taken into
consideration.

Sensitivity to Various Price and Transport Scenarios
Under the base case assumptions both DDGS and WDGS were priced at their average weekly
price ratio to corn of 1.0 and 0.92, respectively (LMIC). Additionally, transport distance was
held at zero. Figures E and F illustrate DDGS and WDGS model results under various
DGS/corn price ratio and transport scenarios. As expected, increasing transport distance has a
much greater impact on optimal WDGS inclusion than on optimal DDGS inclusion. For every
additional 50 miles of necessary transport, WDGS inclusion drops about 5%, whereas for DDGS
the drop is about 3%. At the average WDGS/corn price ratio (0.92), 30-40% can be
economically fed up to 50 miles, between 15% and 30% for the next 100 miles (50-150 miles),
and 0% to 15% at transport distances greater than 150 miles.

Given that transport distance has a much greater impact on optimal WDGS inclusion than DDGS
inclusion, a reasonable question to ask is when does it become economical to switch from
WDGS to the less feed efficient DDGS? When comparing the optimized profit between these
two models at their average DGS/corn price ratios across a transportation distance range of 0-250
miles, optimized profit in the DDGS model begins to exceed that of using WDGS after 250
miles; although, profits were very close at 200 miles. Recall, that the base case assumption was
that transport costs were $2.50/loaded mile. If we increase this cost, as is plausible under the
reality of the rising fuel costs of today's economy, to $3.50/loaded mile this trade-off begins to
occur at about 175 miles.

Results, so far, have been presented holding corn prices at $2.73/bu. However, it is well known
that increased ethanol production has driven up corn prices leading to current corn prices
significantly higher than $2.73/bu. According to our data source, the maximum weekly average
corn price peaked at $4.18/bu in February 2007. To examine sensitivity to higher corn prices,
the model was re-examined with corn at $4.18/bu. Optimal DDGS inclusion does not increase
significantly with a maintained DDGS/corn price ratio of 1.0. However, as this ratio decreases
and DDGS become less expensive relative to corn, the optimal inclusion rate begins to increase
relative to our base case model, with the largest differential being a 5% increase at a DDGS/corn
price ratio of 0.70, after which point the sulfur constraint becomes binding. In other words, if the
DDGS/corn price ratio remains the same (1.0) with an increase to $4.18/bu corn, the optimal
inclusion of DDGS remains at about 22% (as was the case with $2.73/bu corn). However, if
DDGS become less expensive and the DDGS/corn price ratio drops to 0.70, then the optimal
DDGS inclusion which was 44% under $2.73/bu corn increases to 49%. Within the WDGS
model, this higher corn price causes the optimal inclusion rate to increase by 5% over the
$2.73/bu corn price scenario at the average WDGS/Corn price ratio of 0.92. This 5% differential
remains as we decrease the WDGS/Corn price ratio until optimal inclusion reaches its sulfur
constrained optimum of just under 50%. [10]

Sensitivity to the Level of Sulfur Accepted in the Feed Ration
As sulfur becomes more of a concern, particularly in areas with high levels of sulfur within the water, the risk of exceeding the daily sulfur constraint of 0.40% DM is heightened. On average, optimal DDGS and WDGS inclusion rates at the average DGS/Corn price ratios and below decreases by about 10% each time the sulfur constraint is tightened from 0.40% to 0.35% to 0.30%. Above this price ratio the optimal DGS inclusion does not change significantly.

Sensitivity to SURE Estimated Animal Response Function Parameters
Given the large degree of variability in degree and direction of impact DGS inclusion has on both ADG and DMI between trials, we thought it was important to explore what would be an optimal DGS inclusion rate under various levels of risk aversion. For instance, if our SURE estimates are what is expected to happen on average, what would optimal inclusion be if we were not quite so optimistic with regards to our animal response function parameters? What would happen if we are underestimating them?

Table 3 presents the estimated coefficients used in the baseline model (SURE point estimates), along with alternative parameter estimates identified using Krinsky-Robb bootstrapping procedures. Here the "best case" implies a scenario where the producer is likely to experience the estimated animal response (or better) 5% of the time or more, and 95% of the time is likely to experience the estimated parameter (or worse). The "worst case" scenario then implies the parameter estimate the producer is likely to experience (or worse) 5% of the time, and experience (or better) 95% of the time.

Model results under alternative animal response functions are presented in table 4. In the "best case," optimal DDGS inclusion rate increases from 27% to 49%, and in the "worst case" it decreases about 21%, reaching basically 0% inclusion. In the WDGS model, optimal inclusion increases from 39% to 49% under the "best case" scenario, where the sulfur constraint becomes binding. In the "worst case" scenario WDGS inclusion drops to 7%. Intermediate scenarios (e.g., 25% and 75% likelihood cases) are also presented and reveal corresponding intermediate adjustments in optimal DGS inclusions. This sensitivity exercise illustrates the importance of taking animal response functions and associated variability into consideration when identifying optimal DGS inclusion rates.

Sensitivity to Manure Disposal Cost Component
In order to illustrate the impact of including vs. excluding manure disposal costs into ration formulation considerations the base case model (with manure disposal costs incorporated) was compared with the case where manure disposal costs are not included (i.e. MDC=0). Results indicate that when the DGS to corn price ratio is greater than 0.7, optimal DDGS inclusion increases by about 4% when the model goes from the base case to the no manure disposal cost scenario, and optimal WDGS inclusion increases about 2%.[11]

Conclusions
The developed mathematical optimization model serves as a useful tool for analyzing optimal DGS inclusion under a wide range of plausible scenarios, and while we have not even begun to fully exhaust the full range of plausible scenarios, we have presented model results under a

variety of circumstances. The variation in model results across scenarios indicates the importance of taking all economic and animal response function parameters into consideration when identifying optimal DGS inclusion rates.

Keeping this fact in mind, some general conclusions can be drawn regarding optimal DGS inclusion under our base case assumptions. Optimal DDGS inclusion goes from 35-10% as the DDGS/Corn price ratio increases from of 0.8 to 1.2 (approximate historical low and high ratios), and drops about 3% for every additional 50 miles of transport. On the other hand, optimal WDGS inclusion goes from 48-35% as the WDGS/Corn price ratio increases from 0.7 to 1.0 (approximate historical low and high ratios), and drops about 5% every 50 miles. As far as the trade-off between the two distiller grain types is concerned, the cost of transport is a large determining factor; however, even at a transport cost of $3.5/loaded mile, WDGS is still more profitable than DDGS up to 150 miles from the plant.

In addition to the implication of the model results, several key contributions to the economic ration formulation literature have been highlighted. First, our model has expanded beyond the cost minimization world and has organized the problem in a profit maximization framework, making animal response and certain costs a function of ration decisions. Second, estimating ADG and DMI in a systems framework is a novel approach which takes into account correlations in the error term between the two functions. Third, using common bootstrapping methods to evaluate model results under various levels of producer risk aversion is an extension of its traditional use.

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[1] Inclusion throughout this article refers to inclusion within a beef feedlot ration.

[2] Only trials conducted since 1990 were used as to avoid any possible effect older technologies may have had on the results.

[3] A list of these 17 feeding trials plus the data is available upon request.

[4] All variables within these reported equations are assumed to be significant; although, not directly stated within the referenced Vander Pol et al. (2006a) article.

[5] The impact of incorporating DGS into feeder cattle diets on operational fixed costs is not explored within the context of this paper. It is assumed that these costs are unaffected in the short run by a producer's decision to include DGS, and that the operation has the physical capacity/facilities for any DGS inclusion level considered.

[6] The cost of commercial fertilizer is valued at zero within our base case model as an illustration of a case where the manure is not deemed to have economic value. Sensitivity analysis regarding the with and without manure disposal cost incorporation then serves as bounds for the hypothetical farm presented, where any positive commercial fertilizer value increases the optimal DGS inclusion level.

[7] Future sensitivity analysis will include marbling as a function of DGS inclusion using the regression results of a feeding trial where DGS were found to significantly impact marbling.

[8] DGS and corn price ratios were compared on a $/lb DM basis.

[9] While additional handling costs may be incurred with WDGS inclusion, this cost has not been added within our base case model. This cost will be implemented at a later time.

[10] Additional tables and graphs are available upon request

[11] These results are highly sensitive to the manure disposal scenario chosen. Future work will examine model sensitivity to these scenario assumptions.

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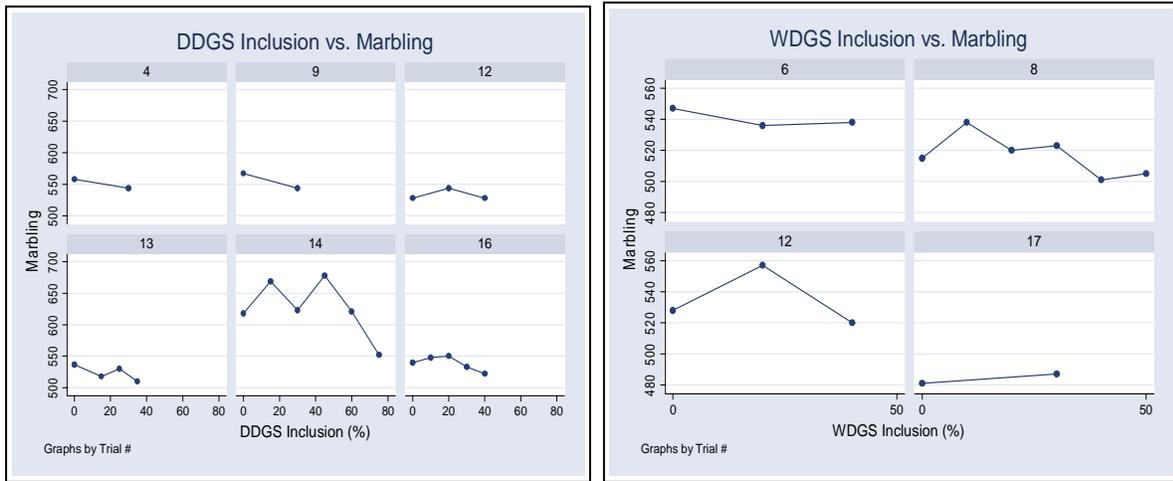
Appendix: Tables and Charts

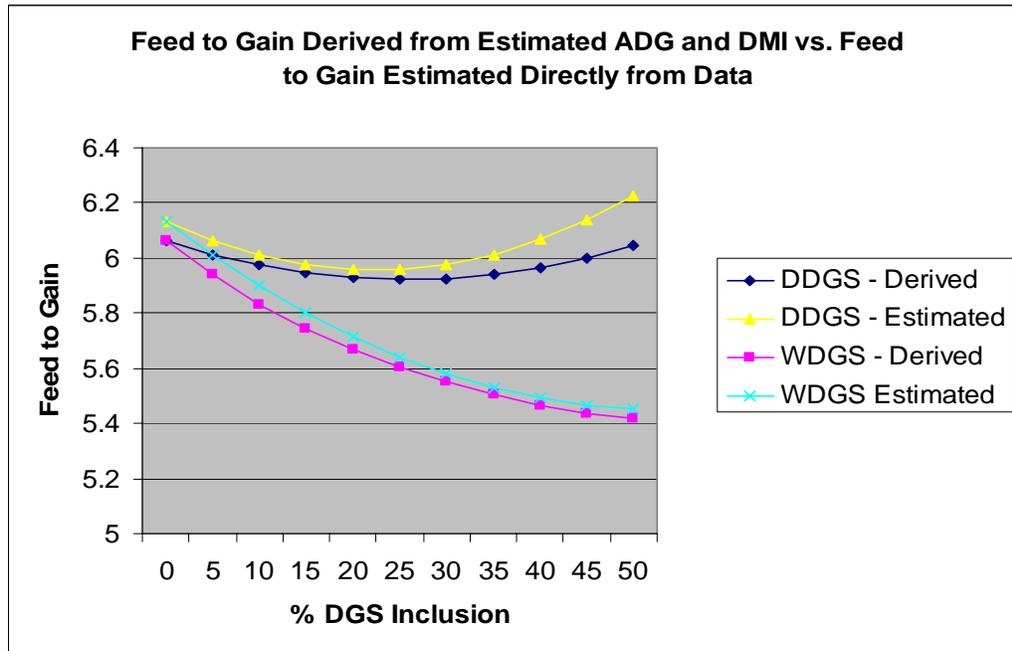**Figure A. Feed to Gain vs. DDGS Inclusion (%), by Feeding Trial**
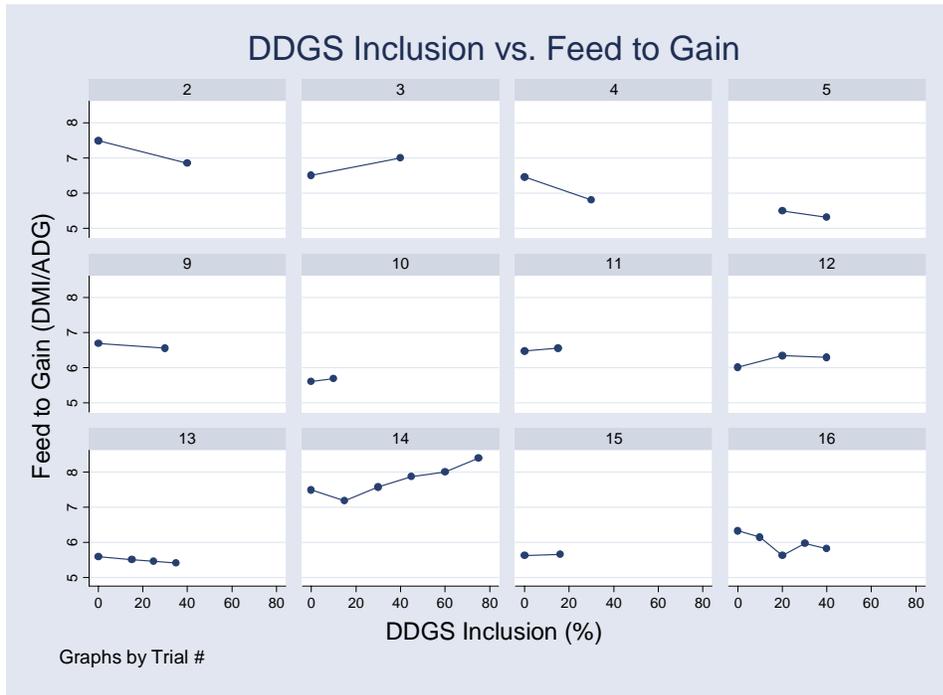
Figure B. Feed to Gain vs. WDGS Inclusion (%), by Feeding Trial
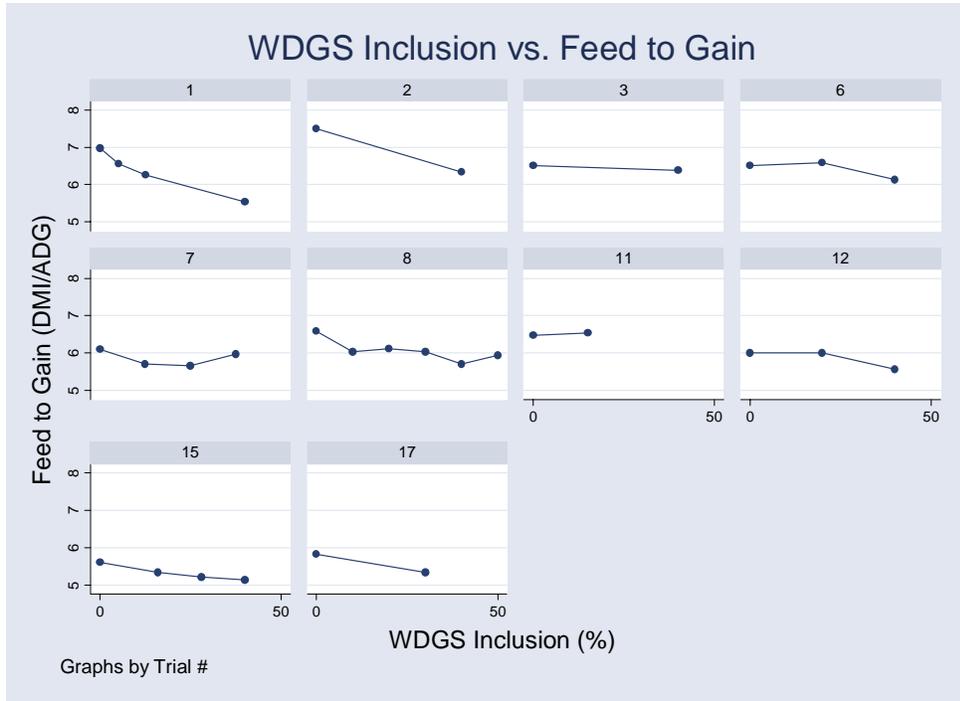
Figure C. Marbling vs. DGS Inclusion (%), by Feeding Trial and DGS Type
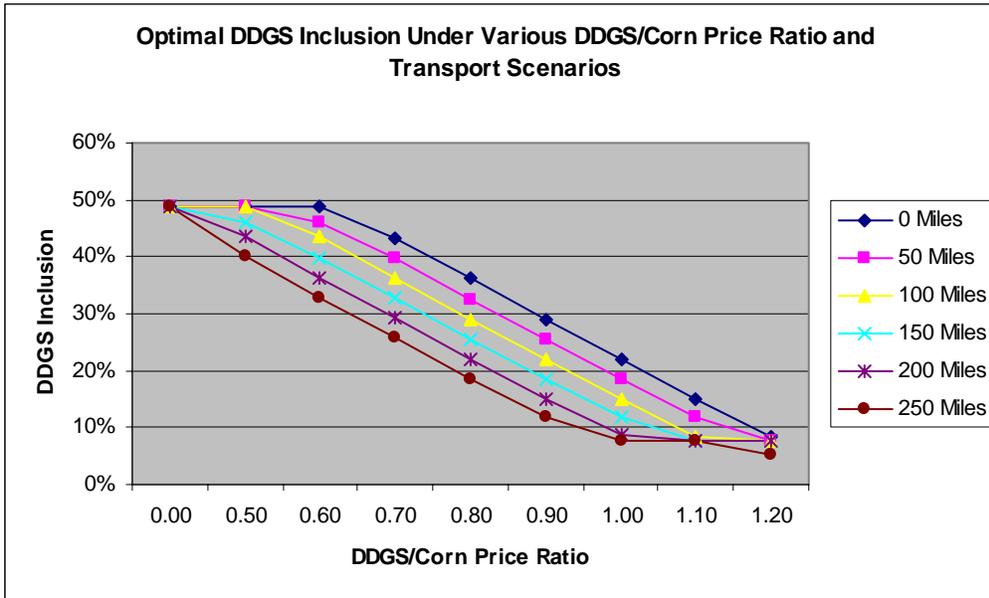

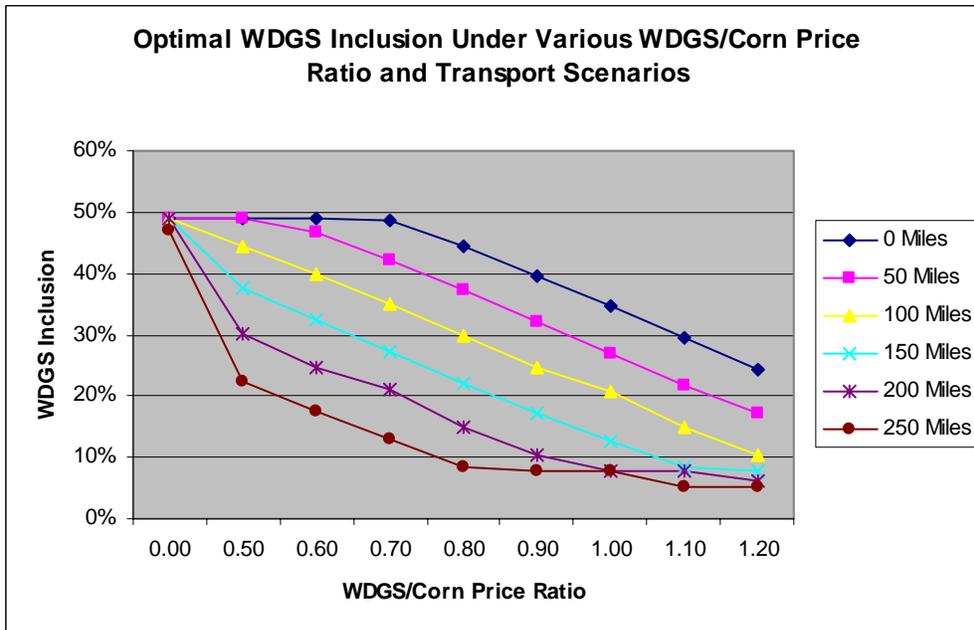**Figure D. Derived Feed to Gain vs. Estimated Feed to Gain Equations**

Note: Variables within the estimated DDGS equation were significant only at the 12% level.

Figure E. Optimal DDGS Inclusion under Various DDGS/Corn Price Ratio and Transport Scenarios

Figure F. Optimal WDGS Inclusion under Various WDGS/Corn Price Ratio and Transport Scenarios

Table 1. Nutrient and Feed Constraints

Constraints	Req./Limit (Kj)		Unit
Nutrient			
Calcium (Ca)	>=	0.30	% DM
Phosphorous (P)	>=	0.30	% DM
Ca:P	>=	1.1	Ratio
Effective Fiber	>=	8.00	% DM
Fat	<=	8.00	% DM
Sulfur	<=	0.40	% DM
Crude Protein	>=	12.00	% DM
Feed			
Urea	<=	0.50	% DM
DGS	<=	50	% DM
Silage + Hay	<=	15	% DM
Silage + Hay	>=	12	% DM

Table 2. Base Case Model Results

Base Case DDGS Model Results						
Feed Ingredient	**Price/Unit**		**Unit**	**%DM**[a]	**$/lb DM**	**% Inclusion in Diet**
DDGS	$	101.53	Ton	90%	0.056	21.8%
Corn,dry	$	2.78	Bu	88%	0.056	62.2%
Corn Silage	$	26.46	Ton	34.60%	0.038	15.0%
Soybean Meal	$	181.00	Ton	89.90%	0.101	0.0%
Hay	$	106.29	Ton	89.30%	0.060	0.0%
Urea	$	326.12	Ton	99%	0.165	0.3%
Limestone	$	200.00	Ton	100%	0.100	0.7%

Base Case WDGS Model Results						
Feed Ingredient	**Price/Unit**		**Unit**	**%DM**[a]	**$/lb DM**	**% Inclusion in Diet**
WDGS	$	31.14	Ton	30%	0.052	38.7%
Corn, dry	$	2.78	Bu	88%	0.056	45.6%
Corn Silage	$	26.46	Ton	34.60%	0.038	15.0%
Soybean Meal	$	181.00	Ton	89.90%	0.101	0.0%
Hay	$	106.29	Ton	89.30%	0.060	0.0%
Urea	$	326.12	Ton	99%	0.165	0.0%
Limestone	$	200.00	Ton	100%	0.100	0.7%

[a] Source: NRC (1996)

Table 3. Estimated Animal Response Function Coefficients: Comparison of SURE Point Estimates and Simulated Scenario Estimates of Animal Response Functions

ADG		DDGS	DDGS^2	WDGS	WDGS^2
SURE Point Estimates		0.01765	-0.00034	0.03118	-0.00060
"Best Case"	5%	0.02924	-0.00004	0.04190	-0.00035
	25%	0.01264	-0.00022	0.03602	-0.00051
	50%	0.01807	-0.00034	0.03170	-0.00062
	75%	0.01264	-0.00047	0.02694	-0.00072
"Worst Case"	95%	0.00515	-0.00064	0.02034	-0.00085
DMI		DDGS	DDGS^2	WDGS	WDGS^2
SURE Point Estimates		0.06271	-0.00122	0.08600	-0.00257
"Best Case"	5%	0.01286	-0.00245	0.04166	-0.00379
	25%	0.04197	-0.00178	0.06716	-0.00305
	50%	0.06331	-0.00126	0.08565	-0.00258
	75%	0.08528	-0.00066	0.10636	-0.00211
"Worst Case"	95%	0.11144	0.00007	0.13683	-0.00152

Table 4. Model Results: Comparison of SURE Point Estimates and Simulated Scenario Estimates of Animal Response Functions

DDGS Model Results: Comparison of SURE Point Estimates and Simulated Scenario Estimates of Animal Response Functions						
		Simulated "Best Case"				Simulated "Worst Case"
Feed Ingredient	SURE Point Estimates	5%	25%	50%	75%	95%
DDGS	21.8%	48.9%	48.9%	23.6%	7.6%	0.4%
Corn,dry	62.2%	35.1%	35.1%	60.4%	76.4%	81.2%
Corn Silage	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Soybean Meal	0.0%	0.0%	0.0%	0.0%	0.0%	2.3%
Hay	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Urea	0.3%	0.3%	0.3%	0.3%	0.3%	0.5%
Limestone	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
WDGS Model Results: Comparison of SURE Point Estimates and Simulated Scenario Estimates of Animal Response Functions						
		Simulated "Best Case"				Simulated "Worst Case"
Feed Ingredient	SURE Point Estimates	5%	25%	50%	75%	95%
WDGS	38.7%	48.8%	48.8%	38.1%	15.9%	7.2%
Corn,dry	45.6%	35.5%	35.5%	46.3%	68.1%	76.8%
Corn Silage	15.0%	15.0%	15.0%	15.0%	15.0%	15.0%
Soybean Meal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hay	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Urea	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%
Limestone	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%