Optimal Forage and Supplement Balance for Organic Dairy Farms in the Southeastern United States

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Abstract

As issues prevail in conventional dairy industry, organic production is a potential alternative; however, economic research is limited and the long-term sustainability of the system is debated. In this study, a whole-farm economic analysis was performed to explore enterprise and feed options on an organic dairy farm in the southeastern United States. Results demonstrated the substitutability of ration components and for the scenario increased milk sales justified the purchasing of additional supplemental feeds.

Key Words: Organic, Dairy, Optimization, Whole-Farm

Introduction

Currently in the United States agriculture industry there is a struggle in the conventional dairy sector. This stems from multiple issues including an oversupply of milk, weak farm economy, changing consumer preferences, and other factors that overall have a lot of producers contemplating their operations future. Their options are also limited with the potential for bankruptcy looming in the future, but one potential option that has arose in recent years and allows operations to continue business is the transition to organic milk production. This production system does have its associated risks though and with a limited amount of research its long term sustainability is debated.

Organic milk sales had been increasing for multiple years prior to 2017 and record demand was set in 2014 that sparked expansion of organic dairy operations (Haddon, 2018). However, consumer preferences began to change around 2017 where demand shifted to dairy substitutes such as plant based alternatives like almond milk. This has resulted in an unexpected oversupply of organic milk and a hit to farm income that has producers re-evaluating their operations to continue production moving forward. With depreciated prices and limited economic research relating to organic dairies, especially in the southeastern United States, producers are seeking solutions to minimize their costs.

Whether it's a conventional, grazing, or organic dairy feed costs extensive role in farm income is recognized where feed costs can potentially make up to 40-60% of total production costs (PennState, 2017). Therefore, this paper will analyze ration components and feed costs for an organic dairy operation in the southeastern United States. This is best executed through a partial whole-farm system approach where linear programing was used to maximize net returns while simultaneously minimizing dairy herd feed costs. The overall objectives of this study was to: 1) Determine the general and optimal feed ration for a given year in the scenario that allowed for maximized net returns; 2) Determine the role that crop enterprises could have on ration composition and net returns; 3) Determine the degree of sensitivity relative to the nutrient requirements of fixed milk production levels; 4) Identify potential bottlenecks or production issues to be explored further by model expansion.

The scenario and the applied linear programming model will be designed around a typical organic dairy farm found in western Kentucky. Herd dynamics, production levels, and nutrient requirements will be fixed and feed options will consist of forages raised on farm and purchased supplements. Output products generating returns for the given scenario are milk and forages harvested for hay. Overall, this study will give economic insight into an alternative production system and facilitate optimizing its operations. The model developed will be the base for future expansion and application that will integrate additional forage and grazing components.

Literature Review

Mathematical programming has commonly been applied in the past to analyze dairy operations and has been explored through models that focus on minimizing feed costs, whole-farm applications, and models that integrate both. This has been done in scenarios such as those relating to policy implications (Van Calker, Berentsen, De Boer, Giesen, & Huirne, 2004; Moraes, Wilen, Robinson, & Fadel, 2012) and multi-objective ration and enterprise applications (Lara & Romero, 1992). However, most of this research has been related to conventional or confinement dairy operations and mathematical programing applications to organic dairy farms has not been thoroughly performed.

In general, an organic dairy farm is more comparable to that of a pasture-based operation due the USDA organic standards and pasture rule that must be followed for certification (Rinehart & Bailer, 2011). General economic analysis' have been applied to pasture-based dairies for such things as comparing this system's profit to a conventional dairy (Gillespie & Nehring, 2014) and the effect that ration balance has on profit and feed efficiency (Tozer, Bargo, and Mueller, 2004). Methods similar to the ones used in this study have also been used to explore optimal forage mixtures and grazing systems for dairy cattle (McCall & Clark, 1999; Neal, Neal, & Fulkerson, 2007; Doole & Romera, 2013). Although this does provide useful insight and grounds for potential comparison, a pasture-based dairy and an organic dairy system have their significant differences and so do their markets. Additionally, a majority of pasture related research has been conducted internationally or in the northeastern United

States where the climates and environments can vary greatly compared to the southeastern United States.

Although organic dairy management has been around for quite some time, research related to this production system has picked up in more recent years as the market has expanded. A majority of the economic related research to this point has primarily looked at the expected costs, returns, and profitability of existing practices used in organic dairy production and how operations compare to their confinement or grass-based equivalents (Thatcher, 2009; Kriegl, 2009; & Tranel, 2017). This has been conducted mostly in the Northeast in such states as Wisconsin, Maine, New Hampshire and others. These Studies have also had primary focuse on the role that ration composition and feeding strategies have on income and profit. A study out of Wisconsin determined that feed strategies on organic dairy farms varied greatly from farm to farm, but feeding strategies in general were major factors in milk production level and income over feed costs (Hardie et al., 2014). Another study out of New England demonstrated the economic advantage that forages can have in organic dairy feeding systems where grass-silage based diets were found to be superior in the study. Overall, general economic research relating to organic dairy has demonstrated the variability in farms production practices and feeding strategies especially between farms in different states (Kriegl, 2009). This has led to large variations in income over feed costs and profitability, while also emphasizing the need for unique and specific research applied to the southeastern U.S.

Whole-farm and feed ration modeling has been previously used to simulate organic dairy farms primarily in European countries. This has been done through linear programming where a study out of Belgium analyzed the economic potential for the conversion to organic farming, while another study out of Norway used stochastic utility-efficient programing to incorporate risk and uncertainty on organic dairy farms (Kerselaers, E. 2007 & Flaten, O. & Lien, G., 2006). These studies continue to reinforce the variability in organic dairy operation's practices, costs, and returns there by supporting further economic research relating to decision making and optimization. Also, actual farm cost and financial data has become more available in more recent years and when paired with current research there is opportunity for real world modeling and application.

Model

A linear programming model was developed to represent an organic dairy operation at the whole-farm level while applying classical formulations relating to minimum cost feed mix, resource allocation, and product mix problems. The equations used and the model in its entirety can be seen in Appendix A where the objective function was to maximize net returns for a given production year. Model decision activities can be broke into three general categories where the decision maker has options relating to enterprises to produce, output products to sell, and feeds to include in the dairy ration. Production activities include milk, grass-legume mix hay, corn silage, and pasture production with enterprise budgeting being used to determine relevant cost factors (operating and ownership costs) and the overall expense per unit of the activity. Herd number and production level were set for the dairy enterprise, but hay could be raised for on-farm use as well as be sold. Therefore, output products to generate returns were milk and baled hay. On the contrary, pasture and corn silage could only be raised for on farm use as a feed source. Along with these forage sources, other supplements could be purchased for feed use and included: Ground shelled corn, soybean meal, roasted soybeans, oats, barley, and wheat. Decision variables were primarily chosen by activities currently available and feasible for organic dairy farms in Kentucky.

Along with decision variables constraints, coefficients, other exogenous data were applied to the whole-farm model. Sets of constraints were implemented to address factors related to resource endowments and nutritional needs of the dairy herd. Overall, the constraints included land and labor availability, upper and lower limits for feed ration dry matter composition, livestock minimum nutritional requirements, feed and marketing balances, as well as a constraint to ensure a fixed herd and milk production level. Constraints related to land put a cap on the total number of acres that could be used for pasture, hay, and cropland. Labor was broken into two categories which included total labor and labor related to forage production. This was done to implement concepts related to suitable field day risk where some activities could only be accomplished when the weather and field conditions are appropriate (Shockley & Mark, 2017). An example of this would be baling hay where moisture status must be considered, while the operation of milking must be conducted daily regardless of weather conditions. Overall, labor requirements and available labor supply were broken down by month for the two labor types. Balance constraints for the model guaranteed that all agricultural products produced were either sold or consumed by livestock; therefore, considerations related to storage were not implemented into the model.

A majority of the constraints that were applied are related to livestock nutrition and feed ration composition. This included the maximum total pounds of dry matter that could be consumed by the herd in a given day, as well as the maximum pounds of dry matter that a given feed ingredient could make up in the ration. These individual upper limits were set for specific concentrates including ground shelled corn, roasted soybeans, oats, barley, and wheat. Being that forages are the foundation of a ruminant animal's nutrition, constraints were employed to ensure that a lower limit was met regarding forage and neutral detergent fiber (NDF) dry matter intake. Regarding nutrition, constraints guaranteed that nutrient requirements such as total digestible nutrients (TDN), crude protein (CP), and net energy were met at their minimum limit for a given milk production level. Finally, a constraint was implemented to enforce "the pasture rule" that is required by the USDA for organic ruminant livestock production (Reinhart & Baier, 2011). This rule specifies that animals must graze a minimum of 120 days out of the year and at least 30% of dry matter intake, during the grazing period, must come from pasture. Therefore, this rule is potentially a strong determinant in organic dairy feed ration composition and overall whole-farm net returns. The model was ran using Microsoft Excel's add-in *Solver* with future model expansions being solved using the AIMMS software (Microsoft; AIMMS 2018).

Data and Assumptions

Research questions, objectives, and hypothesis for this study stem from field research currently being conducted on five organic dairy farms in Kentucky (4) and Tennessee (1). The project seeks to determine optimal forage combinations that promote good herd health, milk production, and economic returns for organic dairy farms in the southeastern United States (SOD, 2018). Data from the project relating to forage yield, forage quality, milk yield, milk components, production practices, and general farm characteristics were applied to the model for this study. In general, the farm being modeled consists of characteristics and factors that are common across the five research farms to best represent a typical organic dairy operation in the southeastern region.

In linear programming or mathematical programing in general, there is data that is solved and provided by the model which is commonly known as endogenous data. To determine this data it first requires exogenous data that is solved outside the model and makes up the technical, objective function, and right hand side coefficients. Data and the assumptions associated with the data was sourced from current research, previous scientific literature, university publications, and private industry sources for the model being used. Land and labor right hand side values were determined through producer surveys of the farmers currently participating in research efforts (SOD, 2018). The technical coefficients associated with labor for the production decision variables were based on field capacities for machinery and general requirements determined through enterprise budgeting (Iowa State, 2018). Production yields for the crop enterprises were based off extension publications and historical averages for the state and region with an assumed yield penalty for organic production (Lee et al, 2007). The milk production levels were assumed based around on farm averages as well as benchmark numbers that are assumed for the organic dairy industry (Miller, 2018). Both the technical coefficients and the right hand side values relating to dairy cows and feed nutrient composition were based on University extension research and those provided by the National Research Council (Univ. of Minnesota, 2018; NRC 2001). These nutrients requirements are based off general assumptions relating to cow characteristics, milk production, and milk composition. Numbers related to the hypothetical farm, technical and right hand side coefficients, and assumptions applied to the model can be seen in Appendix B.

As mentioned previously, the objective function coefficients related to production activities were determined through budgeting and cost analysis methods. Price information for purchased feeds was received from Kentucky Organic Farm and Feed Inc. which is a primary supplier organic dairy farms in western Kentucky (2018). Milk price was determined through Organic Valley Dairy Benchmarks which provided an average pay price over a span of recent years (Miller, 2017). Finally, the output of price of hay was assumed based on the USDA's "National Organic Grain and Feedstuffs Bi-Weekly Report" as well as assumptions relating to expected premium's for organic hay compared to that of conventional hay (USDA, 2018). Further information related to the objective coefficients used can also be seen in Appendix B. In general, the data applied to this version of the model came from a wide range of sources which relies heavily on variety of different assumptions. With the expansion of future research, the goal is to re-evaluate the model with data primarily from research being conducted in Kentucky and Tennessee with less reliance on eclectic assumptions.

Results and Discussions

A partial whole-farm linear programming model was developed and solved for a southeastern United States organic dairy operation and for its feed ration components. Three milk production levels were ran which were 40, 45, and 50 pound averages on a per head/day basis. The 45 pound level was the base for the analysis and with a change in milk level right hand side coefficients relating nutrient requirements and dry matter intakes fluctuated. The change in objective function values, net returns, and other relevant results for the different milk levels can be seen in Appendix C. Although a 5 pound increase in milk production per head may sound modest at first, the results of the model indicate that at the whole farm level it can have a significant impact on net returns and decision variable choices.

At the milk production level of 40 pounds the expected net returns for the whole-farm scenario was $22,406.90. At the 45 and 50 pound levels, expected net returns was equal to $43.352.3939 and $60,311.32 When compared to the optimized activities of the other levels, this level utilized more pasture in production and as a feed source. Also, as a result of the lower milk level, more hay and less corn silage were produced then the other levels. This is related to nutrient requirements needed to sustain a given milk level and by requiring less feed more hay can be sold. As the milk level was increased more corn silage was needed to meet the increased minimum nutrient requirements; therefore, requiring slightly less land to be put into hay production. Also, at the higher levels less pasture ground was utilized demonstrating the need for substitutability to more concentrated feed sources. At the two higher levels, pasture was its minimum amount required by the “pasture rule.” A general hypothesis relating to this study was that maximizing grazing potentially offers higher returns, but at the production levels of interest and with the given feeds it appears that concentrates come at a good value compared to pasture.

The constraints that had the largest impact in determining the solution were those relating to land, the pasture rule, and minimum nutrient requirements. Labor in these scenarios proved not to be binding and resulted in excess slack in all cases. In the base case, pasture rule requirements were adjusted +/- 10% from the original value of 30% to test the effect that this would have. The resulting changes were minimal where relaxing the requirement resulted in the same net returns and increasing the requirement reduced net returns only slightly.

Conclusions

Linear programming was used in a whole-farm economic analysis of an organic dairy operation in the southeastern United States. Three milk production levels were analyzed and with incremental increases of 5 pounds milk per head/day expected net returns increased significantly with each tested level. Enterprise and ration composition differed slightly in each levels results, but overall in the low production level nutrient requirements were not as binding allowing more land to be utilized for hay production. Higher levels though required more silage to be utilized while compromising hay which still allowed for a feasible solution to be determined and increased net returns. Overall, organic hay production was a beneficial and complimentary enterprise to organic dairy production and the increased cost of supplemental feeds was worth it in relation to increased revenue from milk sales.

Future research will continue going forward and the model will continue to be expanded as there are shortcomings in this current version. The results of this paper are useful in giving insight into the general factors of this production system. Expansion will include the addition of other related decision variables related to pasture mixtures and other forage combinations. It will also include more constraints to better represent the nutrition of dairy cattle. Overall, the organic dairy system could offer opportunity to conventional producers, but further research must be done to test the sustainability of this type of system and market.

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Appendix A: Summation Notation Formulation of the Economic model

Maximize Net Returns:

$(\mathbf{1})$ $\boldsymbol{Objective\ Function}$:

$$MAX \quad Z\ (NR) = \sum_{O} Price_{O}Sell_{O} - \sum_{P} Cost_{P}Produce_{P} - \sum_{C} FeedCost_{C}SuppFed_{C}$$

Subject to (s.t.):

$(\mathbf{2})$ $\boldsymbol{Total\ Land}$: $\sum_{P} LandReq_{P}Produce_{P} \ \leq \ TotLand$

$(\mathbf{3})$ $\boldsymbol{Crop\ \&\ Hay\ Land}$: $\sum_{\boldsymbol{P}} \boldsymbol{C}ropHayLandReq_{\boldsymbol{P}}Produce_{P} \ \leq \ CropHayLand$

$(\mathbf{4})$ $\boldsymbol{Total\ Labor\ Endowment}$: $\sum_{M} TotLabReq_{M}Produce_{P} \ \leq \ TotLabEnd_{M} \ \ \forall \ M$

$(\mathbf{5})$ $\boldsymbol{Field\ Labor\ Endowment}$: $\sum_{P} FieldLabReq_{P,M}Produce_{P} \ \leq \ FieldLabEnd_{M} \ \ \forall \ M$

$(\mathbf{6})$$\boldsymbol{Herd\ Nutrient\ Requirements}$:

$$\sum_{F} ForNutr_{F,N}ForFed_{F} \ + \ \sum_{C} ConcNutr_{C,N}ConcFed_{C} \ \geq \ NutrLowLim_{N} \ \ \forall \ N$$

$(\mathbf{7})$ $\boldsymbol{Max\ Total\ Dry\ Matter}$: $\sum_{F} ForDM_{F}ForFed_{F} \ + \ \sum_{C} ConcDM_{C}ConcFed_{C} \ \leq \ MaxDM$

$(\mathbf{8})$ $\boldsymbol{Forage\ Maximum\ NDF}$: $\sum_{\boldsymbol{F}} NDF_{F}ForFed_{F} \ \leq \ MaxNDF$

$(\mathbf{9})$ $\boldsymbol{Minimum\ Forage\ Req}$: $\sum_{F} ForDM_{F}ForFed_{F} \ \geq \ MinForDM$

$(\mathbf{10})$ $\boldsymbol{Organic\ Cert.Pasture\ Rule}$: $ForDM_{"Past"}\ ForFed_{"Past"} \ \geq \ MinPast$

$(\mathbf{11})$ $\boldsymbol{Maximum\ Concentrates\ Fed}$: $\sum_{\boldsymbol{C}} ConcDM_{C}ConcFed_{C} \ \leq \ Max\ ConDM$

$(\mathbf{12})$ $\boldsymbol{Maximum\ Concentrates\ Fed\ (Indiv.)}$: $ConcDM_{C}ConcFed_{C} \ \leq \ MaxIndConDM_{C} \ \ \forall \ C$

$(\mathbf{13})$ $\boldsymbol{Set\ Herd\ Size\ and\ Milk\ Production\ Level}$: $Produce_{Milk} \ = \ 1$

$(\mathbf{14})$ $\boldsymbol{Milk\ Market\ Balance}$: $Sell_{"\mathrm{Milk}"} \ - \ Yield_{"Milk"}Produce_{Milk} \ \leq \ 0$

$(\mathbf{15})$ $\boldsymbol{Hay\ Market\ \&\ Feed\ Balance}$: $Sell_{"Hay"} + \ ForFed_{"Hay"} - \ Yield_{"Hay"}Produce_{"Hay"} \ \leq \ 0$

$(\mathbf{16})$ $\boldsymbol{Pasture\ Feed\ Balance}$: $ForFed_{"Past"} \ - \ Yield_{"Past"}\ Produce_{"Past"} \ \leq \ 0$

$(\mathbf{17})$ $\boldsymbol{Corn\ Silage\ Feed\ Balance}$: $ForFed_{"CornSil"} \ - \ Yield_{"CornSil"}Produce_{"CornSil"} \ \leq \ 0$

Table Added at a later time

Appendix B: Hypothetical Model Farm, Coefficients, and Assumptions

Table added at a later time

Appendix C: Economic Model Results

Appendix C - Table 1: Oragnic Dairy Model Optimal Solutions (50 Head)

		Average Milk Production Levels (lbs./Head/Day)		
		40 lbs.	45 lbs.	50 lbs.
	Exp. Net Returns	$22,406.90	$43,352.39	$60,311.32
Produce (Acres)	Pasture	150	81	81
	Hay	144	124	120
	Corn Silage	26	45	50
Sell	Milk (CWT/Herd)	7300	8212	9124
	Hay (Tons)	460	398	382
Feed (Tons/DM)	Pasture	825	365	365
	Hay	-	-	-
	Corn Silage	256	444	491
	Shelled Corn	-	-	-
	Soybean Meal	-	-	-
	Roasted Soybeans	7	44	47
	Oats	-	-	-
	Barley	-	-	-
	Wheat	-	-	-