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Dairy Farm Management Adjustments to Biofuels-Induced Changes in Agricultural Markets

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Abstract

A mathematical programming model of a representative New York dairy farm is developed to identify optimal management adjustments to increased availability of corn distillers dried grains with solubles (DDGS). While at current prices DDGS feeding is limited to dry cows and young stock, as prices decrease, DDGS in lactating cow rations increase from 7.4% to 20% on a dry matter basis. While expected changes in net farm returns are modest, more important is the consideration of changes in nutrient management practices necessary to deal with increasing levels of nitrogen and phosphorus in the animal waste.

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Introduction

Along with the steady growth in demand for farm commodities in China and India, due largely to population and income growth, the expansion of the U.S. biofuels industry has also contributed to the recent, rather abrupt structural changes in agricultural commodity markets. The increased demands for grains and oilseeds by producers of biofuels have put upward pressure on the level of commodity prices, and have resulted in increased price volatility. These changes, which have already been reflected in higher wholesale and retail prices for some food items, have substantially different implications for crop and livestock producers across the country.

In states such as New York, for example, higher grain prices may provide new opportunities to expand cash crop production. In contrast, the dramatic increase in commodity prices, particularly corn, between 2006 and 2007, translated into an estimated 18% increase in the costs of dairy feed in the Northeast (NASS). To mitigate the effects of these higher feed costs on production levels and profitability, many feed manufacturers and dairy producers alike will shift to lower-cost alternatives. Ration formulations may change dramatically depending on both the forecasted supplies (including potential increased supplies of bio-energy related feedstocks) and the expected relationships among the prices of major feed ingredients.¹ Dairy producers may make other management adjustments, including the use and proportion of alternative forages that is consistent with raising a larger portion of total dairy feed. The extent to which this is possible depends on the nature of a farmer's land resources. These management adjustments may also be

¹ In a recent study to examine the potential value of distillers dry grains (DDGS) in dairy feed, for example, Schmit, Verteramo, and Tomek (2008) estimate that each \$1 per ton increase in the price of corn translates into a \$0.59 per ton increase in the cost of dairy feed when evaluated at 2007 prices and under the assumption that historical price relationship between corn and DDGS continues. However, if this price relationship changes in the future due to increased supplies of DDGS from biofuel production, they estimate that the marginal effect of a \$1 increase in corn prices on dairy feed costs will fall to \$0.36 per ton.

in response to changes in the nutrient content of animal waste from increased use of some less expensive feed ingredients.

The purpose of this paper is to identify effective management adjustments to these recent structural changes in commodity markets. To accomplish this objective we: a) estimate the effects of increased feed prices and changes in the relative prices of important dairy feed components on whole-farm profitability; b) identify optimal adjustments for on-farm feed production, feed purchases, crop sales, and dairy rations that account explicitly for expanded availability of bio-energy related by-product feedstocks; and c) point out potential implications of these production management adjustments on whole-farm nutrient planning.

To estimate these effects, we develop a mathematical programming model of a representative dairy farm in New York. To account for recent structural changes in commodity markets, our initial analysis reflects the most recent relative price differences among major dairy feed ingredients. Because there is a great deal of uncertainty about the future supply of bio-energy related by-product feedstocks, such as DDGS, we map out an effective farm-level demand curve for these feedstocks by varying their prices relative to those for other major feed ingredients.

We extend this model through the inclusion of new components that link bio-energy feedstocks, feed prices, and nutrient loadings. These linkages are established through the use of the CPM-Dairy program to generate alternative dairy rations. This program, a joint effort of Cornell University, University of Pennsylvania Veterinary College and the Miner Institute, has biology similar to the Cornell Net Carbohydrate and Protein System (CNCPS) model (Fox, *et al.* 2004). Since there is some concern that the level of phosphorous in dairy waste may increase through the use of by-product feedstocks from bio-energy production, we also incorporate into

the model information about the nitrogen and phosphorous content of dairy waste that is generated as part of the output from the CPM-Dairy program.

We begin the remainder of this paper with a discussion of the analytical framework and empirical setting. A short description of the representative dairy farm is followed by a detailed discussion of the structure of the mathematical programming model. Throughout the discussion, we describe the sources of the data used to estimate the important coefficients in the empirical model, including the feed ration formulations and crop and livestock production costs and prices. We then go on to discuss the empirical results, summarize the implications for management, and offer some final observations on important issues for future research.

Analytical Framework and Empirical Setting

The application of mathematical programming methods to farm planning, including the formulation of minimum-cost animal feeds, dates back at least to 1950s (e.g. Heady and Candler 1958 and Waugh 1951). Early applications relied almost exclusively on linear programming methods, but since that time, advances in solution algorithms have facilitated the application of both non-linear and mixed-integer models to accommodate more realistic production relationships, such as diminishing marginal productivities of agricultural inputs, to relax the assumption of fixed input and output prices (e.g. McCarl and Spreen 1980), to accommodate management response to price and production risk (e.g. Boisvert and McCarl 1990), and to incorporate lumpy investment or management decisions (e.g. Barry 1971; Cabrini, *et al.* 2004; Wui 2004), including participation in farm programs (e.g. Perry, *et al.* 1989).

Programming methods have also been used extensively to evaluate new opportunities and challenges facing farm operators, including such things as new technologies, alternative cropping methods (e.g. Miranowski 1984), and policies and management alternatives related to the

interface between agricultural production and the environment (e.g. Casler and Jacobs 1975; Schmit and Knoblauch 1995; Teague, *et al.* 1995). Based on similar motivations, the programming model of a representative dairy farm in New York developed here is designed to examine the whole-farm adjustments that would allow farmers to take advantage of potentially lower-cost, increased supplies of DDGS as the biofuels industry continues to expand.²

The Representative Farm Setting

The representative farm setting on which the programming model is based is similar to that in Schmit and Knoblauch (1995). For this initial analysis, we assume that the farm is a 250-cow dairy farm, with characteristics similar to equivalently-sized dairy farms in central New York participating in Cornell's Dairy Farm Business Summary (e.g., Knoblauch 2003). The dairy cows are assumed to weigh about 1,400 pounds and milk production is assumed to be about 21,000 pounds, depending of the feed ration. The farm is assumed to have 620 acres of cropland; about 10% of the land is of high quality, another quarter of the land is of relatively low quality, while the remaining two-thirds is of an average quality for the region. Land quality is based primarily on the land capability class and potential corn silage yields on a dry-matter basis of 4.9, 5.3 and 5.9 tons per acre, for low, average and high quality land, respectively. The proportions of land in the three land classes are derived from survey data on cropland in farms used by Boisvert, *et al.* (1997).

Structure of the Programming Model

In the programming model, the farmer is assumed to maximize revenue over variable cost. A detailed description of the programming activities is included in appendix A, along with

²In a related analysis, Hardish, *et al.* (2008) formulate minimum-cost dairy rations that include DDGS, and compare the optimal levels of DDGS and other nutrients both with and without consideration of nutrient content of the manure and potential differences in manure disposal costs. They do not consider these decisions within a whole-farm context that allows for changes in crop production, etc.

an algebraic formulation of the 27 sets of constraints.³ As is evident in the discussion below, the structure of the model is designed to facilitate an investigation of the potential uses of DDGS in dairy feed under alternative assumptions about the relative prices between DDGS and other feed ingredients and the cost of grown feed.

To explore the potential use of DDGS in dairy feed, 10 separate dairy cow activities are included in the model. These activities are distinguished primarily by the composition of the dairy ration. In a number of them, the quantities of other feed ingredients are adjusted to accommodate the introduction of DDGS into the ration. As is seen in Table 1, the first five rations are based on a forage mix with a 2 to 1 ratio of corn silage to hay crop silage. One of these rations includes no DDGS; others differ by the percentage of DDGS (either 10 or 20 percent DDGS on a dry matter basis), and by the fat content of the DDGS (either 8 percent or 12 percent). The other five rations assume a forage mix with a 2 to 1 ratio of hay crop silage to corn silage. Again, one of these rations includes no DDGS; the others also differ in terms of the percentage of DDGS and by the fat content of the DDGS.⁴ Although the rations are limited to 10 and 20 percent of DDGS, the programming solutions can reflect a percentage of DDGS anywhere within these two extremes if more than one of these 10 dairy activities is in solution. In this case, the effective percentage of DDGS fed to lactating dairy cows is the average of that in the separate rations, weighted by the proportion of the herd fed by each ration appearing in the

³ The names of activities appear in both the objective function and the constraints just as they are defined. In many instances the notation that appears in front of the variable name is either an objective function coefficient associated with that activity or a technical input-output coefficient in a constraint. They are reasonably descriptive. Furthermore, we formulate all constraints so that a positive (negative) technical coefficient implies that the activity uses (produces) the resource or product associated with the constraint.

⁴ These rations are developed by Chase and are based on the CPM-Dairy program. This program is a joint effort of Cornell University, University of Pennsylvania Veterinary College and the Miner Institute. Each of these rations meets a set of specified amino acid and phosphorus constraints. By feeding more distillers, we violated one or more of the ration formulation criteria—thus providing a benchmark on the limits to feeding DDGS. At a recent conference on Ruminant Health, a speaker also indicated that to go much above 10-15% distillers in rations would require a decrease in the quantity of forage fed, and a substantial reduction in milk production.

solution. By including separate activities for dry cows and heifers, we also reflect a broader range of options for feeding DDGS. However, as indicated in Table 2, the options for feeding DDGS to dry cows and heifers are more limited. In these rations, DDGS essentially is a substitute for soybean meal and included at roughly 13% and 10% of the rations on a dry matter basis, respectively.

As is also seen in Tables 1 and 2, the nitrogen and phosphorus contents of the manure differ significantly by ration, and these differences have potential implications for whole-farm nutrient management planning. In the model, the amounts of these two nutrients that appear in the livestock waste are accumulated in equations 21 and 22. More is said about this in the discussion of the empirical results.

In the ration formulations, cows are assumed to be milked for 305 days a year, and equation (1) restricts the herd to some maximum size, in this case 250. The constraints in the model account for several important physical relationships among the numbers of lactating cows and the numbers of dry cows and heifers, and the numbers of cull cows and cull calves (e.g., equations (2-5)).

It is assumed that the farmer can raise four crops (alfalfa, orchard grass, corn silage, and corn for grain). Equations (11) restrict cropping activities to the maximum acres of the three types of land. Crop rotations common in New York are imposed. While alfalfa and orchard grass can be grown continuously, corn can be grown on the same land in at most four out of eight years, effectively limiting corn acres to one-half of total crop acres. These rotations are controlled through the constraints in equations 27 through 29.

Yields of these four crops differ by land class, as do the nutrient requirements. Nutrient requirements may be met from either purchased fertilizer or through the spreading of animal

waste (i.e., equations 24 through 26). All manure must be applied to the land, but it can be spread at either 10 or 20 tons per acre. The optimal application of the manure is determined within the model according to equations 20 and 23.

The structure of the model also facilitates our understanding of how relative prices among feed ingredients affect the composition of the final feed rations, and the amounts of particular feeds that are purchased or grown. This is accomplished by differentiating between the production of agricultural commodities and their use (e.g., for sale, in the case of milk and cull cows and calves, and for on-farm use as feed or for sale, in the case of grown crops). The model also has separate activities for the purchase of all feed ingredients. To facilitate an examination of the sensitivity of the results to the prices of other major inputs, we also isolate in separate activities the purchase of several types of labor, fertilizers, and fuels.⁵

The sales and purchase prices for milk, feed ingredients, labor, fertilizer and fuel are reflected in the objective function coefficients for the respective sale and purchase activities. The constraints that account of the sales of milk, cull animals and crops, and the purchase or use of grown feed and other inputs are included in equations 7, 12 through 19, and 24 through 26. The availabilities of three types of labor are accounted for by equations 8 through 10.

The important prices that affect the optimal farm production plans, and ultimately determine the use of DDGS, are reported in Table 3.⁶ It is evident from this table that both the price of milk and the prices for most major feed ingredients, fertilizer, and fuel in 2008 are well

⁵ By adopting this convention, the model can accommodate the sales and purchases of commodities and inputs from difference sources and allocate them internally within the model to the variety of potential uses. Furthermore, within this structure, it is only the other variable costs that are reflected in the objective function coefficients of the associated livestock (e.g., breeding costs, veterinary services, utilities, supplies, etc.) and crop (e.g., seed, soil testing, lime, repair and maintenance, supplies, etc.) activities. Individually, each of these purchased inputs constitutes a small proportion of total production expenses, and they must be incurred regardless of the particular composition of dairy feed or the type of land being farmed. For these expenditure items, it is also not necessary in the model to consider alternative sources of supply. The input requirements for these inputs are adapted from Schmit and Knoblauch (1995), and their costs are updated using indexes of prices paid and received (NASS).

⁶ Historical prices are taken from NASS and ERS. The recent 2008 prices are taken from *Feedstuffs*.

above the average levels over the past 17 years. The most dramatic differences are seen in the prices of diesel, fertilizer, and corn grain. In these cases, 2008 prices are more than double the '91-'07 averages. The differences are somewhat less dramatic for corn silage and distillers grains and propane, up by only between 50 and 70 percent. Somewhat in contrast, the 2008 prices of milk and soybean meal are only around 20 percent higher than for the historical period.

It remains to be seen if these elevated prices will be sustained into the future. However, to reflect these most recent changes in agricultural prices, we begin the empirical analysis by solving the model using 2008 prices. Even if these new price levels for many inputs are sustained into the future, the price of DDGS relative to other major feed ingredients may change in the future, particularly if the U.S. bio-fuels industry continues to expand. Therefore, in the discussion that follows, much of the focus is on how the demand for DDGS at the farm level changes as the price of DDGS is allowed to differ relative to the 2008 levels for other prices.⁷

The Empirical Results

In this discussion of the empirical results, we focus initially on the derived farm-level demand curve for DDGS. We then go on to discuss the nature of the optimal programming solutions that give rise to the changes in demand for DDGS along the demand curve.

Farm-Level Demand for DDGS

The farm-level demand curve for DDGS as dairy feed derived from our empirical analysis is in Figure 1.⁸ It is a typical “step function” that is characteristic of those generated through linear programming methods. Due to the nature of the feasible region to any linear programming problem, there is often a range in the price of an input, *ceteris paribus*, over which

⁷ To generate this demand curve for DDGS, we actually parametrically change two prices in the model, one for DDGS with 8 percent fat and one for DDGS with 12 percent fat. However, both prices are changed in the same proportion.

⁸ This demand curve represents the combined demand for both DDGS-8 and DDGS-12.

there is no change in the levels of the optimal activities (e.g., Gass 1985). For example, the farm-level demand for DDGS is just over 90 tons as long as the price of DDGS is between \$162 and \$225 per ton. This range includes the current 2008 price of \$195 per ton. Moving up the demand curve, we see that for prices above \$225 per ton, but less than \$297 per ton, demand for DDGS falls to about 30 tons. For prices above \$297 per ton (e.g., a 50 percent increase relative to the 2008 price), the demand for DDGS falls to zero. In contrast, for prices below \$162 per ton, but above \$127 per ton, demand for DDGS rises to just under 225 tons; and for prices anywhere below \$127 per ton, demand reaches its highest level—almost 450 tons. Thus, the price of DDGS would have to fall by 35 percent relative to the 2008 price to reach the maximum farm-level demand for DDGS.

The Programming Solutions

Based on the nature of this demand curve for DDGS, we only need examine five programming solutions. These solutions are the ones that correspond to the prices at which the basis solutions to the model change, and represent the several steps on the demand curve. These prices are reported in Table 4. The information in this table underscores the fact that throughout the analysis, prices for DDGS-12 are assumed to be a constant 4 percent higher than the price of DDGS-8. Also, to facilitate comparisons with 2008 prices, solution III is the one based on the 2008 price of \$195 per ton. It is the same as the solution at a price of \$225 per ton, the price at which the basis actually changes.

Net Revenues, Receipts and Costs

At all points along this demand curve, the net revenue for this representative farm differs, as one would expect. However, since it is only the price of DDGS that changes, it's not surprising the differences are rather modest. Over these five programming solutions that map out

the demand curve for DDGS, net revenue ranges from a low of \$350,811 to a high of \$367,319; on a per cow basis, the range is from \$1,403 to \$1,469 (Table 5). This is a difference of about 4.7 percent. From the perspective of the 2008 situation, if the price of DDGS fell to the level that would lead to a maximum demand for DDGS (e.g. to \$127 per ton), net revenue would increase by about 3.2 percent.

These modest changes in net revenue are, as one would expect accompanied by rather modest changes in total receipts, and total costs of production. These differences in revenue and cost by source are included in tables in Appendix B. These changes are driven effectively by management changes in response to expanded use of DDGS.

Management Adjustments

As prices paid for DDGS decline, there is a general increase in amount of DDGS fed. At a price when DDGS is first purchased as a feed ingredient (e.g. \$297 per ton), its use is restricted to that of a substitute for soybean meal in the rations for dry cows (Table 6). All lactating cows continue to be fed with a corn-silage based ration that includes no DDGS. As prices continue to fall, the next change is to move all heifers to a ration that also includes DDGS-8; thus, at current 2008 prices, the optimal use of DDGS as a feed on this representative dairy farm is only as a substitute for soybean meal in rations for dry cows and young stock. It is only after the price of DDGS falls by 17 percent relative to the 2008 level that lactating dairy cows are fed any DDGS in the ration. At this price, 93 cows (37 percent) are fed a ration with DDGS. The ration contains 20 percent DDGS, but the ration also shifts to an alfalfa forage base rather than a corn silage forage base ration. The remaining cows continue to be feed a corn-silage based ration with no DDGS (Scenario IV, Table 6). If one assumes that the farmer would feed all cows the same ration, this solution implies the percentage of corn silage in the forage base would fall to about

53 percent and DDGS would constitute 7.4 percent of the ration on a dry matter basis. Once the price falls to about \$127 per ton, all cows are moved to this same alfalfa-based forage ration containing 20 percent DDGS.

In summary, as the use of DDGS expands, there is a general decrease in the feeding of corn silage primarily as we shift to an alfalfa forage base. Further, as is evident from the feed ration information in Tables 1 and 2, there is a reduction the feeding of both corn grain and soybean meal.

Since much of the dairy feed is grown, one might expect changes in crop production as the nature of the dairy rations change. For our representative farm, this happens only in the last two scenarios (Table 7). Primarily due to the reduced dependence on corn silage in the ration at these relatively low prices for DDGS, some of its production is replaced with increased production of corn grain. However, it is only at the lowest price for DDGS that the farm switches from a net buyer of corn grain to a net seller. These changes are accompanied by a reduction in the sales of alfalfa. The economic significance of these cropping changes is apparent in the detailed tables in Appendix B.

Waste Production and Manure Management

To evaluate the potential use of new dairy feeds such as DDGS, it is also important to examine the implications for whole-farm nutrient management. Despite accounting for appropriate constraints on amino acids and phosphorus in ration formulation, the N and P levels in dairy waste increase with the percentage of DDGS in the ration (Tables 1 and 2). For this reason, the programming solution in which the DDGS use is highest also has the highest total amounts of both N and P in the dairy waste. When compared with the solution in which no DDGS is fed, the total pounds of N and P in dairy waste for the lactating cows are up by 36 and

34 percent, respectively (Table 1). The P content of the manure also increases for both dry cows and heifers, but the N concentration falls slightly (Table 2).

Although we are careful in our analysis to document changes in the nutrient content of animal wastes, at this stage, the programming model does not include a range of alternatives for disposing of the waste. As stated above, the nutrient requirements for crop production in the model may be met from purchased fertilizer, as well as from through the spreading of animal waste (e.g., equations 24 through 26). Furthermore, we require that all manure must be applied to the land, and it can be spread at either 10 or 20 tons per acre. The optimal application of the manure is determined within the model according to equations 20 and 23.

In all solutions, manure is applied at the rate of 10 tons per acre to all low quality land and to 63 percent of the best land; it is applied to the remaining 37 percent of the best land at a rate of 20 tons per acre. Because of the small increase in total manure production in rations with DDGS, the proportion of average quality land on which manure is applied at 20 tons per area rises slightly as the price of DDGS falls.

Since there is no alternative but to spread all the manure on existing cropland, it is certainly possible that the N and P applied to some cropland could exceed the requirements of the crop being grown. And, this is exactly what we find. In all solutions, the levels of N and P in the manure exceed the soil/crop requirements on some land, but the amounts of excess application increases with the amount of DDGS being fed. As is evident in Table 8, the excess N applied through manure spreading when use of DDGS is highest exceeds the excess N when no DDGS is fed by about 60 percent; the excess P more than doubles. When the excess of these nutrients is averaged over all cropland (including those for which there is no excess), the excess

application would seem problematic, and only to be exacerbated if one considers the concentration on only the acres in which there is excess application.

Hadrich (2008) addresses these issues by spreading all manure at application rates consistent with Michigan's environmental guidelines, and they estimate the additional cost of transporting some manure longer distances. This is but one strategy that deserves examination in our continuing research.

Concluding Observations

In light of recent structural changes in commodity markets, we develop a mathematical programming model of a representative New York dairy farm to identify optimal management adjustments to take advantage of potential increased availability DDGS if the U. S. bio-energy industry continues to expand. The model accommodates a number of dairy rations that differ in terms of the composition of the forage base as well as the percent of DDGS.

At current prices our results suggest there is extremely modest potential for DDGS—serving in this case only as a substitute for soybean meal in the rations for dry cows and young stock. If, however, the price of DDGS were to fall by 17 percent relative to the 2008 level, DDGS would be fed to the dairy herd, accounting for 7.4 percent of the ration on a dry matter basis. It is only after the price of DDGS falls by 35 percent relative to the 2008 price that the farm-level demand for DDGS would reach 20 percent of the ration on a dry matter basis. As the use of DDGS expands, there is a general decrease in the feeding of corn silage, primarily a shift to an alfalfa forage base. There are also reductions in the feeding of both corn grain and soybean meal, and eventually the farming operation goes from a net buyer of corn grain to a net seller.

Despite these expanded opportunities for DDGS at somewhat lower prices, the effects on farm net returns are modest at best—in the neighborhood of two to three percent. Equally

important, even after insuring that nutritional phosphorus intake constraints are accommodated in the ration formulations, the amounts of N and P in dairy waste increase significantly. The extent to which these modest improvements in net return can be sustained depends critically on the identification of low-cost, effective waste management systems or strategies. These issues are of high priority on the agenda for future research.

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Table 1: Alternative Feed Rations for Lactating Dairy Cows

Ingredient	60-40 Corn to Hay Crop Silage					40-60 Corn to Hay Crop Silage				
	CS	CS0810	CS0820	CS1210	CS1220	A	A0810	A0820	A1210	A1220
	-----tons dry matter basis per year, 305 days-----									
Corn silage	3.075	2.945	2.904	2.904	2.904	1.400	1.400	1.416	1.400	1.400
Mixed silage	1.511	1.451	1.427	1.427	1.427	2.843	2.843	2.873	2.843	2.843
Corn grain	0.962	0.619	0.000	0.672	0.031	1.684	1.239	0.654	1.174	0.965
Soy hulls	0.000	0.611	0.611	0.572	0.611	0.003	0.208	0.497	0.265	0.000
Wheat midds	0.371	0.132	0.000	0.157	0.000	0.394	0.058	0.000	0.065	0.000
Fat	0.000	0.000	0.083	0.000	0.044	0.000	0.000	0.000	0.000	0.000
Dry Distillers8	0.000	0.732	1.465	0.000	0.000	0.000	0.732	1.465	0.000	0.000
Dry Distillers12	0.000	0.000	0.000	0.701	1.403	0.000	0.000	0.000	0.701	1.403
Soybean meal	0.244	0.000	0.005	0.008	0.010	0.115	0.000	0.000	0.000	0.000
Blood meal	0.000	0.085	0.152	0.088	0.152	0.000	0.130	0.152	0.130	0.080
SoyPlus	0.460	0.448	0.300	0.395	0.300	0.442	0.300	0.000	0.300	0.300
Mepron	0.002	0.003	0.002	0.003	0.002	0.002	0.003	0.000	0.003	0.000
Mineral mix	0.152	0.152	0.185	0.152	0.191	0.152	0.152	0.185	0.152	0.185
Total tons dry matter	6.776	7.177	7.134	7.080	7.074	7.035	7.065	7.241	7.034	7.176
% DDGS	0.000	10.000	20.000	10.000	20.000	0.000	10.000	20.000	10.000	20.000
Total Manure (tons/year)	21.106	21.350	21.198	21.228	21.198	22.402	22.402	22.814	22.402	22.814
N in manure (lbs./year)	247.780	269.022	305.860	261.830	307.675	265.056	304.986	324.077	305.658	337.589
P in manure (lbs./year)	29.914	30.183	34.418	29.981	34.687	30.586	30.586	35.829	30.586	39.997
Milk Production (cwt./year)	213.500	213.500	202.520	213.500	201.605	213.500	213.500	199.470	213.500	214.415

Note: Rations are based on the CPM-Dairy program. Ration headings are formatted by primary forage base, DDGS fat percentage, and percentage of DDGS fed on a dry matter basis, respectively; e.g., CS0810 = primary corn silage forage base, 8% fat DDGS, and 10% DDGS fed. CS and A constitute the two rations of which DDGS are not fed.

Table 2: Alternative Feed Rations for Dry Cows and Heifers

	Dry Cows			Heifers		
	DCow	DCow12	DCow8	Hef	Hef12	Hef8
Ingredients	----- (tons dry matter basis) -----					
Corn silage	0.360	0.360	0.360	1.095	1.095	1.095
Grass silage	0.180	0.180	0.180	0.000	0.000	0.000
Mixed Silage	0.000	0.000	0.000	1.095	1.095	1.095
Wheat straw	0.090	0.090	0.090	0.000	0.000	0.000
Corn grain	0.060	0.060	0.060	0.548	0.548	0.548
Soybean meal	0.090	0.000	0.000	0.183	0.000	0.000
Soy hulls	0.060	0.060	0.060	0.183	0.183	0.183
Dry distillers 12% fat	0.000	0.120	0.000	0.000	0.319	0.000
Dry distillers 8% fat	0.000	0.000	0.120	0.000	0.000	0.319
Mineral-vitamin	0.023	0.023	0.023	0.082	0.082	0.082
Total tons of dry matter	0.863	0.893	0.893	3.185	3.322	3.322
N in manure (lbs. per year)	33.563	29.397	29.397	165.960	164.914	164.914
P in manure (lbs. per year)	4.483	5.514	5.514	13.998	17.537	17.537
Total Manure (tons per year)	2.400	2.400	2.400	7.300	7.300	7.300

Note: Rations are based on the CPM-Dairy program. Ration headings are formatted by type of DDGS fed. DDGS were included in dry cow rations at approximately 13% of total dry matter, heifers rations included DDGS at 10% of total dry matter; e.g., DCow12 = dry cow ration with 12% fat DDGS, and Hef8 = replacement heifer ration with 8% fat DDGS.

Table 3. Distributions in Important Agricultural Prices

Year	Major Feed Ingredients							Fertilizer			Fuels	
	Milk	Alfalfa	Orchard Grass	Corn Silage	Corn Grain	Distillers Grains	Soybean Meal	Urea	P2O5	K2O	Diesel	Liquid Propane
	\$/cwt	\$/ton (dry matter basis)					\$/lb.			\$/gal.		
2008	18.00	145.00	104.00	167.40	248.00	195.00	397.00	0.57	0.94	0.50	3.77	2.62
1991-2007												
Average	14.77	137.27	108.43	108.28	122.17	122.47	337.52	0.28	0.31	0.16	1.25	1.55
Std. Deviation	1.93	23.27	13.45	18.43	22.66	23.75	55.61	0.08	0.07	0.03	0.52	0.51
Coef. of Variation	0.13	0.17	0.12	0.17	0.19	0.19	0.16	0.28	0.23	0.20	0.41	0.33
Minimum	12.86	102.30	90.91	92.11	99.97	88.00	273.23	0.18	0.23	0.13	0.75	1.11
Maximum	20.17	171.67	137.10	167.36	184.74	175.00	447.92	0.47	0.49	0.25	2.36	2.73
Ratio of 2008 prices to '91-'07 average prices	1.22	1.06	0.96	1.55	2.03	1.59	1.18	2.06	3.00	3.18	3.01	1.70

Figure 1. Demand Schedule for Distillers Dry Grains (DDGS)

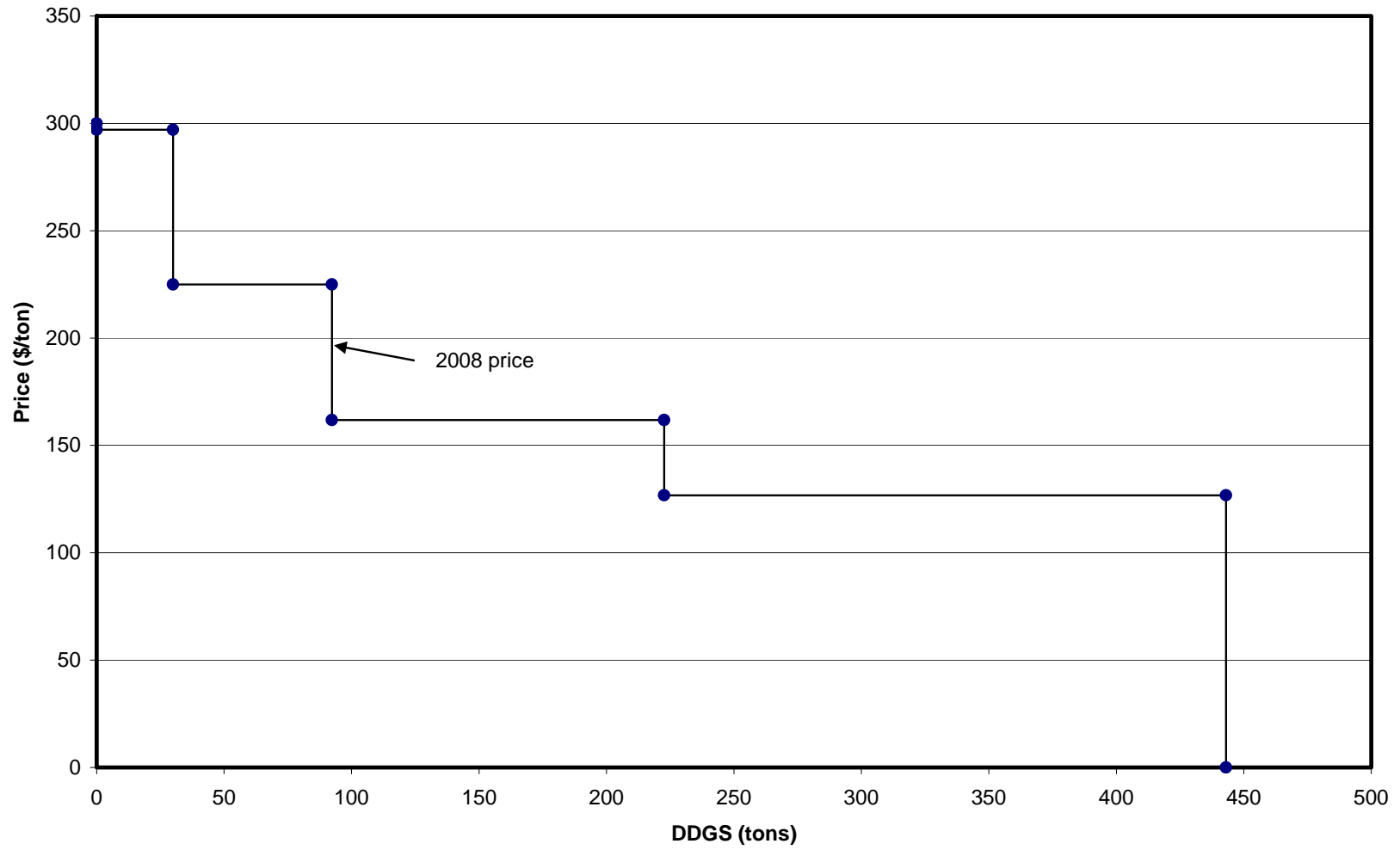


Table 4. Relevant Range in DDGS Prices

DDGS Price Level	BDDGS-8	BDDGS-12 (\$/ton)
	-----\$ per ton-----	
I	300	312.3
II	297	309.18
III	195	203
IV	161.85	168.49
V	126.75	131.95

Table 5: Net Revenues, Receipts and Costs (\$)

DDGS Price	Net Revenue		Receipts		Costs	
	Total	Per Cow	Total	Per Cow	Total	Per Cow
I. 300.00	350,811	1,403	1,062,462	4,250	711,651	2,847
II. 297.00	350,833	1,403	1,062,462	4,250	711,629	2,847
III. 195.00	355,878	1,424	1,062,462	4,250	706,584	2,826
IV. 161.85	359,133	1,437	1,055,918	4,224	696,786	2,787
V. 126.75	367,319	1,469	1,069,507	4,278	702,188	2,809

Table 6: Numbers of Animals Fed, by Ration

DDGS Price	Cows		Dry Cows		Heifers	
	CS-based no DDGS	Alfalfa-based DDGS12-20%	no DDGS	DDGS-8	no-DDGS	DDGS-8
I. 300.00	250	0	250	0	195	0
II. 297.00	250	0	0	250	195	0
III. 195.00	250	0	0	250	0	195
IV. 161.85	157	93	0	250	0	195
V. 126.75	0	250	0	250	0	195

Table 7: Land Use by Crop (Acres)

DDGS Price	Corn Grain	Corn Silage	Alfalfa	Orchard Grass	Total
I. 300.00	111	199	238	72	620
II. 297.00	111	199	238	72	620
III. 195.00	111	199	238	72	620
IV. 161.85	141	169	238	72	620
V. 126.75	190	120	238	72	620

Table 8. Disposition of Nutrients from Manure

DDGS Price	Excess N	Excess P	All cropped acres		Land with excess application	
			Excess N	Excess P	Excess N	Excess P
	-----total lbs.-----		-----lbs. per acre-----			
I. 300.00	11,808	2,011	19.0	3.2	37.6	11.0
II. 297.00	11,544	2,174	18.6	3.5	36.8	11.9
III. 195.00	11,492	2,608	18.5	4.2	36.6	14.3
IV. 161.85	14,213	3,271	22.9	5.3	37.2	16.5
V. 126.75	19,005	4,574	30.7	7.4	49.7	9.9

Appendix A: The LP Model

Programming Activities:

COW_{*i*} = Lactating cows being fed on ration *i* (*i* = 1, ..., 10);
DCOW_{*m*} = Dry cows being fed on ration *m* (*m* = 1, ..., 5);
HEF_{*n*} = Heifer replacements being fed on ration *n* (*n* = 1, ..., 5);
MILK = Total milk production, and sold (cwt);
CULLCOW = Sales of cull cows (cwt.);
CULLCALF = Sales of cull calves (cwt.);
OWNLAB = Amount of owner/management labor utilized (hours);
LABOR1 = Amount of level one labor employed (hours);
LABOR2 = Amount of level two labor employed (hours);
BALF = Amount of alfalfa purchased (tons on dry matter basis);
BOG = Amount of orchard grass purchased (tons on dry matter basis);
BCS = Amount of corn silage purchased (tons on dry matter basis);
BCG = Amount of corn grain purchased (tons on dry matter basis);
SALF = Amount of alfalfa sold (tons on dry matter basis);
SOG = Amount of orchard grass sold (tons on dry matter basis);
SCS = Amount of corn silage sold (tons on dry matter basis);
SCG = Amount of corn grain sold (tons on dry matter basis);
BDDGS8 = Amount of DDGS8 purchased (tons on dry matter basis);
BDDGS12 = Amount of DDGS12 purchased (tons on dry matter basis);
BSOY = Amount of Soybean meal purchased (tons on dry matter basis);
BOPF_{*q*} = Amount of other minor feed *q* purchased (tons on dry matter basis) (*q* = 1, ..., 8);
BMAN_{*j*} = Amount of manure spread at *j* tons/acre (*j* = 0, 10, 20);
NBMAN = Total amount of Nitrogen in Manure (grams);
PHBMAN = Total amount of Phosphorous in Manure (grams)
BNIT = Amount of nitrogen fertilizer purchased (lbs.);
BPH = Amount of phosphorus fertilizer purchased (lbs.);
BPOT = Amount of potash fertilizer purchased (lbs.);
BF_{*f*} = Amount of fuel of type *f* purchased (gallons) (*f* = diesel and propane);
CS_{*jk*} = Acres of corn silage following corn on land class *k* with *j* tons of manure applied;
CG_{*jk*} = Acres of corn grain following corn on land class *k* with *j* tons of manure applied;
CSA_{*jk*} = Acres of corn silage following alfalfa on land class *k* with *j* tons of manure applied;
CGA_{*jk*} = Acres of corn grain following alfalfa on land class *k* with *j* tons of manure applied;
CSOG_{*jk*} = Acres of corn silage following orchard grass on land class *k*, *j* tons of manure applied;
CGOG_{*jk*} = Acres of corn grain following orchard grass on land class *k*, *j* tons of manure applied;
A_{*jk*} = Acres of alfalfa on land class *k* with *j* tons of manure applied; and
OG_{*jk*} = Acres of orchard grass on land class *k* with *j* tons of manure applied.

Objective Function (Maximize Net Revenue):

$$\begin{aligned}
& \sum_i -objcow_i COW_i + \sum_m -objdcow_m DCOW_m + \sum_n -objhef_n HEF_n - objlOWNLAB - objlLABOR1 \\
& - obj2LABOR2 - objaBALF - objjogbBOG - objcsbBCS - objcgbBCG - objd8BDDGS8 - objd12BDDGS12 \\
& + \sum_q -objpfp_q BOPF_q + \sum_f -objff_f BF_f + \sum_j -objman_j BMAN_j + \sum_k \sum_j -objcs_k CS_{jk} + \sum_k \sum_j -objcsa_{jk} CSA_{jk} \\
& + \sum_k \sum_j -objcso_{jk} CSOG_{jk} + \sum_k \sum_j -objcg_{jk} CG_{jk} + \sum_k \sum_j -objcga_{jk} CGA_{jk} + \sum_k \sum_j -objcgo_{jk} CGOG_{jk} \\
& + \sum_k \sum_j -obja_{jk} A_{jk} + \sum_k \sum_j -objog_{jk} OG_{jk} + objasSALF + objogsSOG + objcssSCS + objcgsSCG \\
& + objmilkMILK + objccowCULLCOW + objccalfCULLCALF
\end{aligned}$$

Constraints

$$(1) \text{ CowCap: } \sum_i COW_i \leq COWMAX$$

$$(2) \text{ DryCow: } \sum_i COW_i - \sum_m DCOW_m = 0$$

$$(3) \text{ CullCow: } \sum_i cwtcow COW_i - CULLCOW = 0$$

$$(4) \text{ CullCalf: } \sum_i cwtcalf COW_i - CULLCALF = 0$$

$$(5) \text{ Heifier: } \sum_i 0.78 COW_i - \sum_n HEF_n \leq 0$$

$$(6) \text{ Milk: } - \sum_i mcow_i COW_i + MILK \leq 0$$

(7) Labor:

$$\begin{aligned}
& \sum_i lcow_i COW_i + \sum_m ldcow_m DCOW_m + \sum_n lhef_n HEF_n - OWNLAB - LABOR1 - LABOR2 \\
& + \sum_j lman BMAN_j + \sum_k \sum_j lcs_k CS_{jk} + \sum_k \sum_j lcsa_k CSA_{jk} + \sum_k \sum_j lcso_k CSOG_{jk} + \sum_k \sum_j lcg_k CG_{jk} \\
& + \sum_k \sum_j lcga_k CGA_{jk} + \sum_k \sum_j lcgo_k CGOG_{jk} + \sum_k \sum_j la_k A_{jk} + \sum_k \sum_j log_k OG_{jk} \leq 0
\end{aligned}$$

$$(8) \text{ Own Labor Available: } OWNLAB \leq OWNLABMAX$$

$$(9) \text{ Labor1 Available: } LABOR1 \leq LAB1MAX$$

$$(10) \text{ Labor2 Available: } LABOR2 \leq LAB2MAX$$

(11) Land: (k = 1,...,3)

$$\sum_j CS_{jk} + \sum_j CSA_{jk} + \sum_j CSOG_{jk} + \sum_j CG_{jk} + \sum_j CGA_{jk} + \sum_j CGOG_{jk} + \sum_j A_{jk} + \sum_j OG_{jk} \leq LAND_k$$

(12) Alfalfa:

$$\sum_i acow_i COW_i + \sum_i adcow_m DCOW_m + \sum_n ahef_n HEF_n + SALF - BALF - \sum_k \sum_j ayield_k A_{jk} \leq 0$$

(13) Orchard Grass:

$$\sum_i ogcow_i COW_i + \sum_i ogdcow_m DCOW_m + \sum_n oghef_n HEF_n + SOG - BOG - \sum_k \sum_j ogyield_k OG_{jk} \leq 0$$

(14) Corn Silage:

$$\sum_i cscow_i \cdot COW_i + \sum_i csdcow_m DCOW_m + \sum_n cshef_n \cdot HEF_n + SCS - BCS - \sum_k \sum_j csyield_k (CS_{jk} + CSA_{jk} + CSO_{jk}) \leq 0$$

(15) Corn Grain:

$$\sum_i cgcow_i COW_i + \sum_m cgdcow_m DCOW_m + \sum_n cghef_n HEF_n + SCG - BCG - \sum_k \sum_j cgyield_k (CG_{jk} + CGA_{jk} + CGO_{jk}) \leq 0$$

(16) DDGS:

$$\sum_i dg8cow_i COW_i + \sum_m dg8dcow_m DCOW_m + \sum_n dg8hef_n HEF_n - BDDGS8 \leq 0$$

$$\sum_i dg12cow_i COW_i + \sum_m dg12dcow_m DCOW_m + \sum_n dg12hef_n HEF_n - BDDGS12 \leq 0$$

(17) Soybean Meal:

$$\sum_i sbmcow_i COW_i + \sum_m sbmdcow_m DCOW_m + \sum_n sbmhef_n HEF_n - BSOY \leq 0$$

(18) Other Purchased Feeds: (q = 1, ..., 8)

$$\sum_i pfcow_{iq} COW_i + \sum_m pfdcow_{mq} DCOW_m + \sum_n pfhef_{nq} HEF_n - BPF_q \leq 0$$

(19) Fuel: (f = 1, 2)

$$\sum_i fcow_{if} COW_i + \sum_m fdcow_{mf} DCOW_m + \sum_n fhef_{nf} HEF_n + \sum_j fcs_{jkf} CS_{jk} + \sum_j fcsa_{jkf} CSA_{jk} + \sum_j fcsog_{jkf} CSOG_{jk} + \sum_j fcg_{jkf} CG_{jk} + \sum_j fcga_{jkf} CGA_{jk} + \sum_j fcgog_{jkf} CGOG_{jk} + \sum_j fa_{jkf} A_{jk} + \sum_j fog_{jkf} OG_{jk} - BF_f \leq 0$$

(20) Manure Production:

$$- \sum_i cman_i COW_i - \sum_m dcman_m DCOW_m - \sum_n hman_n HEF_n + \sum_j BMAN_j = 0$$

(21) Nitrogen in Manure:

$$- \sum_i Ncman_i COW_i - \sum_m Ndcman_m DCOW_m - \sum_n Nhman_n HEF_n + NBMAN = 0$$

(22) Phosphorus in Manure:

$$- \sum_i PHcman_i COW_i - \sum_m PHdcman_m DCOW_m - \sum_n PHhman_n HEF_n + PHBMAN = 0$$

(23) Manure Use: (j = 0, 10, 20)

$$\sum_k m_j (CS_{jk} + CSA_{jk} + CSO_{jk} + CG_{jk} + CGA_{jk} + CGO_{jk} + A_{jk} + OG_{jk}) - BMAN_j = 0$$

(24) Nitrogen for Crops:

$$\sum_k \sum_j nc_{jk} (CS_{jk} + CG_{jk}) + \sum_k \sum_j nca_{jk} (CSA_{jk} + CGA_{jk}) + \sum_k \sum_j nco_{jk} (CSO_{jk} + CGO_{jk}) \\ + \sum_k \sum_j no_{jk} (OG_{jk}) - BNIT \leq 0$$

(25) Phosphate for Crops:

$$\sum_k \sum_j phc_j (CS_{jk} + CG_{jk} + CSA_{jk} + CGA_{jk} + CSO_{jk} + CGO_{jk}) + \sum_k \sum_j pha_j A_{jk} \\ + \sum_k \sum_j pho_j OG_{jk} - BPH \leq 0$$

(26) Potash for Crops:

$$\sum_k \sum_j potc_j (CS_{jk} + CG_{jk} + CSA_{jk} + CGA_{jk} + CSO_{jk} + CGO_{jk}) + \sum_k \sum_j pota_j A_{jk} \\ + \sum_k \sum_j poto_j OG_{jk} - BPOT \leq 0$$

(27) Rotation Soilk-CA: (k = 1,2,3)

$$4 \sum_j (CSA_{jk} + CGA_{jk}) - \sum_j A_{jk} \leq 0$$

(28) Rotation Soilk-CA: (k = 1,2,3)

$$4 \sum_j (CSO_{jk} + CGO_{jk}) - \sum_j OG_{jk} \leq 0$$

(29) Rotation Soilk-C: (k = 1,2,3)

$$3 \sum_j (CSA_{jk} + CGA_{jk} + CSO_{jk} + CGO_{jk}) - \sum_j (CS_{jk} + CG_{jk}) = 0$$

Appendix B: Detailed Revenues and Costs

Table B1. Milk, Livestock and Crop Receipts

DDGS Price	Milk Receipts*	Livestock Sales**	Crop Sales	
			Alfalfa	Corn grain
-----\$ per cow-----				
I. 300.00	3600	279	127	0
II. 297.00	3600	279	127	0
III. 195.00	3600	279	127	0
IV. 161.85	3605	279	95	0
V. 126.75	3615	279	40	99

*Milk receipts less costs of milk marketing.

**Livestock receipts include cull cow and calf sales.

Table B2: Production Costs

DDGS Price	Total Costs	Costs by Major Component					
		Purchased		Energy	Labor	Crop Production*	Livestock Production**
		Feed	Fertilizer				
-----\$ per cow-----							
I. 300.00	2847	892	29	193	629	323	537
II. 297.00	2847	892	29	193	629	323	537
III. 195.00	2826	872	29	193	629	323	537
IV. 161.85	2787	834	28	196	628	320	537
V. 126.75	2809	858	26	202	626	315	537

*All Costs associated with growing crops, except for fuel, labor, and purchased fertilizer.

**All costs associated with livestock activities, except for feed, fuel, labor.

Table B3. Costs of Purchased Feed Ingredients

DDGS Price	Total (\$ per cow)	Percentage Cost by Feed Ingredients				
		Orchard Grass	Corn Grain	DDGS*	Soybean Meal, etc.	Other**
-----%						
I. 300.00	892	6.4	8.7	0.0	41.7	43.2
II. 297.00	892	6.4	8.7	4.0	37.7	43.2
III. 195.00	872	6.5	8.9	8.3	32.1	44.2
IV. 161.85	834	9.3	0.0	17.7	26.4	46.6
V. 126.75	858	13.1	0.0	27.0	13.9	46.0

*Includes DDGS of 8%, and 12% fat content.

**Other feeds include wheat straw, soyhull, wheat middlings, blood meal, vitamins and minerals.

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