ECONOMIC AND ENVIRONMENTAL EVALUATION OF DAIRY MANURE UTILIZATION FOR YEAR ROUND CROP PRODUCTION

by

ZANA CONSTANTIN SOMDA

(Under the Direction of Michael E. Wetzstein)

ABSTRACT

Dairy farms with limited amounts of land potentially develop an imbalance of manure nutrients. Reducing the impact of excess on-farm manure nutrients on water pollution necessitates a method for determining carrying capacity allocating the manure supply. An efficient approach to address this problem requires balancing manure nutrient and crop uptake and crop nutrient and animal use. A whole farm linear programming model was used to balance animal nutrient use, plant nutrient production in manure, animal nutrient production by crops and manure nutrient utilization by plants.

The theoretical underpinning of this analysis is expected utility maximization. The producer maximizes expected utility by considering milk production, manure production, the ability of crops to take up manure nutrients and the supply of forage for cow rations. This model is utilized to determine economically optimal dairy herd intensities, and crop mix for unrestricted and restricted scenarios of nutrient losses.

Representative farm operations were simulated for dairies with 600 available cropland acres and flexible cow numbers and for dairies with 500 cows and flexible cropland acres that utilized manure for year round crop production. The results showed that farms were substantially affected by the imposition of restrictions on N and P losses, although profitability decreases were smaller on the farm when restrictions were imposed on N alone than farms when restrictions were on P alone. When a fixed land base was net returns to land and management was reduced by 5.8% and 56.8% on the farms with N and P restrictions, respectively, compared with 6.7 and 9.7% when acre adjustments were allowed for a farm with 500 cows.

The model developed provides farmers with a tool most profitably meet current and future surplus nutrient applications. Whether dairy farmers are able to make cropland adjustments under N and P loss may well determine future sustainability and survival of the farming operations. If additional acres are not available or feasible to acquire, herd reductions may be necessary to meet restrictions on N and P.

INDEX WORDS: Linear programming model, Dairy operations, Dairy rations Dairy manure utilization, Forage production, Milk production, Profitability, Water pollution, Georgia-USA

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DEDICATION

To my dear Begaleaon Helene and Henrietta Somda with all my love.

"Success is like a mountain. Every time you a good deed, you climb a step higher until you reach the tip of the mountain which is heaven."

Helene Somda

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CHAPTER 1

INTRODUCTION

Background

Major structural changes in the livestock and poultry industries have occurred since the 1970s, when the United States Congress passed the Federal Water Pollution Control Act, also known as the Clean Water Act (33 U.S.C. § 125(a)). The Clean Water Act (CWA) establishes a comprehensive program for restoring and maintaining the chemical, physical, and biological integrity of the nation's waters. In response to the CWA, the Environmental Protection Agency (US-EPA) established two regulatory programs pertaining to livestock and poultry operations, commonly referred to as animal feeding operations (AFOs) and concentrated animal feeding operations (CAFOs). Despite more than twenty years of regulation, there are persistent reports of discharge and runoff of manure and manure nutrients from confined animal operations. As a result, the existing regulations have been recently updated to reflect structural changes in these industries over the last few decades (see EPA's 2003 Final Rule).

Since the 1970s, when the existing regulations for CAFOs were first instituted, total consumer demand for meat, eggs, milk, dairy products has continued to increase. To meet this demand, U.S. livestock and poultry production has risen sharply, resulting in an increase in the number of animals produced and the amount of manure and wastewater generated annually. Not only are more animals produced each year, but also the animals are larger in size. It is reported that economies of size accounts for much of the growth in farm size (MacDonold, et al., 2000; McBride, 1997). At the same time, cost and efficiency considerations are pushing farms to become more specialized and intensive. Steep gains in production efficiency have allowed farmers to produce more with fewer animals because of higher per-animal yields and quicker turnover of animals between production and the consumer market.

Similar to the other livestock and poultry sectors, the dairy industry has also undergone significant structural changes driven by competitive economic, social and political forces toward integrated confinement operations since the mid 1980's. These structural changes encompass large farms size, geographical location of firms, changes in firms' market shares, changes in organizational arrangements used by firms, and changes in the competitive strategies of firms. This shift is a moving trend toward higher performance efficiency and production self-sufficiency in a competitive market. Large firms experience economies of size through labor saving techniques, input purchasing and energy and overhead costs. Organizational features include forage production, feed mills, milk packaging plant, and transportation and distribution divisions.

Production efficiency gains at dairy operations have resulted in higher per-animal yields of milk (NMPF, 1999). These efficiency gains have allowed farmers to maintain or increase production levels with fewer animals. Although animal inventories at dairy farms may be lower, this may not necessarily translate to reduced amounts of manure generated on a farm. Higher yields are largely attributable to improved, and often more intensive, feeding strategies. While this results in lower nutrient excretion per unit of milk, it also results in greater nutrient excretion per cow.

Historically, the majority of farming operations were concentrated in rural, agricultural areas, and manure nutrients generated at animal feeding operations were readily incorporated as a fertilizer in crop production. In an effort to reduce transportation costs and streamline distribution between animal production and food processing sectors, livestock and poultry operations have tended to cluster near manufacturing plants as well as near end-consumer markets (McBride, 1997; Kohls and Uhl, 1998). Ongoing structural and technological changes in these industries is also influencing where facilities operate and is contributing to locational shifts between the more traditional production regions and the more emergent regions (Kohls and Uhl, 1998; McBride, 1997; MacDonald et al., 2000). This trend toward fewer, larger, and more industrialized operations has contributed to large amounts of manure being concentrated within a single geographic location.

Increasingly, more animals are produced annually at fewer AFOs, leading to an increasing share of animal production at larger operations that concentrate more animals (and thus manure and wastewater) at a single location. This continued trend toward fewer but larger operations, coupled with greater emphasis on more intensive production methods and specialization, has coincided with increased reports of accidental large-scale spills from these facilities and has fueled concern that manure runoff is contributing to the eutrophication of certain vulnerable U.S. waterways (USEPA, 2000).

Nationally, there are an estimated 1.3 million farms with livestock. About 238,000 of these farms are considered animals feeding operations producing annually more than 500 millions tons of manure that, when improperly managed, can pose substantial risks to the environment and public health. Operations in more traditional producing states tend to grow both livestock and crops and tend to have adequate cropland for land application of manure. Operations in these regions also tend to be smaller in size (McBride, 1997; Outlaw et al., 1996). In contrast, confinement operations in more emergent areas, such as dairy operations in the Southwest, tend to be more specialized and often do not have adequate land for application of manure nutrients (McBride, 1997; Gollehon and Caswell, 2000). Production is growing rapidly in these regions due to competitive pressures from more specialized producers who face lower per-unit costs of production (McBride, 1997). These geographic shifts in farming operations may be shifting the flow of manure nutrients away from areas where these nutrients can be effectively used to areas where they cannot be easily absorbed.

Despite more than 25 years of regulation of CAFOs, reports of discharge and runoff of manure and manure nutrients from these operations persist. A USDA analysis of 1997 Census data shows that animal confinement operations with more than 1,000 animal units account for more than 42 percent of all confined animals but hold only 3 percent of all cropland on these operations (Letson and Gollehon, 1996). As a result, large facilities need to store significant volumes of manure and wastewater that have the potential, if not properly handled, to cause significant water quality impacts. By comparison, smaller operations manage fewer animals and tend to concentrate less manure nutrients at a single farming location. Smaller operations also tend to be more diversified, engaging in both animal and crop production. These operations often have sufficient cropland, and fertilizer needs, to land apply manure nutrients generated by the farm's livestock operation. The greatest potential risk is, therefore, from the largest operations with the most animals, given the sheer volume of manure generated at these facilities. Because these larger operations typically have inadequate land available for utilizing manure nutrients, the amount of excess manure nutrients being produced has been rising both at the farm and county levels. At the same time, the opportunity to jointly manage animal waste and crop nutrients decreases (Gollehon and Caswell, 2000).

Among the principal reasons for the farm-level excess nutrients generated is inadequate land for utilizing manure. USDA defines "excess manure nutrients" on a confined livestock farm as manure nutrient production that exceeds the capacity of the crop to assimilate the nutrients. According to the USDA report, the amount of nutrients, and the amount of excess nutrients, produced by confined animal operations rose about 20 percent from 1982 to 1997 while cropland and pastureland controlled by these farms declined on average from 3.6 acres to 2.2 acres per 1,000 pounds live weight of animals during the same period. Roughly 60 percent of nitrogen (N) and 70 percent of phosphorus (P) generated by large-sized operations must be transported off-site. The regions of the United States that show the largest increase in excess nutrients between 1982 and 1997 are the Southeast and the Mid-Atlantic. The USDA's analysis also indicates which counties have potential for excess manure nutrients. These excess nutrients represented manure nutrients produced in a county in excess of the assimilative capacity of crop and pastureland in that county. The areas of particular concern for potential county-level excess manure nutrients include Georgia.

Dairy production in Georgia was in a growth phase from the mid 1980's through the mid 1990's reaching a peak of 1.56 billion pounds of milk in 1994. Since 1995, market conditions have resulted in a down turn in milk production (Figure 1.1). Estimated milk production for 1999 exceeded 166.9 million gallons with a farm gate value of almost $23 million and the total economic value of the dairy industry was over $75 million. While the production throughout 2000 was down 0.96%, the demand increased about 3%. Historical cattle populations and crop data per county are available from the *Georgia Agricultural Facts* published by the USDA-National Agricultural Statistics Service (NASS). The analysis of these data showed that the dairy operations have changed dramatically between 1990 and 2002 as the number of animal units concentrated in fewer counties. Overall, the total number of milking cows steadily declined from over 147,000 animal units in 1990 to less than 123,000 in 2002, a 17 percent decrease.

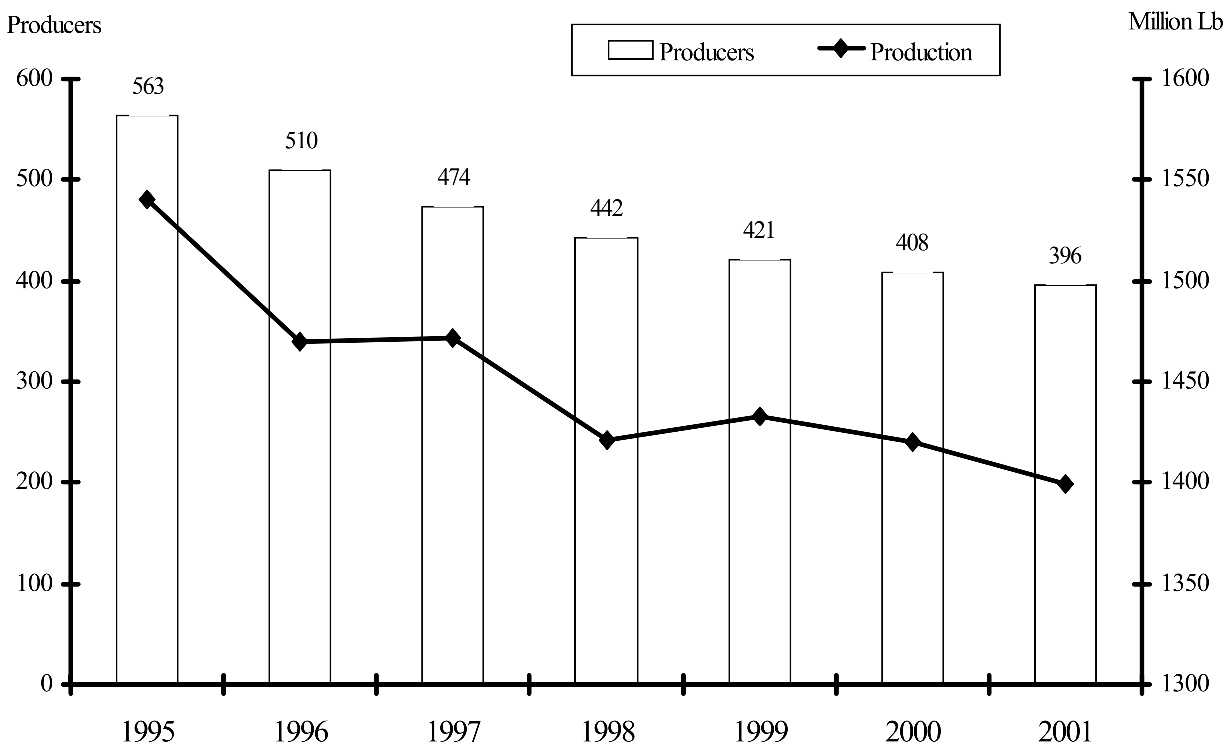

Figure 1.1. Georgia dairy producers and milk production from 1995 to 2001

Similarly, there were 90 counties with less than 500 animal units and 40 counties with over 1000 animal units in 1990 compared to 103 and 33 counties in 2002, respectively (Table 1.1). The number of counties without dairy cows steadily increased from 36 in 1990 to 73 in 2002, a 51 percent increase. During the same period, the average number of cows per county increased over 10 percent in the counties with over 1000 animal units. Macon County was the leading county in number of milk cows on January 1, 2003, with 10,800 head followed by Putman County with 7,600 head (Figure 1.2). A large share of the growth has taken place in the southern part of the state where lower population density, warmer climates, and poor soil fertility favor animal agriculture. In contrast, urban pressures and economic and environmental concerns are limiting farming activities in northern Georgia. Dairy farmers who wish to remain in the industry have to seek ways to reduce the costs of production by adopting, for example, low-input production methods and management practices to avoid periods of relatively high cost inputs. With the exception of feed, waste disposal costs are by far the most important variable cost in dairy farm operation. In some cases, environmental and financial goals are in direct conflict.

Dairy production in Georgia as in the United States occurs primarily in concentrated animal feeding operations (CAFO) where huge volumes of nutrients in feeds are imported to support milk and meat production. For more efficient milk production, animals are confined in loafing areas where they deposit large amounts of manure that must be collected, stored and reused to irrigate forage crops in the place of or addition to conventional inorganic fertilizers (Newton et al., 2003). Trends in manure production are directly related to trends in animal population. As the structure of the dairy industry is shifting toward fewer, but larger numbers of animals in confinement, utilization and disposal of animal waste on croplands becomes an issue of environmental concern.

Table 1.1 Number of counties and average number of milking cows by animal unit (AU) size, 1990 – 2002

Year	0	1 - 500		501 - 1000		1001 - 2500		>2500	
	County	County	[1]AU	County	[1]AU	County	[1]AU	County	[1]AU
1990	36	54	224.7	28	721.6	27	1457.2	13	5644.5
1991	28	66	205.1	21	716.2	29	1563.8	14	5623.6
1992	37	55	195.9	26	737.0	26	1546.3	14	5131.3
1993	34	61	182.4	26	741.2	23	1570.5	14	5091.7
1994	53	38	229.4	32	705.2	23	1792.0	12	5349.1
1995	56	36	297.7	34	679.7	20	1871.6	12	5563.1
1996	58	44	297.2	25	718.9	22	1756.8	10	6378.4
1997	58	46	295.3	23	722.7	22	1738.3	10	6142.5
1998	58	48	291.3	20	689.2	23	7103.9	10	6418.9
1999	61	45	274.7	20	661.5	22	1498.8	11	5921.4
2000	67	37	268.4	19	672.1	26	1522.9	10	6310.8
2001	71	32	287.1	22	684.9	23	1465.0	10	5712.5
2002	73	30	289.1	23	689.2	21	1495.5	12	6027.0

[1]AU = average number of animal units per county.

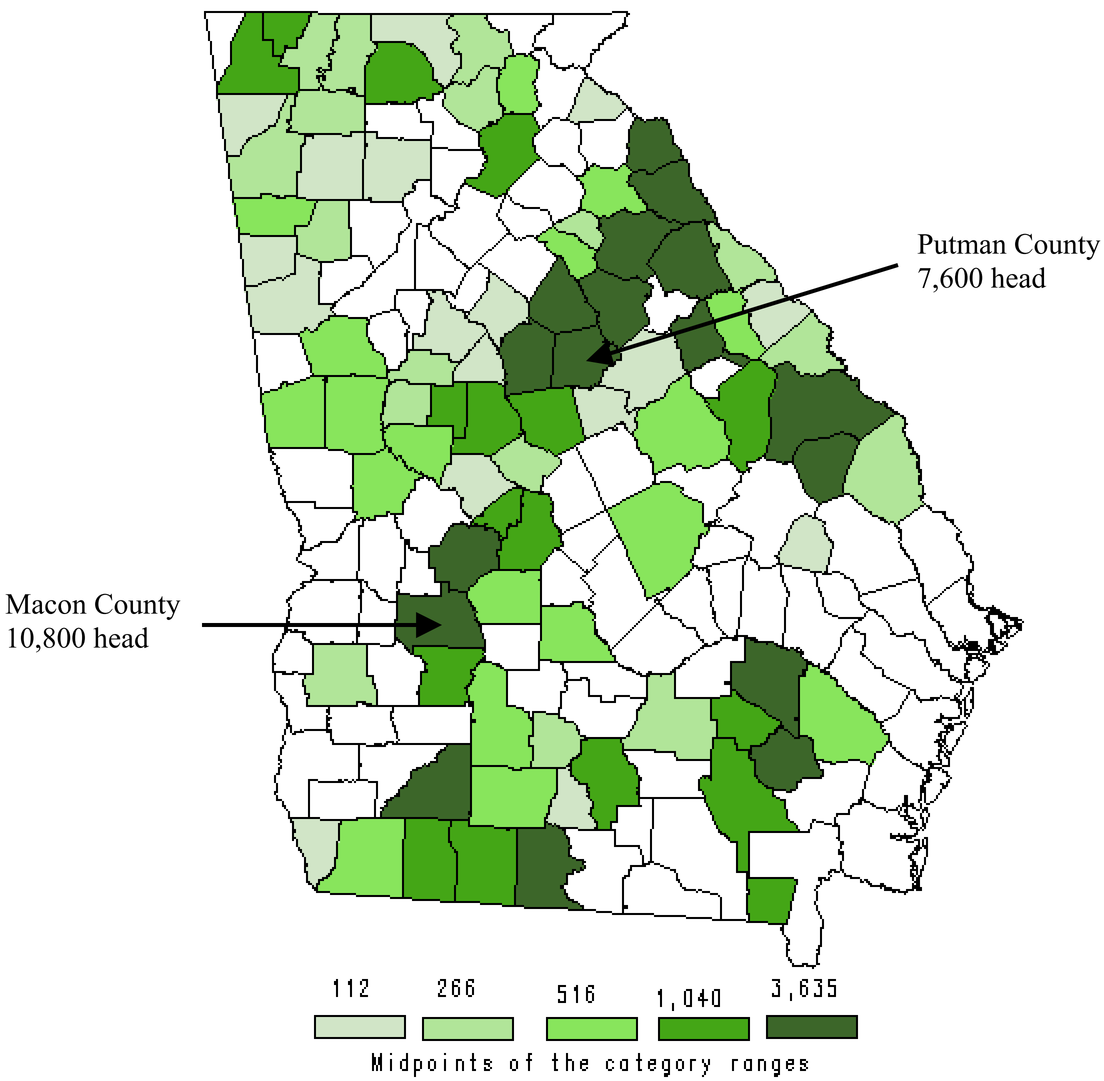

Figure 1.2. Georgia dairy farms by category per county in January 1, 2003
Source: *www..georgiastats.uga.edu*

A major environmental concern with land application of manure is potential contamination of ground and surface waters with excess nutrients. When manure application rates exceed the capacity of the land to assimilate nutrients, repeated applications can lead to a buildup of nutrients in the soil. This increases the potential for some of the nutrients to move from the field through leaching and runoff into water resources and impair water quality. As a result, regulators are focusing on the ways to induce animal producers to operate in a manner to protect the environment while maintaining profitability and competitiveness. In addition, there are active programs in many states to develop training materials and distribute information tailored to local manure management situations (for example, AWARE, 2003).

Estimation of the spatial and temporal relationships between the quantities of dairy manure production and manure nutrients excreted and recoverable for cropland application provide insight to identify counties in Georgia where animal production might contribute to water pollution. The analysis of data from the *Georgia Agricultural Facts* using the USDA's estimated coefficients (Kellogg et al., 2000) revealed that nearly 113 million pounds of manure N and over 30 million pounds of manure P (as excreted) were produced by all cattle in Georgia in 1990. However, manure nutrient production decreased for milk cows by 19 percent between 1990 and 2002. Given the fact that dairy cows are kept in confinement facilities, the increased share of dairy cows in the mix of cattle increases the portion of the total manure nutrients excreted that can be collected after accounting for losses for land application. Of the total amount of manure nutrients produced (as excreted), approximately 25 percent of the N and 37 percent of P were recoverable from the confined facilities and thus were available for land application. Dairy cattle often spend portions of their time in pasture areas where a significant proportion of the nutrients excreted would have been dropped and used by plants. The remaining nutrients – those that are not recoverable - would have been lost to the environment.

On another hand, land available for manure application fluctuates from year to year due to changes in land use and cropping patterns. Where recoverable manure nutrients exceed the assimilative capacity of an entire county, the potential is high for runoff and leaching of manure nutrients and subsequent water quality problems. As the exact amount of the recoverable manure nutrients is unknown and because the quantities of unrecoverable manure nutrients produced each year are large, it is possible that they contribute to water quality degradation in livestock production counties. As a result, the ratio of confined livestock to acres available for manure application is used as a measure of livestock pressure in an area, and, as such, is an indicator of areas where excess manure nutrients may occur. In general, the concept of excess of manure nutrients is limited to the use of manure for land application.

The capacity of cropland to assimilate nutrients can be estimated as the amount of nutrients taken up and removed at harvest of crops. Based on production data estimated for nine agronomic crops, recoverable manure nutrients are substantially lower than overall assimilative capacity for dairy farm operations in Georgia. The assimilative capacity estimates however, vary from county to county and among years because of variability in yields and acres harvested. Yields vary because of weather and change in production technology. For this reason, assimilative capacity should not be considered fixed. Nevertheless, county-level estimates of excess nutrients are useful indicators of which counties face serious problems with livestock waste utilization and disposal.

The potential for nutrient contamination of water from manure sources in Georgia can be easily visualized by the spatial and temporal trends of the county-level cattle number. A majority of counties have dairy manure N or P nearly equal to or less than crop nutrient requirements. Examination of the data used in estimating manure nutrient excesses reveals that there were only 25 and 38 more counties in Georgia with excess manure N and P in 2002 than in 1990, respectively. The changes over time in the number of counties that have county-level excess manure nutrients are an indication of whether the situation is improving or worsening. It must be recognized that county-level excess manure nutrients overstate the potential of over application of manure because of the unrealistic restriction that farms cannot export manure to surrounding counties. In addition, where alternatives to land application technologies have been adopted, the county-level excess manure nutrients will be overestimated.

Alternatively, estimates of excess manure nutrients at the farm level provide a measure of the off-farm export requirements in the county. It measures the balance between assimilative capacity and the quantity of manure nutrients produced on a representative farm within a county. Farms that produce more manure nutrients than can be applied to the land without accumulating nutrients in the soil have excess manure nutrients. In some cases a farm has sufficient cropland to properly utilize the manure on the farm. In other cases the farm operator must use land owned or operated by others to avoid over-applying manure. The Georgia county-level estimates indicate that the problems associated with livestock waste utilization and disposal have become more widespread over the past decade as the structure of animal agriculture shifted toward fewer and larger operations.

Growing public opposition and environmental concerns associated with large numbers of animals in confined localities have led to the development and implementation of regulatory waste management plans at the federal, state and local level of government (Ribaudo, 1997; Centner, 2000). Georgia regulations for manure disposal also require livestock producers to implement management plans so that the manure nutrients, especially N and P, cannot exceed the needs of crops grown and soil reserves on land where manure will be applied. For a dairy operator, this policy change could result in need to find additional land on which to spread manure, thereby, increasing the cost of transporting and applying animal waste to more land. Such costs may be substantial and could affect the economic viability of the operation. For dairy farms with scarce cropland, some producers may apply manure at rates that lower disposal costs rather than optimize the nutrient contribution to the crop. Alternatively, some producers may need to transport manure off-site, and incentive may be required to encourage local farmers without animals to use manure. Because the distance that manure can be hauled for land application has practical limits, alternative methods of manure utilization must be adopted.

Management objectives of the farmers, subjective risk perceptions and attitude towards all goals can be related to the sensitivity of the predicted farmer responses to the policy alternative. The dairy farmers operate under widely differing constraints, such as amount of cropland, types and number of crops per year (single, double or triple), opportunity to irrigate, local hauling to alternative fields and N versus P application restrictions in addition to a considerable degree of uncertainty related to the production levels and market prices. Because of its potential to provide plant nutrients, animal manure must be contained and stored until it can be applied to the land at the appropriate time and rate to limit leaching and runoff into water bodies. Unless the manure is properly managed, significant environmental deterioration is likely. When the manure is over managed, the cost of a particular dairy producer becomes greater than that of other competitors restricting his/her ability to survive in the market.

One major objective for proper manure management is defining an acceptable balance between the farmer's economic incentives and environmental quality. Nutrient losses to surface and groundwater can be avoided, and significant economic value can be achieved from manure as fertilizer, if management strategies account for the nutrient flows to, from and within a dairy farm (Lemberg et al., 1992). Despite a number of research efforts to identify safer and more efficient nutrient utilization management practices (Fleming, Babcok, and Wang, 1998), dairy manure continues to have decisive impacts on producers' choices among the sizes and locations of their dairies. As livestock population becomes spatially concentrated (Kellogg et al., 2000), the production of recoverable manure nutrients exceeds the assimilative capacity of croplands available for manure application, especially in high production areas (Lander, Moffitt and Alt, 1998). However, the literature has not explicitly explored land-based agronomic recommendations and economic incentives associated with dairy manure utilization for forage production in Georgia.

Further regulations to limit manure application on land based on P standards could significantly increase (1) the acreage needed for spreading, (2) manure application costs, and (3) the number of farms that will need alternative ways to dispose of manure. To maximize whole-farm income, therefore, a dairy producer needs to account not only for the value of milk, but also the resource value as well as the management cost of manure produced. This requires cost-effective alternative technologies to optimize nutrients flow and utilization within the total dairy farm system. As a result, a dairy operator may decide to dispose of the manure at least cost - or maximum benefit - by trading off the manure nutrient benefits with its costs of application and transport to nearby areas where crop producers are willing to accept the manure as a source of plant nutrients.

Factors that affect dairy farmers' decisions include expected milk price, manure and wastewater management costs, expected crop yield response and price, risk perception, role of government programs designed to minimize risk to farmer income and water pollution. Manure management requires an understanding of milk production technologies, soil-plant-water processes and economic factors affecting choice of crop planted. A possible source to study dairy manure use in Georgia is the herd numbers. It is difficult to assess dairy manure use directly, because there are few, if any, records of manure production. However, there is relatively a better time series data of dairy farm and herd numbers available per county. Examining recent history of dairy operations in Georgia reveals that through most of the 1990s there were sharp decreases in the number of dairy operations. Although only a relatively few counties have excess manure nutrients due to dairy cattle populations, dairy cattle are still part of animal mix contributing to potential water quality problems in Georgia. Dairy cattle often spend portions of their time in pasture areas, feeding and lounging barns, and milking parlors. Manure dropped in any of these locations may be of concern.

As previously described, the estimated 406 dairy farms in Georgia with over 85 thousand head have been located near infrastructure facilities in counties with less croplands. One possible explanation of this phenomenon is the ongoing consolidation in the animal production industry (MacDonald et al., 2000; McBride, 1997) to minimize the downside of risk associated with milk production. Another explanation is that, historically, larger operations have been found to be more profitable relative to small operation units. As a larger number and size of farms are being located in some watersheds, concerns about water quality impairment increase. With larger amounts of manure production per farm, there was a motivation for bringing a larger amount of land under forage crop production to enhance the expectation of profits for manure nutrients utilization.

In Georgia, with its estimated 7,500,000 acres of farmland, 11,813 lakes with a total acreage of 425,382 and 70,150 stream miles, it is unknown precisely how much manure agriculture is used on a farm basis and how much manure nutrients are entering the water bodies. In absence of this information, policy proposals and decisions regarding comprehensive manure nutrient management are made under incomplete, and potentially inaccurate, information. This level of information is desirable to better understand the balance between manure production and crop nutrient demand by county basis. Crop rotation by farm identifies the variation in nutrients demand owing to unique soil, climate and market conditions in a county. To better understand manure nutrient demands in the context of cropping mix in Georgia, this analysis focuses closely on a dairy farm model that optimizes milk production while balancing manure nutrients with crop demand and minimizing ration costs over produced and purchased feed nutrients.

Problem Statement

A dependable manure management plan is vital to the economic development of the dairy industry in Georgia. Proposals to develop comprehensive nutrient management plans have created serious problems about estimating animal manure production in the state. Furthermore, there is little information on the potential agricultural use of manure nutrients in Georgia. Specifically, dairy farmers do not have an economic model to justify their manure management decisions. On the other hand, policy makers do not have a clear understanding of the spatial and temporal trends of dairy manure available for use by farms in Georgia. An understanding of manure production and manure nutrient utilization patterns within a dairy farm is imperative to improved decision-making and dairy production policy in Georgia. This dissertation will address the economic returns from a dairy farm when alternative manure management policies are implemented.

Presently, available potential sources to quantify manure production and to forecast manure use by county in Georgia are insufficient. The potential sources of information on dairy manure production are the estimates made by county extension agents on the cattle population numbers on a county basis. There are aggregated to reflect measures of dairy numbers for a given operation for the county or total number in the entire state for all dairies combined. One limitation of using these data is that dairy numbers are not static and cows may be moved from, say, one county to another. There is also a tendency to under- or over-estimate the number of cows and size of cropland. Most importantly, manure production and utilization cannot be broken down on a county by farm level and, therefore, site-specific manure use patterns remain unknown. Alternatively, current models of manure management examine only the agronomic and environmental parameters while disregarding the economic forces driving the farmer's choice of the dairy size and crop to be planted. Balancing agricultural manure demand and use requires economic and institutional variables, such as expected profits and government regulatory policies.

Demand for manure is driven by several economic factors. The decision to apply manure on a given crop depends in turn on several factors, such as the market price a producer expects for the crop, the cost of inorganic fertilizers, the downside risk associated with manure use, the effect of government programs and total cropland available. A thorough examination of manure utilization in agriculture must, therefore, take into consideration these economic factors in addition to the agronomic and environmental relationship. A key variable, manure production, results directly from milk production. On the other hand, the demand for manure is derived from the value of the crop produced. Therefore, the appropriate modeling strategy is the approach that examines the changes in the cropping mix patterns committed to manure application in addition to profitability derived from milk and crops.

Several alternatives are perceived to influence farm nutrient balance and the potential to increase profit and/or reduce pollution. The on-farm constraints include animal feed requirement, forage availability and fertilizer value of manure whereas the environmental constraints represent current and future regulations of land application of manure based on N and P rates. Changes in nutrient standards for manure application have an important bearing on manure application rates. Conceivably, these changes will impact farm returns above variable costs through changes in cropping patterns and animal feeding regime as well as milk output. Conversely, if the manure produced exceeds local use potential, a dairy farmer has the option to reduce the herd size and, therefore, both manure and milk outputs. Additional options may be to store and then transfer the excess manure to other growing periods or greater distances until enough land can be found for application. The farmer can utilize alternative cropping practices that entirely eliminate the need to transport the manure off-farm.

To summarize the problems, while efforts have been directed toward better understanding of animal manure issues in the nation, the spatial and temporal dimensions of dairy manure in Georgia are missing from this discourse. Knowledge of dairy and crop production at a farm-level can aid future projection of water pollution problems related to dairy operation. The currently available dairy nutrient management plan in Georgia is solely based on balancing the amount of nutrients generated on a farm and crop nutrient needs and is thus inappropriate for profit optimization forecasting. Accurately modeling dairy operation requires a consideration of agronomic, economic and institutional determinants.

Various accounting, econometric, optimization, and simulation models have been developed to assist producers in planning manure and nutrient management programs (Weersink, Jeffrey, and Pannell, 2002). However, only optimization models have the advantage of providing the solution that best achieves the specific objective, and most importantly allows for a detailed specification of farm-level activities. As a result, several optimization models, including linear programming and spreadsheets, have been used in the literature to investigate the role of manure in crop production and to develop manure nutrient budgets and disposal technologies (Allison et al., 1999; Wang and Sparling, 1995; Henry et al., 1995; Govindasamy et al., 1994). Most of these studies focused on the balance between manure nutrient and crop uptake (manure-nutrient balance) and the balance between crop nutrient and animal use (crop-nutrient balance).

As part of a Comprehensive Nutrient Management Plan, researchers at The University of Georgia have developed Nutrient Balance Spreadsheets to assist livestock producers to balance their nutrient application on each field based on the crop nutrient needs and manure and soil analyses. However, these models have limited information on costs associated with crop and livestock production, feed intake and manure excretion, storage, hauling, and application. A manure management tool for forecasting optimal milk production level while minimizing the impact of manure nutrients on the environment will be of importance to Georgia dairy farmers and regulators. A farm economic model is aimed at linking milk production level with the balance between manure production and utilization to grow crops for the dairy rations and for sale.

This study is undertaken to further assess the economic and environmental feasibility of land application as a dairy manure management strategy. In linking manure nutrient demand with cropping patterns, the model will complement the Georgia Nutrient Generation

Spreadsheets. It will also improve the information base for future Georgia agricultural policy where animal wastes are involved. The desire for a farm specific nutrient management tool leads to this study.

Objectives

The primary purpose of this study is to develop a dairy farm model that can be used to compare profitability and environmental pollution risks for alternative land application rates of manure nutrients. The specific goal is to use a linear programming approach to evaluate profit-maximizing enterprise combinations for cropping systems that match dairy cows' nutritional needs to forage produced using manure as the nutrient source with farm size varying according to the level of milk production. Developing such a dairy farm economic model requires:

1. Developing a linear programming model for use to maximize profit from a large dairy enterprise considering agronomic, economic and environmental determinants. The objective function is to maximize profits from a dairy enterprise considering milk production, manure production, crops grown for forage and crops grown for sale while maintaining a balance of nutrients in the system.
2. Conducting a sensitivity analysis given the changes in crop mix patterns and economic and institutional conditions.

Procedures

Objective 1 is achieved by developing an optimization model based on economic theory of expected utility maximization. Finally, sensitivity analysis is conducted on the parameters of the dairy optimization model to trace the effects of alternative nutrient restrictions, crop rotations, prices and dairy herd sizes.

To summarize, manure-nutrient balance and crop-nutrient balance as well as return over feed costs are compared for lactating cow diets divided into five groups according to the level of milk production. The DART ration model (Smith et al., 1994) is used to generate biological values to characterize the energy and protein content of each feed for the specific group for which the diet is being formulated. All sources of receipts and costs arising from animal and crop production are recognized in the profitability analysis. With producer's predetermined or existing plan, economic factors (net profit per cwt of milk and crop acreage) are presented and environmental concerns (excess nutrients) are shown.

After developing and executing the model, sensitivity analyses are performed in order to allow risk considerations for a dairy operator. Whether dairy farmers are able to make land adjustment under restrictions on nitrogen and phosphorus losses may well determine future sustainability and survival of the farming operations. If additional lands are not available or feasible to acquire, herd reductions may be necessary to meet restrictions on nutrients losses, dropping profitability even further. The combination of individualized input for each farm and/or field allows for customized, farm-specific manure management plans. An important feature of the model is that the environmental benefits of manure utilization for crop production and better nutrition of animals are accounted for. The model can be easily adapted for conditions encountered in other situations where animal wastes are involved.

This dissertation is organized into six sections including this introductory Chapter. After reviewing some related literature in Chapter 2, the expected utility maximization framework is used in Chapter 3 to describe theoretical dairy farm decisions. In Chapter 4, a linear programming model is constructed to determine the economically optimal dairy herd intensities, manure application rates, and crop mix for unrestricted and restricted scenarios of manure nutrient application rates. Sensitivity analyses are conducted in Chapter 5 and the major findings and policy implications of this study are summarized in Chapter 6.

CHAPTER 2

REVIEW OF RELATED LITERATURE

Recent Trends in the Dairy Industry

Major structural changes in the dairy industry have occurred since the 1970s, when the regulatory controls for CAFOs were first instituted. Among dairy operations, net farm income remained relatively stable during the mid- to late 1990s. USDA reports in 1997 net dairy farm income averaged $36,600 per operation while the average debt-to-asset ratios ranged from 17 percent to 26 percent, depending on facility size (USDA/ERS, 1999). Whereas the number of dairy cows on U.S. farms dropped from more than 10.7 million cows to 9.1 million cows between 1974 and 1997, the average number of fed cattle and dairy cows per operation more than doubled during this period, rising to nearly 250 fed cattle and 80 milking cows by 1997 (USDA/NASS, 1999). The average annual milk production rose from under 10,000 pounds per cow in 1970 to more than 16,000 pounds per cow in 1997 (NMPF, 1999). In general, farms are closing, especially smaller operations that cannot compete with large-scale, highly specialized, often lower cost producers. USDA reports that in a normal year, 3 percent to 4 percent of all livestock and poultry farm operators discontinue farming for a variety of financial and personal reasons (Stam, et al., 1991). Involuntary exits caused by financial stress vary considerably by farm size and production region, and commodity produced (Bentley, et al., 1989).

Historically, dairy farms are concentrated in proximity to consumption centers due to the perishable nature of milk. However, the dairy industry being one of the most heavily regulated commodity sectors since the Great Depression has been under increasing competitive economic, social and political pressures since the mid 1980's (Chavas and Klemme, 1986; Adelaja, Miller, and Taslim, 1998, Yavuz et al., 1996). The ongoing structural and technological change is also influencing where facilities operate and is driving geographic shifts in where milk is produced.

In a competitive market, dairy production will shift to that region which is the most productive or has lower production costs (Chavas and Magand, 1998; Gilbert and Akor, 1988) and more lenient environmental control policies. Various studies have used environmental indicators and spatial lag factors in bio-econometric models to explore this geographical shift in the U.S. dairy farm location (Rahelizatovo and Gillespsie, 1999; Yavuz et al., 1996). Some of these models incorporated biological and physical components from a risky production environment into an input/output representation of a dairy growth and survival with production technology and productivity measurements in various regions of the U.S. (Kirkland and Mittelhammer, 1986; Tauer and Lordkipanidze, 1999; Rahelizatovo and Gillespie, 1999).

As reported by Census data, the locational shifts in dairy production are creating closer ties between producers and various industry middlemen (USDA/ERS, 1999). This continued relationship is driven by the competitive nature of dairy production and the dynamics of the milk marketing system, in general, as well as seasonal fluctuations of production, perishability of dairy products, and inability to store and handle fresh milk. Most farm milk is generally produced under marketing type contracts by independent, privately owned facilities (Manchester and Blaney, 1997). Contracts reduce farmer exposure to price risk by combining market functions and allowing them to secure a constant price and buyer (Kohls and Uhl, 1998). As farms become larger, they may contract out some phases of the production process with specific detail regarding the production inputs used, outputs level and facilities where the animals are raised (USDA/ERS, 1996; Martinez, 1999). This raises policy questions regarding ownership responsibility for ensuring proper manure disposal and management at the animal feeding site. In general, these contracts do not deal with management of manure and waste disposal.

Environmental Impact of Dairy Manure

Despite substantial improvements in the nation's water quality since the inception of the Clean Water Act, agricultural operations including CAFOs now account for a significant share of the remaining water pollution problems in the United States. As reported in the National Water Quality Inventory: 2000 Report, pollutants from animal manure and wastewater continue to be released from treatment and storage lagoons as well as from cropland where manure is often applied. The leading pollutants impairing surface and ground water quality in the United States include nutrients (particularly N and P), organic matter, pathogens, and oxygen depleting substances. However, the composition of manure at a particular operation depends on the animal species as well as on the composition of animal feed. USDA reports that the dairy industry is the second largest producer of CAFO manure nutrients, generating 25 percent (0.6 billion pounds) of all N and 17 percent (0.2 billion pounds) of all P (Kellogg et al., 2000).

The scientific literature, which spans more than 30 years, documents how improperly managed manure has caused serious acute and chronic water quality problems throughout the United States. Among the principal reasons are excess manure nutrients relative to the capacity of crops to assimilate the nutrients on the confined livestock farms. USDA data show that the amount of nutrients, and the amount of excess nutrients, produced by confined animal operations rose about 20 percent from 1982 to 1997. During that period, cropland and pastureland controlled by these farms declined from an average of 3.6 acres in 1982 to 2.2 acres per 1,000 pounds live-weight of animals in 1997. These findings resulted from the consolidation trends in the industry toward larger-sized operations that tend to have less available land on which to spread manure.

Traditionally, manure management has been concerned with optimizing the economic return from its nutrients used for crop production. In general, nutrients in manure are valued at the price of commercial fertilizers only to the extent that plant needs are met. Today, the agronomic and economic requirements of nutrient management remain central, but in addition, the process considers the potential impact of these nutrients on the environmental quality. When manure application rates exceed the capacity of the cropland to assimilate nutrients, the potential exists for a buildup of nutrients in the soil and water quality impairment through leaching and runoff. Thus, manure nutrients constitute an ecological and economic liability when managed as a waste for disposal. Large dairies with limited amounts of land potentially develop an imbalance of N and P for the total farm creating serious environmental concerns regarding water and soil pollution.

The main source of environmental problems created by the dairy industry is the quantity of waste and the way it is managed. In the literature of animal agriculture, a number of economic models have being developed to assess the on-farm cost of manure handling. Fleming, Babcock and Wang (1998) estimated the net cost to a farm for spreading manure at agronomic rates to meet the requirements of a nutrient management plan. Ribaudo et al. (2002) assessed the impact of proposed EPA provisions on costs of land application of hog manure. Similarly, Yap et al. (2001) developed a non-linear programming model to determine the optimal mix of management activities for a phosphorus-based regulation. Other researchers used an optimization framework to predict how a representative farm's return or costs would change under an N and/or P-based restriction on manure applications (Huang and Magleby, 2001).

Huang, Magleby and Somwaru (2001) applied a whole-farm modeling approach using survey data on Heartland hog farms to assess the economic impacts of alternative manure management regulations.

Results from these studies that P-based regulation of manure application to cropland decreases whole-farm returns above variable costs and increases crop acres planted. The general conclusion is that P-based policy increases manure disposal costs and reduces returns more than an N-restriction (Yap et al., 2001; Fleming et al., 1998; Schnitky and Miranda, 1993). Because of the narrow N and P ratio in animal manure, many large farms have to lease additional land to meet restrictions on manure P application.

In addition to renting additional land, there are three other adverse effects on the cost of applying manure based on P standard. First, the distance traveled to haul the manure increases causing transportation costs to rise. Secondly, the adjusted application rates are much lower than under nitrogen standard resulting in nitrogen under-application. The farmer has then to pass over the field again with commercial fertilizer in order to supply the remaining nitrogen needed by crops. This causes farmer to bear both manure and commercial fertilizer application cost for the same land area. Thirdly, the time needed to apply manure is increased, which results in higher labor and other operational costs.

While these research efforts generally incorporate restrictions on land availability, most farm-level models do not endogenously consider the effects of competition from nearby farms also seeking land on which to spread manure. In this line of research, Wimberley and Goodwin (2000) examined the cost of exporting surplus poultry litter from the Eucha/Spavinaw watershed in Arkansas and Oklahoma. The fact that the litter exported pass through other litter production areas places this watershed at a competitive disadvantage relative to other areas regarding litter export. To study the relationship between manure demand and supply, Gollehon et al. (2002) developed a regional model to capture the critical dimension of competition for land among animal producers under N-based and the more restrictive P-based nutrient standard policy goals for the Chesapeake Bay Watershed. They indicated that to reduce competition for land involved coordinating manure supplies and off-farm management at the regional level, increasing prices paid for raw manure in target markets through buyer education efforts, and assessing value-added options such as composting and energy generation.

Investing in manure storage structure can be profitable for a dairy participating in a cost-share manure management policy. In simulating dairy farms' annualized (operating and fixed) costs pertaining to lagoon and liquid tank waste management systems, Bennett, Fulhage, and Osburn (1993) found that the annualized cost for each waste management systems decreased as dairy cow numbers increased. Borton and coworkers (1995) reported that manure systems using long-term storage with spreading, injection, or irrigation have greater direct costs to the farmer than a daily haul system. Investments in dairy manure storage facilities can also yield a negative annual return when the increased nutrient conservation benefits and decreased labor costs cannot offset the increased cost of manure storage structures (Christensen et al., 1981; Cason and McAuslan, 1973; Lessley and Via, 1976; Safley et al., 1979; Heimlich, 1982).

In short, the literature has not been particularly indicative of profitability associated with long-term manure storage structures. Many components of waste management systems are based on parameters that are greatly affected by the manure nutrients content as well as land availability for manure application at agronomic N and P rates. However, few studies have explicitly explored the relationship between feeding regime, nutrient excretion and waste management costs (Ancev, Carter and Stoecher, 2002). Furthermore, not all landowners are willing to take animal manure because of the uncertainty associated with manure nutrient availability and high transportation and handling costs relative to commercial fertilizers (Carriera and Stoecker, 2000; Risse et al., 2001). The fewer landowners willing to use manure on their cropland, the more costly it will be for livestock farms to store and/or move manure to enough suitable land. Alternatively, animal density restrictions in a region can adversely affect those profit-maximizing farmers who are not currently contributing to excess nutrients in the environment.

Crop and Livestock Management Models

Adverse environmental impacts of agricultural practices are of great concern in the United States because of diffuse nature and uncertainty of agricultural pollution. In the literature, integrated farm-level models have successfully linked changes in environmental quality with agricultural practices so that the relevant tradeoffs for policy analysis are quantified. A variety of approaches used for determining optimal input use and output supply in agricultural production economics have often involved modeling behavioral and technical relationships at the farm level. One class of production models is based on econometric models that explain observed outcomes, such as land use and net returns, as reduced-form functions of economic variables (output and input prices) and biophysical characteristics of land units (Wu and Segerson, 1995). Because reduced-form models do not explicitly represent the relationship between productivity and the physical environment, they cannot be linked to biophysical-process models of crop or livestock production (Antle and Capalbo, 2001).

Another approach utilizes representative farm programming models to estimate optimal resource allocations (Prato et al., 1996). Kruseman and coworkers (1995) developed a bio-economic modeling approach that integrated biophysical information with linear programming models. These models allow for discrete choices among technologies and land use. Another important feature of these models is that they represent production technology explicitly, so they can be linked to biophysical-process models of crop and livestock production (Antle and Capalbo, 2001). The development of a mathematical programming model requires that an explicit objective be defined reflecting the decision maker's behavior or goals (Weersink, Jeffrey and Pannell, 2000). A good discussion of optimization models, including structure, assumptions, and applications, is provided by Hazell and Norton (1986) and Paris (1991).

Associated with every linear programming problem, and intimately related to it, is a corresponding dual linear programming problem. Both problems are constructed from the same underlying constraint coefficients but in such a way that if one of these problems is one of minimization the other one is a maximization problem. Based on its duality approach, linear programming has been incorporated into the three most widely used spreadsheet programs (Microsoft Excel, Quattro Pro, and Lotus), and has been used extensively to evaluate economically and environmentally optimal alternative agricultural production systems (Batte, Bacon, and Hopkins, 1998; Boland et al., 1999). Nevertheless, one of the most difficult tasks faced by an analyst is to create a realistic mathematical model of current and future problems faced by a decision maker.

Agricultural economists' interest in integrated assessment of agricultural production systems stems from risk perceptions in market and policy analysis under government intervention. Although there are a number of techniques available to represent risk and risk attitudes in empirical models, risk typically enters the model through a producer optimizing expected utility (EU) based on the expected value and variance of returns assuming returns are normally distributed. As a portfolio selection tool developed by Markowitz (1952), the expected value-variance (EV) model has been extensively used to order choices into efficient and inefficient sets. However, Tobin (1958) showed that EU maximizing decisions are always members of the EV set where choices are represented by various combinations of risky and safe assets. Furthermore, Meyer (1985) proved that Tobin's condition is a special case of a more general condition requiring linear combinations of random variables. Because few random variables have normal distribution and also decision situations concern choices involving more than one risky asset, the EV approach as decision tools is closely related to more general EU models (Porter, 1973; Tsiang, 1972; Levy and Markowitz, 1979).

In the literature, several risk models are used to evaluate economic and environmental effects of agricultural activities while accounting for the stochastic nature of environmental impacts (Qiu et al., 2001). The most common methods of assessing the trade-offs among economic and environmental objectives and environmental risks and return have been Target MOTAD (Tauer, 1983), chance-constrained programming (Charnes and Cooper, 1963) and safety-first constraints (Qiu et al., 2001). The Target MOTAD model requires the decision maker to select a risk level for the expected deviation from an environmental objective. Under the safety-first rules, the decision maker is concerned with probability of economic or financial variables falling below critical or target levels (Atwood, 1985).

Other procedures used as conceptual means of characterizing risk efficient choices in agriculture include the stochastic dominance analysis and its generalized form (Myer, 1977; Klemme, 1985). While risk preferences determine farming decisions, several studies indicated that behavior, including cost and availability of other forms of risk protection programs, may be more important in guiding farmer actions (Williams, Harper, and Barnaby, 1990; Harper et al., 1991). Although most farmers are averse to risk (e.g., Antle, 1987), some authors argued it often is not worthwhile modeling risky variables and risk attitudes explicitly (Weersink et al., 2000; Pannell et al., 2000) because the difference in optimal value of recommended strategies from models with and without risk aversion is, in most cases, extremely small. For practical analyses, rather than modeling the relevant probability distribution endogenously, it may often be sufficient to employ sensitivity analysis for exploring consequences of alternative risky outcomes (Pannell, 1997).

In the literature, the economic theory on animal waste management has been developed according to specific issues that needed to be addressed. The choice of one production portfolio over an alternative one depends primarily on the individual's income and attitude regarding the impact of the production practices on the environment. The basic premise is that ecological and economic considerations must be in balance at steady state (Innes, 2000; Ancev, Carter and Stoecker, 2002). In general, the costs of waste management are costs associated with the production system, number of animals, in-house management, type of storage and treatment facility, type of land application and information on available land and grown crops in addition to the imposition of environmental constraint limiting nutrient pollution.

Dairy operations, which integrate forage crop and animal production, can utilize manure as plant nutrient sources, both to reduce expenditure on commercial fertilizer and manure disposal cost. Although manure is a valuable agronomic resource for crop production, its optimal use depends on the crop response to manure application, the use of other inputs such as N and P, the nutrient content of the manure, the prices of the output and manure, and the fertility of the land (Govindasamy, et al., 1993).

At the crop production level, farmers are concerned about the fertilizer value of manure to grow crops. They are indifferent for fulfilling the crop nutrient requirement from commercial fertilizer or from dairy manure except for differences in handling and spreading costs. Conversely, from a water-quality standpoint, the environmental concerns focus on nutrient runoff from crop fields. When the enforcement of environmental constraints prevents land application, transportation off-farm and alternative use of manure become more attractive options (Vervoort and Keeler, 1999; Bosch et al., 1997; Bosch and Napit, 1992).

Transportation costs become higher as environmental constraints become stricter and as the land base for application becomes smaller relative to manure production. It is noteworthy to mention that the severity of environmental constraints is jointly determined by (1) the total amount of manure that must be disposed of, (2) the total quantity of available cropland, and (3) the level of the constraint itself. At the dairy production unit level these constraints may create opportunities for cost reduction or may entail additional cost because of changes in practices, changes in the structuring of the production facilities and changes in environmental management of manure.

However, the cost of producing milk is often determined by assuming that the only farm enterprise is the milking herd ignoring the complementarity and potential comparative advantage of other inputs and outputs (e.g., forage feed production using manure as nutrients source). Furthermore, milk production varies throughout the year indicating that input levels are not constant over time, being highest in the spring and lowest in the late summer (Washington, Lawson and Kilmer, 1999). During cooler months of the year, more milk per cow is produced at lower cost levels (Kaiser, Otenacu, and Smith). These yearly patterns of production are not only causing imbalances in milk supply and demand during various times of the year, but also are creating the need for seasonal patterns of manure management plans that, in turn, can change the nature and level of production factors.

Farm-level analysis is typically conducted using a static model; that is, annual model of production is developed where the results reflect the activities of representative farm operation for a representative year. However, there are instances when a representation of making farm-level decisions requires a more dynamic approach with time explicitly incorporated into the analysis. In the context of farm management, time may be considered in terms of multiple decision making periods, most often represented by extending the analysis over more than one year. Hazell and Norton (1986) and Rae (1994) discussed the implications of including the aspect of time in optimization models. Additionally, time may be relevant within a single decision making period; that is, the year may be divided into multiple time periods. An example of incorporating this aspect of time within risk-programming models is discrete sequential programming (Apland and Hauer, 1993) and dynamic equilibrium models (Pannell, 1996).

Both aspects of time (i.e., multiple years and multiple periods within a year) become potentially important when considering environmental issues. For example, the timing of pesticide or fertilization application, or disposal of manure for a livestock operation may affect the degree to which these practices impact on the environment. In some cases, the management choices made by farmers influence not only farm returns but also the level of pollution associated with both intensive input choices, such as rate of application, and extensive management choices, such as tillage systems. This could include defining cropping activities as rotation rather individual crops.

Despite the competition among commodities for acreage, few studies incorporate risk effects in a system-wide modeling framework (Bettendorf and Blomme, 1994; Barten and Vanloot, 1996; Holt, 1999). Specifically, total acreage constraints have not been incorporated into model specifications. On another hand, the majority of the literature primarily focuses on the acreage response for a single commodity relative to multiple crop settings (Blinkley and McKinzie, 1984). Single commodity studies are potentially incomplete since they fail to incorporate all alternative uses of land. Given land fixity, a system of cropping activities within a one-year decision making period provides information about the allocation of land to any one use and its substitutability to other uses.

Justification of the Present Study

Dairy manure can provide an economical source of N, P and K for plant growth. Von Horn et al. (1994) found the range in value for N, P and K in manure to be $107 to $146 per year for each cow. As a result, dairy operations that integrate crop and animal production can utilize manure as a plant nutrient source to reduce expenditure on both fertilizer and manure disposal. On the other hand, dairy producers operate under widely differing constraints, such as amount of cropland, crops, and number of crops per year, opportunity to irrigate, local hauling costs to alternative fields, and N versus P application restrictions, in addition to a degree of uncertainty related to the manure nutrient content. In areas where land application exceeds crop requirements, unused nutrients in manure not only represent an economic loss to dairy farmers but can also potentially contaminate surface and ground water.

Economic theory suggests dairy production decisions should focus on the joint value of milk and the manure that are produced. If the net return to the last unit of manure produced added to the whole farm income, a greater volume of milk and manure is likely to be produced. Alternatively, if returns from manure disposal are negative, specifically, if disposal costs exceed nutrient benefits, there is an incentive to reduce milk production and therefore the amount of manure produced. However, the net result depends on the organization of individual farms (Lanyon, 1994) and the interrelated manure management decisions (Hoag and Roka, 1995).

Several alternatives are perceived to influence farm nutrient balance and the potential to increase profit and/or reduce pollution. Throughout the United Sates confined animal feeding operators including dairy farmers are required to develop and implement comprehensive nutrient management plans to mitigate water pollution by animal wastes. On another hand, researchers have described the on-farm cost of additional manure handling under the changing policies for animal wastes. Various mathematical and economic models have been developed to assist producers in planning manure and nutrient management programs under environmental regulations. However, the literature has not explicitly explored land-based agronomic recommendations and economic incentives associated with dairy manure utilization for crop production.

To alleviate feed availability and manure disposal constraints for Georgia's dairy farmers, a study was conducted to evaluate two forage production systems using liquid dairy manure and commercial fertilizer as plant nutrient sources at the University of Georgia, Coastal Plain Experiment Station (Newton et al., 2000; Newton et al., 2001). Focus of that research was on the balance between manure nutrient and crop uptake. The feasibility and economic returns of these production systems were also evaluated over 3 years. The economic analysis was conducted using partial enterprise budgets and stochastic dominance criteria to determine which system or systems were economically and environmentally viable for a dairy producer (Somda, 2001). The analyses indicated a relatively low net cost per cow or per unit of milk of handling the manure but the cost would increase if quantities of manure applied were reduced to levels in which the P quantities applied were limited to those removed by the crops.

Many management tools have been developed by the USDA-Natural Resources Conservation Service to assist farmers in making decision about nutrient management.

Information about these nutrient management tools can be found at the website: http://www.nrcs.usda.gov/technical/nutrient.html). Researchers at the University of Georgia have also developed dairy Nutrient Management Plan Generator Spreadsheets specifically for Georgia conditions. However, these spreadsheets focus on the amount of nutrients generated on a farm based on animal units, storage methods, and crop nutrient needs and manure and soil analyses.

Overall, there is very little research been conducted with dairy farm models in Georgia. Moreover, less research has been done that considers developing an integrated dairy economic model, either on county or farm level. The present study develops a method to forecast profit from a dairy enterprise considering milk production and manure utilization to produce forage for the dairy ration and additional crops for sale while maintaining a balance of nutrients in the system. The method employs the linear programming framework for crop acreage and nutrient response to changes in the economic, environmental and institutional climate of Georgia. The following chapter addresses the theoretical model development, which closely follows the expected mean variance (EV) framework of representative dairy operator.

CHAPTER 3

THEORETICAL FRAMEWORK

Introduction

Generally agricultural production analysis is concerned with describing the relationships that characterize the transformation of inputs – land, labor, purchased materials, etc. – into marketable outputs – corn, milk, meat and so on. Such outputs are desirable in the sense that they are demanded by consumers and yield utility in consumption. But, within the process are created outputs which society deems undesirable products because they yield disutility in consumption outside the farm. Among such outputs could be included the contamination of ground and surface waters due to runoff and leaching of manure nutrients. These "bad" outputs impose costs, either in direct monetary terms – when, for example, dairy operators are faced with the cost of removing contaminants from water supplies – or in a more indirect, but equally valid, loss of welfare – such as that suffered by consumers as a result of water contamination by manure. However, efforts to lower these negative outputs likely come at the cost of reduced producer's returns since the shadow prices of an undesirable output can be interpreted as marginal costs that the producer faces.

Manure nutrient management decisions have several important dimensions, including the storage and handling practices, rate, timing and method of application, and off-field practices to mitigate pollution. On the farm, the level and/or variability of economic returns to crop and livestock production may be affected by each of these dimensions. Furthermore, federal, state, and local government legislations limiting the management options frequently generate additional costs to producers and, therefore, threaten the economic viability of the agricultural sector. Optimization models provide a tool for better understanding the relationship between management practices and the level and variability of farm income as well as for identifying management practices consistent with environmental regulations while maximizing net returns from dairy and crop production.

The following sections of this chapter lay out the theoretical underpinning for the dairy farm economic model analysis. First, expected utility theory is defined for a general case. Second, the properties of a representative dairy farmer's utility function are formalized. Finally, a theoretical model of manure and crop nutrients balance is derived base on expected utility function of a dairy farming enterprise.

Expected Utility Theory

The supply of manure nutrients evolves from the milk and crops produced. However, given risk in yield, prices, and environmental quality, there is uncertainty involved with profits of a dairy enterprise. The major analytic tool for solving decision problems under risk is the expected utility model. The expected utility hypothesis states that the individual assigns a utility value to each mutually exclusive activity with an associated probability distribution that is an outcome of a decision. In an expected utility model, a representative agent maximizes expected utility subject to an endowment constraint.

In making future management plans, a representative firm will consider the probability of possible outcomes. The firm is then faced with choosing alternatives with uncertain outcomes by means of known probabilities. These risky alternatives are called states of nature or lotteries, L. Being unable to jointly consume two or more states of nature is a fundamental assumption of many theories dealing with choice under uncertainty. This assumption is summarized by the following independence axiom:

If L, L', and L" are alternative states of nature and ρ *is the probability of the state of natures L and L' occurring, then L ≥ L' if and only if* $\rho L + (1-\rho)L'' \geq \rho L' + (1-\rho)L''$

In other words, the preference a firm has for one state of nature, L, over another state, L', should be independent from other states of nature, say, L". This other state of nature L" should be irrelevant to a firm's choice between L and L'.

Base on this independence axiom, the utility function for choice under uncertainty is additive for consumption in each possible state of nature. Such utility function is called the expected utility function or also called the von Neumann-Morgenstern utility function (von Neumann and Morgenstern, 1944). For two possible states of nature, 1 and 2, the expected utility function is

$$U(\vec{x}_1, \vec{x}_2, \rho_1, \rho_2) = \rho_1 U_1(\vec{x}_1) + \rho_2 U_2(\vec{x}_2) \qquad (3.1)$$

and $\rho 1 + \rho 2 = 1$

where U_1 and U_2 are utility functions associated with commodity bundles $\vec{x}_1$ and $\vec{x}_2$ consumed in states of nature 1 and 2 with probability of occurrence $\rho 1$ and $\rho 2$, respectively. With uncertainty, the probabilities are $0 < \rho 1, \rho 2 < 1$, and the utility function represents the average or expected utility given the alternative possible states of nature. If only one of the states of nature occurs, say state 1, then $\rho 1 = 1$ and $\rho 2 = 0$, and the utility function becomes

$$U(\vec{x}1) = U1(\vec{x}1) \qquad (3.2)$$

The change in the marginal utilities of expected utility represents changes in preferences. Specifically, $MU1 = \partial U / \partial \vec{x}1 = \rho 1 \partial U1 / \partial \vec{x}1$ represents the change in utility from a change to the consumption bundle $\vec{x}1$. Because of violating the independence axiom, a monotonic transformation of the expected utility functions may yield a different measure of firms' preferences. However, a group of transformations that do not violate the independence axiom are increasing linear transformations (also called positive affine transformations) such as

$$V(U) = aU + b, a > 0 \qquad (3.3)$$

Expected utility is a convenient representation of firms' preferences when faced with uncertainty. This is why it is generally used throughout economic theory, yielding positive as well as normative implications. In the following section, properties and assumptions of a representative utility function are presented. They are followed by model development for a farming enterprise with von Neumann-Morgenstern preferences.

Representative Utility Function

Several assumptions about individual preferences and the distribution of returns are made to simplify the expected utility model for empirical analysis. Assuming returns are normally distributed, the decision maker can rank alternatives using only two parameters, expected value and variance, without concern to the higher moments of the distribution. The decision maker is assumed to be a risk averter, thus, the individual wants to minimize the dispersion of returns. Alternatively, maximizing expected value, *ceteris paribus*, is the individual's appropriate goal.

A Taylor series expansion of the utility of profits, $U(\pi_i)$, for the commodities of interest in the analysis (crops grown for dairy ration and for sale) about the expected value, $h = E[\boldsymbol{\pi}]$, is carried out to formalize the results of expected utility maximization. Given the gradient vector $G(\boldsymbol{\pi})$ and the Hessian matrix $\mathbf{H}(\boldsymbol{\pi})$, the Taylor series for U can be written in the vector-matrix form as follows

$$U(\boldsymbol{\pi} + \mathbf{h}) = U(\boldsymbol{\pi}) + \mathbf{G}(\pi)^T \mathbf{h} + \tfrac{1}{2}\mathbf{h}^T \mathbf{H}(\pi)\mathbf{h} + \ldots \qquad (3.4)$$

In that case, the gradient vector is defined having components

$$G_i(\boldsymbol{\pi}) = \partial U(\boldsymbol{\pi}) / \partial \pi_i, \qquad i = 1, \ldots, n \qquad (3.4a)$$

and the Hessian matrix having components

$$H_{ij}(\boldsymbol{\pi}) = \partial^2 U(\boldsymbol{\pi}) / \partial\pi_i \partial\pi_j\,, \qquad \text{i, j = 1,…, n} \qquad \text{(3.4b)}$$

By Young's theorem, these partial derivatives, when continuous, are invariant to the order of differentiation. If the second partial derivatives of U are all continuous, then H is a symmetric matrix; i.e., $H_{ij}(\boldsymbol{\pi}) = \partial^2 U(\boldsymbol{\pi}) / \partial\pi_i \partial\pi_j = \partial^2 U(\boldsymbol{\pi}) / \partial\pi_j \partial\pi_i = H_{ji}(\boldsymbol{\pi})$, (3.5)

with $\mathbf{h}^T H_{ii}(\boldsymbol{\pi})\mathbf{h} = \sigma_{ii} = \text{var}(\pi_i)$ and $\mathbf{h}^T H_{ij}(\boldsymbol{\pi})\mathbf{h} = \sigma_{ij} = \text{cov}(\pi_i,\pi_j)$.

The expected utility of a risky prospect can be expressed in terms of the mean and a series of higher moments of the associated probability distribution. Based on the central limit theorem, returns are more likely to have normal distribution pattern (Samuelson, 1970) completely specified by functional form that incorporates only the first two moments (Hogg and Craig, 1978). Furthermore, the expected utility of profits, $EU(\boldsymbol{\pi})$, is an increasing function of the first moment of expansion and a decreasing function of the second moment for the risk averse decision maker.

Expected utility functions for an individual are typically categorized in three ways. An individual is said to be risk averse if for constant wealth, a certain sure outcome is always preferred to a lottery with the same expected value but some positive variance. In contrast, a risk neutral individual is indifferent between the certain outcome and the gamble while a risk-seeking individual prefers the lottery (Binger and Hoffman, 1997). As a result, indifference curves for the risk-averse individual are convex with respect to the horizontal axis, which assumes that the direction of increasing expected utility is upward and to the left.

Theory in Cropland Manure Application Decision

There are three theoretical considerations for cropland manure application decision-making: expected utility maximization, agronomic and environmental considerations. First the expected utility maximization is laid out and then the agronomic and environmental considerations are incorporated in the theoretical framework for manure application decision-making.

The comparison of risky prospects usually requires an assumption about individual risk preference, such as indifference to risk (profit maximization) or risk aversion (second degree stochastic dominance). Risk can be defined as a deviation of realized economic returns from those expected. A producer facing risk is assumed to maximize the expected utility generated from all activities entered. Utility is defined to be a function of both income and some dispersion function representing risk. This utility function exists if the completeness, reflexivity, transitivity, and continuity behavioral preference axioms hold (Varian, 1992). When choosing among alternative strategies, activity ***A*** would dominate activity ***B*** if and only if the following condition is met with at least one strict inequality:

$$E(\pi_a) \geq E(\pi_b) \text{ and } R_a \geq R_b, \tag{3.6}$$

where $E(\pi_i)$ and R_i are expected income and a measure of dispersion, respectively. This unique and complete ordering procedure is derived from the von Neumann-Morgenstern expected utility hypothesis. Therefore, action choices can be ordered according to calculated expected utility indices when the precise risk preferences represented by the derivatives of the utility functions are known (Tembo, Kaitibie, and Epplin, 1999). Under the assumption of a strictly increasing utility function with continuous first and second derivatives, the Jenson's inequality can be used to describe two risk preference choices:

$$U(\pi_a X_a + \pi_b X_b) \geq \pi_a U(X_a) + \pi_b U(X_b), \tag{3.7}$$

where U represents utility function, X_a and X_b are states of nature or net returns, and π_a and π_b are the probabilities of the states of nature occurring. An individual is said to be risk neutral if the utility of the expected returns is equal to the expected value of utility. For a risk averse (seeking) individual the utility of expected returns is greater (less) than the expected utility, and the degree of concavity (convexity) of the utility function provides a convenient measure of risk aversion (seeking). The more risk averse (seeking) is a producer, the more concave (convex) will be the utility function and the higher will be the absolute risk aversion or Pratt-Arrow coefficient (Arrow, 1971) defined as:

$$r(y) = \frac{-U''(y)}{U'(y)}, \qquad (3.8)$$

where $U'(y)$ and $U''(y)$ are the first and second derivatives of a monotonically increasing von Neumann-Morgenstern utility function that depends on net returns (y). This type of utility function implies that increases in net return increase the utility of producers but at a decreasing rate. Based on the expected utility theory, this farm decision-making framework represents an important conceptual means of characterizing risk efficient choices in agriculture. However, in application, a farmer's expected utility function is generally unknown.

The dominant procedures used in the literature of production theory to compare a farmer's preference for one risky state over another include the mean-variance (EV), the mean-absolute deviation (MAD), the minimization of total absolute deviations (MOTAD), and the stochastic dominance analysis. The commonly used decision tool in applied economics is the mean-variance analysis of the probability distribution of the individual's wealth. The larger the variance the greater is the risk of experiencing possible losses in wealth. Because stochastic dominance analysis involves a pair-wise comparison of cumulative outcome probability distributions from a set of alternative (Klemme, 1985), it has been one of the dominant conceptual means of characterizing risk efficient choices in agriculture. Furthermore, its generalized form (Myer, 1977) does not require specific knowledge of an individual's utility function, but has the ability to evaluate the full range of risk preferences. The utility function with the highest probability of not preferring action ***A*** to action ***B*** is identified within an interval bounded by upper and lower values of the Pratt-Arrow coefficient. If, for this utility function, the expected utility of ***A*** is still greater than the expected utility of ***B***, then action ***A*** is said to be preferred to action ***B*** for all decision makers in the selected class of risk preference. However, the wider is the interval between the lower and upper bounds, the greater the accuracy, but the lower the discriminatory power.

Risk preferences determine farming decisions (Tauer, 1986). However, behavior including cost and availability of other forms of risk protection may be more important in guiding farmer action (Williams, Harper, and Barnaby, 1990; Harper et al., 1991). In many cases, the motivation for increasing input such as manure applications is self-protection against the probability of not achieving the lower bound requirement (e.g., applying less nutrients than the crop needs).

In the literature of production economics, the effects of production uncertainty on input demand are often quantified by estimating the marginal effect of input levels on the moments of output. If an input such as manure increases (decreases) yield uncertainty, then a risk-averse firm demands less (more) of that input than a risk-neutral firm. If the producer response to uncertainty is dominated by the input's marginal effect on variance, then one should observe farmers applying less manure than the amount needed to equate the marginal product of manure to its (real) per unit cost.

Alternatively, the choice of one production portfolio over an alternative one will depend primarily on the individual's income and attitude regarding the impact of the production practices on the environment. The basic premise is that ecological and economic considerations must be in balance at steady state. Following Randhir and Lee (1997), dairy producers maximize expected utility of wealth subject to stochastic environmental conditions as follows:

$$\underset{xi}{Max}\ E[U(W_i)] \qquad (3.9)$$

where $U(.)$ is their von Neumann-Morgenstern utility function, W_i the wealth in state i, and $E[U(.)]$ is the expected utility over all states. The wealth in each state is determined by the initial wealth (W_o) and net return (R(X_i)) from all activities X_i in state i as shown by equation (3.10):

$$W_i = W_0 + R(\mathbf{X}_i) \ \ \forall\ i = 1 \ldots n \qquad (3.10)$$

The resources allocated to activities are limited to an endowment B as an inequality constraint in equation (3.11) where A is a technology matrix,

$$\mathbf{AX} \leq \mathbf{B} \qquad (3.11)$$

The income in each state is calculated as net profit from production activities given the product prices r_i and the per unit cost c_i in inputs of practice (p) under state (i).

$$R(\mathbf{X}_i) = \sum_{x_i} (r_i x_i - c_i p_i) \qquad (3.12)$$

The biophysical and production processes involved in the system are represented by equation (3.13), where M_i represents the production environment facing the farmer (weather, soil conditions, etc.), and $f(.)$ is the relationship involved in activity x_i.

$$x_i = f(p_i, M_i, B) \qquad (3.13)$$

The pollution loading of environmental contaminant, say nutrients (***N***), is generated according to equation (3.14), where φ(.) is an emission function for pollutants by farmer activities.

$$N_i = \varphi(p_i, M_i) \qquad (3.14)$$

By solving simultaneously equations 3.9 through 3.14, the environmental benefits of nutrients can be conserved, their economic value captured, and both environmental and economic goals can be met. Both of these goals are essential to determine a tactical manure management plan agreed upon by the society at large.

Dairy operations, which integrate forage crop and animal production, can utilize manure as plant nutrient sources, both to reduce expenditure on commercial fertilizer and manure disposal cost. Although manure is a valuable agronomic resource for crop production, its optimal use depends on the crop response to manure application, the use of other inputs such as N and P fertilizers, the nutrient content of the manure, the prices of the output and manure, and the fertility of the land (Govindasamy, et al., 1993). The optimal trade-off between commercial fertilizer and dairy manure application for forage crop production can be investigated using the traditional cost minimization technique, assuming that nutrients from manure are perfect substitute for the same nutrients from inorganic fertilizer.

Lets assume that $\boldsymbol{x_i}$ factors such as manure, fertilizer N, P and K with input prices $\boldsymbol{w_i}$ are available for producing $\boldsymbol{y}$ level of crop yield. Because the yield response curve to nutrient application rates is not linear, quadratic equations are commonly used in production agriculture to describe the relationship between yield response data and the use of production factors $\boldsymbol{x_i}$.

$$f(x_1,\ldots,x_n) = a_0 + \sum_{i}^{n}\sum_{j}^{n-1}[a_i x_i + b_i x_i^2 + d_{ij} x_i x_j + \varepsilon] \qquad (3.15a)$$

One characteristic of the quadratic production function is the diminishing marginal productivity. The marginal product of factor $\boldsymbol{x_i}$ can be derived as

$$MP_{x_i} = a_i + 2b_i x_i + \sum_j^{n-1} d_{ij} x_j \qquad (3.15b)$$

The negative of slope of the isoquant between two factors of production, $\boldsymbol{x_i}$ and $\boldsymbol{x_j}$, is called the marginal rates of technical substitution (MRTS) and can be derived directly from marginal products of inputs as

$$MRTS_{x_i x_j} = \frac{MP_{x_i}}{MP_{x_j}} \qquad (3.15c)$$

Furthermore, the least cost combination of inputs that produces a given level of output can be solved for as:

$$\text{Min } c = \sum_i^n w_i x_i + \lambda[y - f(x_1,\ldots,x_n)] \qquad (3.16a)$$

where $\boldsymbol{\lambda}$ is the Lagrangian multiplier. The cost function is represented as $c(w_1,\ldots,w_n, y)$:

$$c = w_1 x_1 + w_2 x_2 + \ldots + w_n x_n \qquad (3.16b)$$

$$x_i = \frac{c}{w_i} - \sum_j^{n-1} \frac{w_j}{w_i} x_j \,, \qquad (3.16c)$$

Because each input can be expressed in function of the other factors for a given level of cost, *ceteris paribus*, the first-order conditions for the cost minimization problem are given as

$$\frac{\partial c}{\partial x_i} = w_i - \lambda a_i - 2\lambda \sum_i^{n-1} b_i x_i - \sum_j^{n-1} dijxj = 0 \qquad (3.17a)$$

$$\frac{\partial c}{\partial \lambda} = y - f(x_1 \ldots x_n) = 0 \qquad (3.17b)$$

$$x_1 \ldots x_n \geq 0 \qquad (3.17c)$$

The solution, $x_i^* = f_i(w_1, w_2,\ldots, w_n, a_1,\ldots, a_m, b_1,\ldots, b_m, d_1,\ldots, d_m)$, provides the cost minimizing input levels given the level of output.

Now consider a dairy farming enterprise in a given county engaged in producing ***n*** crops over ***A*** acres of cropland. Let A_i denotes acres of the i^{th} crop with a corresponding yield of Y_i per acre. Y_i is sold at the market price of p_i per unit of yield. The above activity results in the following revenue function, ***R***, for the farm:

$$R = \sum_{i=1}^{n} p_i Y_i A_i \qquad (3.18)$$

Revenue (R) is a linear function of stochastic prices and yield. By assumption, the vector of prices $\vec{P} = p_1,..., p_n$ and yield $\vec{Y} = Y_1,...,Y_n$ are unobserved at the time of acreage allocation, R is a risky variable. Let the total variable cost, ***C***, of the farming enterprise be defined as

$$C = \sum_{i=1}^{n} c_i A_i \qquad (3.19)$$

with c_i as the variable cost of production per acre of the i^{th} crop. Given input prices, per acre costs are known at the time of cropped acreage commitment and thus, the total variable costs for such an enterprise are known with certainty.

Constraints on land resource require that all cropland is allocated to one of the **n** enterprises and that cropped acreage does not exceed the total available acreage. These constraints may be represented as follows:

$$\begin{aligned} & f(\mathbf{A}) = 0, \\ & \sum_{i=1}^{n} A_{iy} = A_y \end{aligned} \qquad (3.20)$$

where f(**A**) = 0 is the production frontier representing the multiproduct multifactor technology of the firm. Variable A_{iy} denotes cropped acres of i^{th} crop in a farm or county and A_y are total cropped acres available in the y^{th} farm or county.

If the representative firm maximizes expected utility under competition, then the decision model is

$$\max_{A} EU(\boldsymbol{\pi}) = \max_{A_i}\{EU[(\sum_{i=1}^{n} \pi_i A_i)]\} \qquad (3.21)$$

subject to the acreage constraints in equation (3.20). The per-acre profit accounting from the i^{th} crop is

$$\pi_i = p_i Y_i - c_i \qquad (3.22)$$

The formulation of (3.21) indicates that the acreage decision A is made under both price and production uncertainty. Both yields $\vec{Y}$ and output prices $\vec{P}$ are random variables with given subjective probability distributions. Consequently, the expectation operator (E) in (3.21) over the stochastic variables $\vec{Y}$ and $\vec{P}$ is based on the information available to the firm at planting time. The optimization model in equation (3.21) has direct economic implication for the optimal acreage allocation, A_i^*. If the firm is not risk neutral, the optimal acreage decision will depend not only on expected profits, but also on higher moments of the profit distributions.

As mentioned above with normally distributed returns, the expected utility function is completely specified by the expected value and variance of returns. In that case, if the expected value of the choice A is greater than or equal to the expected value of choice B, and the variance of A is less than or equal to the variance of B, with at least one strict inequality, then A is preferred to B by the decision maker.

According to the expected value-variance theory an increase in the profits of the ith crop increases the expected utility of the producer. This drives the producers to add more acres of the ith crop by substituting away from the jth crop and vice-versa for all crops where $i \neq j$. On the other hand, increases in the variance of the ith crop increase risk and drives expected utility of the producer down. The producer, therefore, will reduce acreage of a crop with higher variance. However, increased variance of the jth crop with $i \neq j$, shows an increased risk associated with crop j. Reducing acreage of the jth crop frees up resources to commit to crop i.

Agronomic considerations, such as rotation, play an important part in manure decision making. Crop rotation is the successive planting of different crops in the same field. Rotations may range between two and five years in length and generally involve a farmer planting part of his land to each crop in rotation (National Research Council, 1989). Rotations provide well-documented economic and environmental benefits to agricultural producers. Some of the benefits of rotation are inherent to all rotations; others depend on the crops planted and the length of the rotation; and others depend on the types of tillage, cultivation, fertilization and pest control practices used in the rotation.

Like many business managers, a farm operator is maximizing profit based on the appropriate input mix by equating the value of marginal product (VMP_i) to marginal cost (MC_i) of the inputs:

$$\frac{VMP_i}{MC_i} = 1 \text{ for all } i \qquad (3.23)$$

Viewed in this way, feed decisions in dairy production are essentially maximized relative to a given level of milk output and inputs choice. As producing milk yields manure that can be used to produce forage crops, manure can be incorporated as a substitute of chemical fertilizer into the crop production function. In this case, the same combination of inputs with manure and fertilizer is expected to produce the same output within a production system. Specifically, forage yields will remain constant between manure and fertilizer sources of plant nutrients when the same input combination is used in the production function.

When discussing the performance of management, it is common to describe them being more or less efficient or being more or less productive. In general, productivity and efficiency are success indicators in crop and livestock enterprises of dairy operations (Harsh, Wolf and Wittenberg, 1998). In crop production, inputs such as seeds, fertilizer and pesticides are used to produce forage feed. This ratio of output to input is defined as total factor productivity, which varies with different production technologies, processes and environments. Variation in output across production systems is known as efficiency variation. Technical efficiency refers only to quantity change while allocative efficiency includes both quantities and prices of input and output factors.

In using manure and chemical fertilizer for crop production, the technical efficiency can change due to the cropping practices. Considering the soil resource fixed and holding the level of input constant, the more technically efficient system is the one that produces more output than the other systems. However, because management costs vary with the different systems, the most efficient system might not be the lowest cost system. One system is more efficient than the other because it is able to produce more output and net return to land and management. Because the delivery of the manure and chemical fertilizer to the field requires essentially the same machinery complements and labor, the profitability of each management system depends on the revenue from the output produced and the cost of the variable inputs necessary to produce that output. Specifically, utilization of manure augments input efficiency resulting in a profit gain through cost savings as follows:

$$\pi = p_i f(Z, S, X_i) - w_i X_i - \sum r_i K_i \qquad (3.24)$$

where $\boldsymbol{p_i}$ is the price of crop produced, $\boldsymbol{w_i}$ are price vectors of purchased inputs $\boldsymbol{X_i}$

associated with given crop rotation $\boldsymbol{Z}$ and nutrient source ($\boldsymbol{S}$) and $\boldsymbol{r_i}$ represents the implied cost of fixed capital $\boldsymbol{K_i}$ necessary to produce that crop. Considering the same cost of fixed capital for the different management approaches, the differences in total cost should equal the major variable factor costs. In that case, the structure of implied producer surplus is then:

$$\pi = p_i f(Z, S, X_i) - r_i X_i \qquad (3.25)$$

This model assumes all factors are purchased and sold in a perfectly competitive market. The cost function is linear in input prices and the output price is also linear in output.

Suppose dairy farmers produce output $\boldsymbol{Y_o}$ in a given crop rotation system using dairy manure ($\boldsymbol{S_m}$) with input vector $\boldsymbol{X_m}$ to get a profit of $\pi_{\boldsymbol{m}}$ and using chemical fertilizer ($\boldsymbol{S_f}$) with input vector $\boldsymbol{X_f}$ to get a $\pi_{\boldsymbol{f}}$ profit. If manure is more efficient than chemical fertilizer, then $\pi_{\boldsymbol{f}} \leq \pi_{\boldsymbol{m}}$ and there is a cost saving equal to $\boldsymbol{w_i}(\boldsymbol{X_{fi}} - \boldsymbol{X_{mi}})$. In addition to this, if yield also increases, then the farmer will receive greater revenue equal to $\boldsymbol{p_i}\,[f(\boldsymbol{Z_{mi}}, \boldsymbol{S_{mi}}, \boldsymbol{X_{mi}}) - f(\boldsymbol{R_{fi}}, \boldsymbol{S_{fi}}, \boldsymbol{X_{fi}})]$. In that case, it may be possible to substitute manure for commercial fertilizer in the production factors providing appropriate measures are taken to protect surface and groundwater contamination from runoff of manure nutrients.

Given the representative firm decision model to maximize expected utility under competition, $\max_{A} EU(\boldsymbol{\pi}) = \max_{A_i}\{EU[(\sum_{i=1}^{n} \pi_i A_i)]\}$ subject to acreage constraints, the choice of optimal acreage allocation, A_i^*, is a function of total cropped acres available, expected profits for each commodity in addition to the dispersion of all cross-commodity profits. The optimal acreage may be decomposed into substitution and expansion effects. In making decisions about acreage allocations, producers may compare the first and second moments of profits of alternative management. Comparison of expected per acre profits for recent alternate enterprises is assumed to drive the substitution among crops for a utility maximizing firm. On the other hand, substitutions between manure and fertilizer have been accompanied by an overall increase in cropped acreage over time. Changes in manure management technology, costs of application, application policy, and producer's assessments of future economic conditions in dairy operation all may stimulate expansion or contraction of total cropland acreage.

Suppose a dairy producer decides to compare profitability from different cropping systems. Several criteria can be used to specify the objective function, including maximizing profit above production costs (Batte, Bacon, and Hopkins, 998) or minimizing cost from a combination of manure management strategies (Boland et al., 1999). Both problems are constructed from the same underlying constraint coefficients but in such a way that if one of these problems is a minimization the other one is a maximization problem. This is defined as a primal-dual pair of problems expressed as follows:

Primal	Dual
minimize $\mathbf{c}^{\mathbf{T}}\mathbf{x}$	maximize $\boldsymbol{\lambda}^{\mathbf{T}}\mathbf{b}$
subject to $\mathbf{A}\mathbf{x} \geq \mathbf{b}$	subject to $\boldsymbol{\lambda}^{\mathbf{T}}\mathbf{A} \leq \mathbf{c}^{\mathbf{T}}$
$\mathbf{x} \geq \mathbf{0}$	$\boldsymbol{\lambda} \geq \mathbf{0}$

If $\mathbf{A}$ is an *m x n* matrix, then $\mathbf{x}$ is an *n*-dimensional column vector, $\mathbf{b}$ is an *m*-dimensional column vector, $\mathbf{c}^{\mathbf{T}}$ is an *n*-dimensional row vector, and $\boldsymbol{\lambda}^{\mathbf{T}}$ is an *m*-dimensional row vector. The vector $\mathbf{x}$ is the variable of the primal problem, and $\boldsymbol{\lambda}$ is the variable of the dual problem. By the dual theorem, the objective functions values of primal-dual problems evaluated at optimal solutions are equal if and only if both problems possess feasible solutions.

In the following section, the manure problem is discussed in the duality-based approach of a representative dairy operator.

The profit maximization problem can be expressed as:

$$\text{Maximize} \quad \sum_i P_i y_i - \sum_i \sum_j VC_{ij} x_{ij} - CRL \qquad (3.26)$$

subject to constraints:

$$\text{A)} \quad \sum_i b_i x_{ij} \leq h_j \text{ for all j} \qquad (3.26a)$$

$$\text{B)} \quad \sum_j - Y_{ij} x_{ij} + y_i \leq 0 \text{ for all i} \qquad (3.26b)$$

$$\text{C)} \quad \sum_i \sum_j x_{ij} - L \leq 0 \qquad (3.26c)$$

$$\text{D)} \quad \sum_j x_{ij} - \sum_j x_{i+1,j} = 0 \text{ for all pairs of crops } (x_i) \qquad (3.26d)$$

In these equations, $\boldsymbol{y_i}$ represents the quantity of the ***ith*** commodity sold while $\boldsymbol{P_i}$ is its market price, $\boldsymbol{VC_{ij}}$ the variable cost of using manure to produce one acre ($\boldsymbol{x_{ij}}$) of crop ***i*** in the ***jth*** planting period, and ***CR*** per acre cash rate for land rented (***L***). The variable $\boldsymbol{b_i}$ represents machine time requirements (hours) per acre of crop ***i*** and $\boldsymbol{h_j}$ number of hours of field time available in period ***j*** while $\boldsymbol{Y_{ij}}$ being the yield per acre for crop ***i*** in period ***j***.

Under this profit maximization scenario, the objective function represents a selection of quantity of specified crops planted in each available planting period so as to maximize farm total return above variable costs. Subtracting total fixed costs from the solution value yields return above total costs (excluding management), assuming homogeneous production function and no price premiums for some commodities. With regard to the decision constraints, set **A** reflects the available field time in each period and time required (per acre) for each crop, set **B** transfers the appropriate crop yields (reflecting planting delay yield penalties) to the cop marketing activities, and set **C** refers to the land resources while constraint set **D** forces each crop in the rotation to be planted in equal amounts.

The primal representation of the manure management problem can be represented mathematically as:

$$\underset{T_{ij}}{\min imize}\, TC = \sum_i \sum_j C_{ij} T_{ij} + \sum_k P_k F_k \qquad (3.27)$$

with the following restrictions:

$$\gamma_i T_{ij} \geq NH \frac{S}{365} \qquad (3.27a)$$

$$q_k Q + F_k \leq L_n Z_{kn} \qquad (3.27b)$$

$$q_k Q + F_k \geq L_n M_{kn} \qquad (3.27c)$$

$$NH = Q, \text{ and } Q > 0 \qquad (3.27d)$$

In the objective function, ***TC*** is total costs for the i^{th} manure storage alternative (***i*** = different type and capacity associated with deep pits, slurry tanks, and lagoons) and j^{th} manure application system (***j*** = different type and capacity associated with broadcast, injection, and irrigation), C_{ij} is the sum of the annualized fixed and variable costs associated with the i^{th} storage and j^{th} application system, T_{ij} is a dummy variable taken the value of one if the i^{th} storage unit and j^{th} application is used and zero otherwise, P_k is the cost of nutrient ***k*** (***k*** = N, P, or K), and F_k is the amount of nutrient ***k*** applied in the form of inorganic commercial fertilizer.

In the constraints, γ_i is the i^{th} system's annual storage capacity, ***N*** is the number of animals within the production system, ***H*** is the amount of manure produced annually by the animal, and ***S*** is a regulatory agency's minimum number of days storage capacity requirement.

Similarly, $\boldsymbol{q_k}$ is the amount of the nutrient obtained from $\boldsymbol{Q}$ (sum of liquid and solid manure), $\mathbf{L_n}$ is the acres of land for the $\boldsymbol{n^{th}}$ crop enterprise, and Z_{kn} is the maximum amount of nutrient $\boldsymbol{k}$ that can be applied to crop $\boldsymbol{n}$. Otherwise the maximum amount of nutrient $\boldsymbol{k}$ is equal to the amount of the nutrient $\boldsymbol{k}$ required for crop production. $\boldsymbol{M_{kn}}$ is the amount of nutrient $\boldsymbol{k}$ required per acre for the $\boldsymbol{n^{th}}$ crop. Finally, the total quantity of manure, Q, must be a positive number.

Many state and federal agencies have developed regulations requiring a minimum capacity volume for manure storage. In other words, the storage capacity volume of the system must satisfy the regulatory agency's minimum capacity requirement (Equation 3.27a). Similarly, these regulatory agencies limit the amount of nutrients that can be applied to a given acreage (Equation 3.27b). As a result, the nutrients required for a given crop enterprise and land acreage cannot exceed the sum of the total manure and commercial fertilizer nutrients with an equality relationship linking the total amount of manure produced by animal to the total amount for crop production (Equations 3.27c and 3.27d).

Calculating manure application rates requires information such as nutrient content in manure, availability of nutrients for use as a fertilizer, and loss factors for different storage and application methods. Likewise, calculating manure disposal costs requires information on the mileage charge for transporting the material to the field including the number of miles manure is hauled as well as the base charge for manure production, handling, storage, and application to fields. For manure slurry that is directly applied without being stored in lagoons, the mileage charge represents time on the road in a vehicle from the production facility to the field and back. For lagoon liquids that are sprayed on cropland, the mileage charge represents the cost of the added equipment and assembly cost needed to deliver wastes to the field.

In the literature, the economic theory on animal waste management is based on the production system, number of animals, in-house management, type of storage and treatment facility, type of land application and information on available land and grown crops in addition to the imposition of environmental constraint limiting nutrient pollution. As a result, the cost function of manure management can be expressed in the following form:

$$MC = f(PC, STC, LAC) \qquad (3.28)$$

Here ***PC*** is manure production costs that, in turn, depend on the volume of water used to flush the manure from the house whereas the storage treatment costs (***STC***) are highly dependent on the total volume of manure. Conceivably, PC and STC are expected to be more sensitive to the changes in the dry matter excreted than to the changes of nutrient excreted by cows. Net land application costs (***LAC***) are determined through an interaction of direct land application costs, the fertilizer value of manure and the costs of hauling manure away from the farm in the case that the produced manure is in the excess of the land capacity for application. Therefore the effects of nutrients excreted in manure on ***LAC*** are theoretically expected to be greatly dependent on the farmland available for manure application.

In general, the major variable cost of manure management is represented by land application costs, which, in turn, are dominated by spreading costs because of low manure nutrient densities relative to commercial fertilizers. Therefore, the optimal solution of the cost function (3.28) is reduced to minimize the total costs of disposing of the manure as follows:

$$\min_{i} LAC = PC_i + STC_i + CHA_i - G_i \qquad (3.29)$$

where the subscript ***i*** refers to the manure form (***i*** = liquid, slurry, or solid); ***CHA*** is the cost of hauling away; and ***G*** is the price that a crop producer is willing to pay for a unit of manure. It is assumed that this price would be negative if a farmer requires a subsidy to accept the manure (Vervoort and Keeler, 1999). Similarly, ***CHA = 0*** when the waste generated from the dairy farm is fully applied to available land and no manure is hauled away, otherwise, ***CHA > 0***.

Without environmental constraints it is not necessary to restrict quantities of manure disposed. With environmental constraints the problem of the manure disposal cost can be expressed as (Vervoort and Keeler, 1999):

$$\min LAC = \sum LAC_i \mathbf{X}_i + \sum LAC_j \mathbf{X}_j \qquad (3.30a)$$

subject to

$$E_i(X_i) \leq K \qquad (3.30b)$$

$$\sum \mathbf{X}_i + \sum \mathbf{X}_j \geq X \qquad (3.30c)$$

where **X** denotes the quantity of manure that needs to be disposed of on cropland. This quantity indicates the total amount of manure produced relative to the assimilative capacity of the available cropland. The subscript ***j*** refers to an alternative disposal method that does not lead to nutrient runoff, ***E(x)***, expressed as a function of manure applied with respect to the environmental constraint, ***K***. In that case, the breakeven cost (***BEC***) is defined as function of the share (***g***) of total manure that available land could absorb and still meet the environmental constraintt (***K***) as follow:

$$BEC = \sum gLAC_i/(1-g) \qquad (3.31)$$

However, the equation is valid for $1/A \leq g < 1$, with A being the proportion of waste that can be absorbed by a given land area. When the environmental constraint is so severe that the ratio ***1/A*** falls below ***g***, then the corner solution ***g = 1/A*** defines the most attractive possible scenario for alternative disposal methods such as composting and exporting to non-agricultural land areas. However, transportation costs generally become higher as environmental constraints become stricter and as the land base for application becomes smaller relative to manure production.

It is noteworthy to recall that the severity of environmental constraints is jointly determined by (1) the total amount of manure that must be disposed of, (2) the total quantity of available cropland, and (3) the level of the constraint itself. At the crop production level, farmers are concerned about the fertilizer value of manure to grow crops. They are indifferent for fulfilling the crop nutrient requirement from commercial fertilizer or from dairy manure except for differences in handling and spreading costs. As a result, a dairy producer obtains value from manure either by using it as a substitute for commercial fertilizer on crops or by exporting it, or a combination of the two uses. Following Bosch et al. (1997), the total value (TMV) of manure for on-farm use and for export can be summarized as:

$$TMV = V_f Q_f + P_e Q_e \qquad (3.32)$$

where $\boldsymbol{V_f}$ is the per unit value of manure as a commercial fertilizer substitute, $\boldsymbol{Q_f}$ is the amount of manure used on the dairy farm for fertilizer, $\boldsymbol{P_e}$ is the export price per ton of the amount of manure ($\boldsymbol{Q_e}$) exported from the farm. These quantities $\boldsymbol{Q_f}$ and $\boldsymbol{Q_e}$ partially depend on the manure nutrient content relative to crop requirements. For a given crop, the value of manure ($\boldsymbol{V_f}$) is estimated by equating the total cost of using the manure as a fertilizer substitute to the total cost of commercial fertilizer. The value ($\boldsymbol{V_f}$) depends on the application rate of manure while the export price ($\boldsymbol{P_e}$) depends on supply and demand.

Manure supply represents the amount produced on the farm. When all manure on the farm cannot be used according to a nutrient management plan, then the producer must reduce the herd size or export the excess manure: whichever option is least expensive will be chosen.

Specifically, the producer will accept a low or even negative price to export manure as long as net returns from the dairy operation are positive. Conceivably, if the manure export price is too negative, the producer's losses from manure disposal may cause net returns to the dairy enterprise to be negative and the supply of manure to go to zero. Conversely, if the export price is very high, the dairy farmer may reduce own cropland applications, causing the supply curve to have a positive slope.

Alternatively, manure demand is downward sloping. As a result, some users are willing to pay higher prices for higher valued uses such as composting. For higher quantities, willingness to pay declines and more manure must be exported to greater distances where, in general, it will earn a lower return to the dairy producer due to added transportation and handling costs. As the amount of manure produced increases, the dairy firm will seek customers located further from the production source, and manure delivery costs increase (Bosch and Napit, 1992). If the amount of manure to be transferred is known (***Q***), the total costs (***TC***) incurred by the firm can be determined as a cost minimization problem. A dairy farm will attempt to minimize the costs of transferring all manure exceeding potential use on cropland to deficit areas as follows:

$$\text{Minimize } TC = \sum_{i}^{m} \sum_{j}^{n} w_{ij} Q_{ij} \qquad (3.33a)$$

subject to

$$\sum_{j}^{n} Q_{ij} = Q_i \quad \text{for } 1 \le i \le m \qquad (3.33b)$$

$$\sum_{i=1}^{M} a_{ij} Q_j \le Q_j \quad \text{for } 1 \le j \le n \qquad (3.33c)$$

where w_{ij} equals the per-unit cost of transferring manure from the surplus farm for crop i^{th} use in the j^{th} deficit area; m is the number of crops in each of the n manure deficit areas; Q_{ij} represents the amount of manure transferred for use by crop i in the deficit area j; Q_j is the amount of nutrient required from external applications by crops in deficit area j; and a_{ij} is the amount of nutrient taken up by the crop per unit of applied manure. Constraint (3.33b) requires the farm to transfer all surplus manure to deficit areas while constraint (3.33c) states that no deficit area can receive more manure than it has potential to use on cropland or pasture.

In areas where manure is applied in excess of crop requirements, nutrients are at risk of being leached into groundwater or eroded into surface water. This pollution runoff can be expressed as a function of some deterministic variables that the farmer controls in the production process and other stochastic random variables as follows:

$$e = \sum (r + \varepsilon) x , \qquad (3.34)$$

where ***e*** is the runoff rate, ***x*** is the level of the farm activity (e.g., acres of crop produced using a specific production system), ***r*** is the expected pollution runoff per unit of the farm activity (e.g., expected nitrogen loss per acre of crop produced by a given production system) and ε is the stochastic variation of runoff per unit of the activity.

Based on this model specification, the most efficient choice for an individual producer will greatly depend on the average level of net returns (Yiridoe et al., 1994). Specifically, the farmer's expected cost of the pollution control is the expected profit forgone by re-allocating the farm resources or choosing alternative cropping systems. Manure transfer to deficit areas results in the substitution of these surplus nutrients for commercial fertilizer nutrients. If the economic benefits of manure transfer from surplus to deficit areas are less than the costs, then regulations that require such transfers will lead to higher costs and reduce competitiveness of dairy production unless the public sector subsidizes the disposal.

CHAPTER 4

DAIRY FARM MANAGEMENT MODEL

Farm management decisions such as manure use and land allocation are modeled (i.e., estimated) as a function of prices, policies, technology, and physical characteristics of the field. The purpose of this chapter is to construct a whole-farm model by incorporating as many factors surrounding dairy nutrient management as possible. The economic model has two main components: livestock and crop sectors. The first component deals with the nutrient requirement of lactating cows. The second component estimates the cropping systems requirement for manure nutrient utilization and forage nutrient supply for the lactating cows over the planning horizon. The biophysical model is used to estimate environmental impacts on the individual field.

The first section describes assumptions and techniques used to develop a linear program model for a dairy farm. The second section describes the objective function and the underlying constraints. These constraints involve milk production, feed ration requirements, manure nutrient outputs, crop nutrient needs, and the ration nutrients supplied by the alternative crops. The third section describes the data sources and alternative farm management decision scenarios. The last section presents a sensitivity analysis framework of risk involved in a dairy operation.

Model Assumptions

The optimization model involves the specification of a behavioral assumption of profit maximization or cost minimization typically using systems of equations and/or inequalities designed to replicate farm-level activities. The main item of interest is the profit emanating from milk production, including crop grown for sale and manure transactions. Alternatively, the model minimizes feed costs by selecting cropping systems based on their feeding value and their ability to meet N and P uptake requirements. Within the model, the farmer is constrained by land, government regulation, manure storage capacity, feed supply and nutrient requirements for cattle and crops. The farmer has access to commercial fertilizer in addition to dairy manure to grow two different rotational forage crops, namely temperate corn-tropical corn-rye/clover (CCR) and temperate corn-bermudagrass-rye/clover (CBR) in addition to grain corn, wheat, soybean or cotton. The model also balances fertilizer requirement with the need for disposing of manure for a variety of crops and number of acres the manure would be spread on. This implies that the producer would dispose all the manure produced on the farm by the end of the planning horizon. Altering the exogenous variables allows one to determine the tradeoff between farm-level activities and the behavior and goals of the producer or decision maker.

A major contribution of this analysis is accounting for the influence of economic variables on manure nutrients demand. Incorporating the profitability of competing farming enterprises requires information on prices and costs for a given enterprise. The data on prices, yields and costs enter the model on a commodity basis. The variable cost data are based on the actual costs incurred by producers in Georgia. Generally, a producer's revenue per unit of output ***i*** in period ***t*** is related to the market price for that output. However, the market prices for crops to be planted will not be known in advance to producers before planting decisions are made. Operator's planting decisions will therefore have to be based on expected revenue per unit. The second component of expected profits is the expected yield. Expected crop yield may be estimated by regressing yield on lagged yield and a time trend. Observation of four years of yield data used in this study showed that yields were identically and independently distributed within cropping periods and plant nutrient sources.

It is assumed that a dairy farm operator will maximize the net return, π **,** from the milk and crop production portion of the operation for CBR and CCR rotations given the availability of manure produced on the farm and crop acreage operated by the farm on which manure can be applied. From these forage crops, only the hay can be utilized for feed or sold while the corn and rye/clover crops can be used for feed only since there is no established market for silage commodities in Georgia (G. Larry Newton, personal communication). The farm has the possibility of producing non forage crops (corn grain, soybeans, cotton and wheat) for manure application. The corn grain crop can produce grain for dairy feed ration or for sale while the cotton crop can produce cottonseed for the dairy ration. The farm has access to additional land for manure application if current acreage is insufficient. The farm also determines the manure application rate, MA_i, the amount of j nutrient from commercial fertilizers for crop i, Fer_{ij}. The farm has the options to choose minimum acreage for crop production for a given dairy cow number or maximum herd size for a given crop. The model also has the possibility of choosing maximum production level by period.

Objective Function and Related Constraints

The objective function maximizes net returns, π **,** over the planning horizon t, which is the sum of the yearly net returns from milk and crop for sale. Algebraically, this objective function of the whole farm model is specified as in equation (4.1):

$$\underset{MA,Fer}{Maximize}\,\pi = \left[\sum_t (m_t MPC - LOC_t) NMC\right] + \left[\begin{array}{l}(\sum_i (p_i CRPY_i - CO_i) ACMi - \sum_i \sum_j (f_j Fer_{ij} ACM_i) - MAC - rLS) \\ + (\sum_i piCRPYi - COi - \sum_j (f_j d_{ij} CRPY_i) ACF_i)\end{array}\right]$$

$$- \left[\sum_h \sum_t z_{ht} Fed_{ht} + \sum_p \sum_t w_{pt} Min_{pt}\right] - \left[\sum_i \sum_t v_{it} CRPTran_{it} + \sum_t s_t ManTran_t\right]$$

where

m_t = price (\$/cwt) of milk in period t (t = 1,2,3,4),

LOC_t = livestock management cost (\$/cow),

MPC = total amount of milk produced per cow (cwt/cow)

NMC = total number of milking cows

p_i = price (\$/unit) of crop i grown,

$CRPY_i$ = crop i yield (lb/acre),

CO_i = production costs (\$/acre) other than nutrient and land ownership costs of crop i,

ACM_i = cropping acreages with manure application (including supplemental fertilizers to meet crop nutrients requirement),

ACF_i = cropping acreages receiving only commercial fertilizers,

f_j = cost (\$/unit) of the j nutrient of commercial NPK fertilizers,

d_{ij} = unit of j nutrient needed to produce one unit of i crop,

MAC = manure application cost (to be described later),

r = land rent (\$/acre),

LS = additional acreages of land leased for manure application,

Fed_{ht} = unit of commodity h fed in period t (determined by dairy ration requirement),

z_{ht} = price (\$/unit) of commodity h in period t,

$\boldsymbol{Min_{pt}}$ = unit of concentrated mineral nutrients $\boldsymbol{p}$ purchased in period $\boldsymbol{t}$,

$\boldsymbol{w_p}$ = cost (\$/unit) of concentrated mineral nutrients $\boldsymbol{p}$ purchased

$\boldsymbol{CRPTran_{it}}$ = unit of crop produced for ration transferred from production period to other periods,

$\boldsymbol{v_i}$ = cost (\$/unit) of storing forage $\boldsymbol{i}$ per period,

$\boldsymbol{ManTran}$ = unit of manure transferred from period $\boldsymbol{t}$ to $\boldsymbol{t+1}$,

$\boldsymbol{s_t}$ = cost (\$/unit) of storing manure per period.

The terms in the first bracket define net return from milk production and the terms in the second brackets define the net return from the crop production with and without manure applications. The terms in the third bracket represent feed ration cost. The terms in the last bracket represent forage and manure storage costs. Annual operation costs are composed of crop production costs, livestock management costs, purchased feed costs, and forage and manure transferred costs. The objective function is subject to the following set of restrictions.

Acreage Restrictions:

The total crop acreage is composed of the farm's own tillable acres and acres leased by the farm for disposal of manure only. This is expressed as

$$\sum_i (ACM_i + ACF_i) = LAV \qquad (4.2)$$

where LAV is the total land available including acres leased by the farm for disposal of excess manure.

Crop Rotation Relations

These relations restrict the yields of forage crop $\boldsymbol{i}$ receiving manure nutrients in corn-bermudagrass-rye/clover (CBR) and corn-corn-rye/clover (CCR) rotation to those expected in the rotation periods.

$$\text{CBR}_i = CCR_i \qquad (4.3)$$

The model can choose to produce hay (CBR rotation) or tropical corn (CCR rotation) during the summer cropping period.

Manure Use Restrictions

The model requires that all the manure effluent is used for forage crop production. In other words, the total amount of manure available for land application is determined by the dairy herd size. Algebraically,

$$TACM = \sum_{u} ex_u CC \qquad (4.4)$$

where ***TACM*** is the total amount of manure applied to cropland; $\boldsymbol{ex_u}$ is the amount of manure produced annually by one unit of cow capacity; and ***CC*** is the total cow capacity. The manure production capacity of a cow, $\boldsymbol{ex_u}$ is held constant by milk production level to avoid difficulty in the assessment.

Two constraints are included to control the balances for manure and crop nutrients within the nutrient recycling system. The manure nutrient constraints ensured that the manure nutrient balance is met. These constraints allow for transfers of manure among production periods, but force the annual manure balance to equal to zero.

Annual Nutrient Restrictions

These restriction require the purchased fertilizers and the manure nutrients excreted during a given production period to be equal to the sum of nutrients removed by the crops at harvest and the nutrients in manure stored for use during the following cropping periods. This relation requires that all nutrients available must be utilized for crop production within a crop rotation cycle. The functional form of this restriction is expressed as follows:

$$\sum_{i}\sum_{j}\sum_{t}(AC_{it}NU_{ji} + NUTRAN_{jt}) = \sum_{j}\sum_{t}(Fer_{jt} + MANU_{jt}) \qquad (4.5)$$

where

AC_{it} = acres of crop ***i*** in period ***t***,

NU_{ij} = pounds per acre of nutrient ***j*** taken up by crop ***i***,

$NUTRAN_{jt}$ = pounds of nutrient ***j*** transfer from period ***t*** to ***t + 1***,

$MANU_{jt}$ = pounds of manure nutrient ***j*** available from the farm in period ***t***.

Nutrient Application Restrictions

The nutrient application constraints ensure that all nutrients on-hand are sufficient to produce crops. In other words, the quantity of nutrients required for crop production represents the lower bound of the commercial fertilizer and manure nutrients that are available on the farm. Algebraically, this restriction can be expressed as:

$$\sum_{i}\sum_{j}(Fer_{ij} + man_{j}MA_{i} - d_{ij}CRPY_{i} + masu_{ij}) \geq 0 \quad \text{for } j = N, P, K \qquad (4.6)$$

where $\boldsymbol{Fer_{ij}}$ is the pounds of ***j*** nutrient applied to crop ***i***; $\boldsymbol{man_{j}}$ is the pounds of j nutrient in manure; $\boldsymbol{d_{ij}}$ is the pounds of ***j*** nutrient needed to produce unit of crop ***i***; $\boldsymbol{masu_{ij}}$ is the amount of surplus manure nutrient ***j*** applied to crop ***i*** but not utilized by the crop and $\boldsymbol{masu_{ij}} > 0$, but has no value to the farm. $\boldsymbol{masu_{ij}}$ is set to zero when nutrient ***j*** is restricted. For example, $\boldsymbol{masu_{i}}$ becomes zero when N is restricted.

Surplus manure can occur when the manure application rate is restricted based on one specific nutrient. Restricting the manure application rate for crop based on N may result in a surplus of P from manure because the N:P ratio of the manure may be greater than the N:P ratio of nutrients utilized by crops.

Per-Acre Nutrient Required by Crops

This restriction states that the amount of each nutrient applied per acre from commercial fertilizer and manure must meet the amount needed by the crop. Any excess amount of manure nutrients applied is assumed to have no value to the farm. The relation between crop nutrient requirements and field application rates can be represented by the following inequality function:

$$\sum_i \sum_j (Fer_{ij} + man_j MA_i - d_{ij} CRPY_i) \geq 0 \quad \text{for } j = N, P, K \qquad (4.7)$$

Annual Crop Supply Restrictions

Forage supply constraints ensure that the cow nutrient requirement is met. This restriction is used to balance the proportion of forage crops used for feed or sold with the milking cow needs. These constraints allow transfers of forage between seasons, but force an annual crop nutrient balance at the end of the growing cycle. Mathematically, this restriction is written as follows:

$$\sum_i \sum_t AC_{i(t-1)} CRPY_i (1 - CRPS_{i(t-1)}) = \sum_i \sum_g \sum_t (CRPU_{git} + CRPTran_{it}) \qquad (4.8)$$

where

$AC_{i(t-1)}$ = acres of crop ***i*** in period ***t-1***,

$CRPY_j$ = per acre yield of crop ***i***,

$CRPS_{i(t-1)}$ = percentage of harvest crop ***i*** sold (Note that hay is the only forage crop that can be sold because there is no established market for silage),

$CRPU_{git}$ = pounds of forage ***i*** in period ***t*** used by milking cow group **g** (g = 50, 60, 70, 80 and 90 lbs milk/day per cow)

$CRPTran_{it}$ = transfer of forage ***i*** to period ***t***.

This relationship also assumed no feed loss during harvest and storage of crop ***i*** in period ***t***.

Feed Ration Restrictions by Milk Production and Period

These constraints are included to control the balance of ration nutrients and milking cow requirements. Two constraints for each characteristic (greater than and less than) are used to allow a range for the model to select an economical level. The first constraint for diet regime forces the amount of a diet component to be greater than the amount required by the cow. The second constraint forces the percentage of a dietary characteristic in a diet to be less than a certain percentage of DMI. Algebraically, these constraints are expressed as:

$$\sum_{i} CRPU_{git} RAT_{qi} + \sum_{h} Fed_{ght} RAT_{qh} + \sum_{k} STOC_{gkt} RAT_{qk} \geq IR_{gqt(mpl)} NMC_{gt} DA_{t} \qquad (4.9a)$$

$$\sum_{i=1} CRPU_{git} RAT_{qi} + \sum_{f=1} Fed_{ght} RAT_{qh} + \sum_{g=1} STOC_{gkt} RAT_{qk} \leq DMI_{gt} FDM_{gq} \qquad (4.9b)$$

where

$\boldsymbol{RAT_{qi}}$ = ration ***q*** associated with crop i, commodity ***h***, or forage on hand ***k***,

$\boldsymbol{STOC_{ght}}$ = stock of forage feed ***h*** for cow group ***g*** on-hand in period ***t***,

$\boldsymbol{Fed_{ght}}$ = unit of commodity ***h*** fed in period ***t*** to cow group ***g***,

$\boldsymbol{IR_{gqt(mpl)}}$ = requirement per cow for ration ***q*** for cow group ***g*** in period ***t***, by milk production level (***mpl***),

$\boldsymbol{NMC_{gt}}$ = number of milking cows in group ***g*** during period ***t***,

$\boldsymbol{DA_{t}}$ = number of days in period ***t***,

$\boldsymbol{DMI_{gt}}$ = total ***DM intake*** for group ***g*** in period ***t***, and

$\boldsymbol{FDM_{gq}}$ = minimum forage dry matter in ration ***q*** from forages.

Annual feed costs were composed of crop production costs, purchased feed costs, costs of feed on hand, and purchased fertilizer costs.

Manure Application Cost

The model estimates the land required for the manure application while minimizing the impacts on the environment as follows,

$$VMA = \sum_{i} ACM_i MA_i \qquad (4.11)$$

where ***VMA*** is the total volume of manure applied to the cropped field and both manure application rate (MA_i) and acres to receive manure (ACM_i) are decision variables.

Land application of manure includes setting up the machinery and equipment, loading the lagoon and irrigation systems, field travel time, and time spent actually applying in the field. Another question on many producers' minds is how manure application costs increase with hauling distance. However, this question may be more relevant when locating a new facility or purchasing manure than when considering changes in existing facility where manure must be disposed of regardless of the hauling cost. From this standpoint, the cost of transporting manure from storage to the field and then applying it depends on a mileage charge in addition to the base charge for manure application (Fleming, Bacock and Wang, 1998). Algebraically,

$$MAC = [(ac)(VMA)] + [(tc)(VMA)TD] \qquad (4.12)$$

where ***ac*** is the field application cost ($/unit of manure applied), and ***tc*** is the manure transportation cost ($/unit of manure per mile). The travel distance ***TD*** is the sum of travel miles to each block of the field receiving manure.

Annual Resource Restrictions

These resource constraints limit the use of physical and labor resources to be less than the amounts available. This relation is represented by the following mathematical expression:

$$\sum_{i=1} AC_i Q_{\lambda i} = M_{\lambda} \qquad (4.10)$$

where $\boldsymbol{AC_i}$ is the total acreage of crop $\boldsymbol{i}$ and $\boldsymbol{Q_{\lambda i}}$ is the amount of resource associated with the production of an acre of crop $\boldsymbol{i}$ (λ = land, labor, lagoon, cow, milk production capability, etc.), and M_λ = maximum or minimum quantity of resource λ available.

Default Input and Data Sources

Farm management decisions such as manure use and land allocation are modeled (i.e., estimated) as a function of prices, policies, technology, and physical characteristics of the field. The model used specific information to determine optimal nutrient management strategies for dairies. General farm information included number of the dairy cattle, crop acreage availability, labor availability, costs of purchased livestock feed and crop nutrients, storage capacity for manure and feed, and the concentration of nutrients in manure wastewater.

The model allows cows to be fed to produce milk at lower production level than their maximum production level. Milk production is varied from 50 to 90 lbs of milk/day per cow in 10-lb increments to determine the effects of milk production on optimal manure management strategies. Feed nutrients and associated rations are adjusted for milk production and available excreted manure nutrients (N, P and K) are adjusted for crop uptake and by milk production level and season. Nutrient excretion is affected by milk production and ration nutrient concentration. Default values for available nutrients excreted were based on a cow producing 55 pounds of milk per day and a total volume of 329.86 gallons of manure waste applied to one acre of crop field. Nutrient values were 0.13, 0.05 and 0.13 kg /day per cow for N, P and K, respectively.

Crop nutrient uptake has been determined by crop yield and concentration of N, P or K in dry matter (DM). The amounts of nutrients available for crop uptake are variable, depending on the area and season in which they are grown. Although nutrients, especially N, may be lost during the recycling process by volatilization, leaching, and runoff, we assumed here that all nutrients in manure are readily available and losses during storage and field application are negligible. As a result, the default values for manure and fertilizer application rates are based on the minimum and maximum nutrient requirements for each crop (Table 4.1).

Nutrient concentrations for forages were taken from the study at the dairy research farm in Tifton, Georgia. Nitrogen uptake varied from 281 to 433 lb/acre, and estimated P uptake varied from 57 to 77 lb/acre by a corn-corn-rye/clover and corn-bermudagrass-rye/clover crops. These crops vary in quality and yield, depending on the cropping year. The commodities available for use in dairy rations are those typically available in Georgia. These include corn grain, soybean meal, soybean hulls, whole cottonseed, and mineral salts in addition to the corn silage, bermuda hay and small grain crops. Nutrient requirements for milking cow performance and maintenance were derived from the DART ration least-cost formulation and adjusted for production level and period. Upper and lower bonds were used for many animal nutrient requirements in balancing the rations.

Livestock default inputs encompass the flow of incurred livestock expenses (feed, veterinary expenses, depreciation on building, machinery and animals, interests on capital stock) including operating costs (electricity, heating fuel, etc.). Labor represents the sum of hours worked annually by all classes of labor (family, hired and casual). Crop inputs consist of annual expenditure on seeds and crop protection and other miscellaneous variable crop costs. The flow of service emanating from capital stock items such as machinery, buildings and land improvements is measured by summation of all maintenance and running costs, depreciation charges and interest on the capital stock. Land is measured as the total agricultural area available for each farm. Finally, all output and input variables defined in value terms are deflated using the appropriate annual price indices (Table 4.2).

Table 4.1. Crop nutrient requirement rates

Crop	Nitrogen		Phosphorus		Potassium	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
	---------- lb/acre ----------					
Temperate corn	150	190	39.27	48.00	78.86	95.47
Tropical corn	150	170	34.91	43.64	70.56	87.17
Bermuda hay	125	135	39.27	48.00	78.86	95.47
Winter small grain	225	250	30.55	34.91	58.11	66.41
Corn grain	120	140	30.55	39.27	66.41	83.01
Cotton	60	80	26.18	34.91	49.81	66.41
Wheat	112.5	125	15.27	17.46	29.06	33.20

Table 4.2. Default inputs of dairy farm operation costs

Category	Unit	Value
Revenue		
Corn for grain	$/cwt	3.00
Cottonseed	$/cwt	4.00
Cotton lint	$/ton	63.00
Wheat	$/cwt	2.75
Hay	$/ton	40.00
Milk	$/cwt	16.07
Livestock operation costs		
Tractor and machinery	$/cow	73.91
Livestock	$/cow	350.10
Labor	$/cow	450.00
Other	$/cow	120.59
Herd replacement	$/cow	550.00
Interest (operating)	$/cow	0.00
Total operating costs	$/cow	1544.60
Depreciation	$/cow	270.00
Interest	$/cow	200.00
Taxes and insurance	$/cow	10.00
Total fixed costs	$/cow	480.00
Total costs	$/cow	2024.60
Ration feed ingredient costs		
Cotton seed	$/cwt	5.15
Corn	$/cwt	4.34
Soybean hulls	$/cwt	3.35
48 soybean meal	$/cwt	10.60
Calcium phosphate	$/cwt	16.00
Limestone	$/cwt	4.00
Mineral salt	$/cwt	8.00
Dyna-Mate	$/cwt	9.00
Commercial fertilizer costs		
Nitrogen	$/cwt	27.03
Phosphorus	$/cwt	28.07
Potassium	$/cwt	17.87
Lime	$/ton	23.00
Land rent	$/acre	0.00
Forage storage	$/cwt	0.00
Manure storage	$/cwt	0.00
Manure application	$/cwt	0.00
Manure transportation	$/cwt	0.00

The prices of inputs and outputs were obtained from local fertilizer, pesticide and seed retailers. Crop prices used were Georgia 2002 farm gate prices. Fertilizer nutrient prices used were $27.03/cwt nitrogen, $28.07/cwt phosphate, and $17.87/cwt potash, based on 2002 retail prices. The information on seed, pesticide, and nutrient inputs, as well as the specific farming operation was obtained from an experimental study evaluating two intensive triple- cropping systems each using liquid dairy manure and commercial inorganic fertilizers as nutrient sources for four consecutive years at The University of Georgia, Coastal Plain Experiment Station in Tifton, Georgia.

Crop production costs including lime application costs were, on average, $371.67/acre for temperate corn, $436.64/acre for tropical corn, $150.69/acre for bermudagrass, and $120.64/acre for rye/clover from 1997 to 1999 (Table 4.3). Labor required for forage production and livestock management was estimated by calculating the number of hours that were required for each activity. Machinery performance for each field operation and resulting machinery costs were estimated from enterprise budgets developed at the Georgia Branch Experiment Station. Fixed costs included depreciation on tractors, machinery, buildings and livestock, interest on operating capital and taxes and insurance. It is assumed that the farmer owns the necessary machinery and equipment needed to produce crops using similar dairy manure systems and coefficients for manure production, nutrients in manure, manure transportation and field application costs, and nutrients required by crops. The dairy operation maintains the same type of operation, and manure storage and application system regardless of manure application restrictions but milk production was allowed to vary by feeding regimes and cow capacity. Increasing the size of storage in response to the restriction could incur higher cost to a farm than expanding the land application (Boland et al., 1998).

Table 4.3. Partial enterprise budget data for cropping systems at Coastal Plain Experiment Station in Tifton, Georgia (1997 – 1999)

Enterprise	Year	Cropping System	Variable costs	Fixed costs	Total costs	Total revenue	Total yield
			---------------------------$/acre)		-----------------------		(Ton/acre)
Temperate corn	1997	CBR-M	206.23	168.27	374.5	416.55	4.53
Temperate corn	1997	CCR-M	204.51	164.35	368.86	536.14	6.08
Temperate corn	1998	CBR-M	246.51	180.59	427.10	723.39	6.79
Temperate corn	1998	CCR-M	260.46	176.78	437.24	854.74	8.86
Temperate corn	1999	CBR-M	204.63	177.07	381.69	1184.49	7.83
Temperate corn	1999	CCR-M	202.09	173.72	375.80	949.53	8.42
Yearly average of temperate corn			220.74	173.46	394.20	777.47	7.09
Bermuda hay	1997	CBR-M	68.04	88.16	156.20	498.10	6.65
Bermuda hay	1998	CBR-M	79.51	71.07	150.58	384.67	3.49
Bermuda hay	1999	CBR-M	70.60	71.13	141.74	395.86	3.77
Yearly average of Bermuda hay			72.72	76.79	149.51	426.21	4.64
Tropical corn	1997	CCR-M	262.57	174.07	436.64	350.14	3.97
Tropical corn	1998	CCR-M	340.17	165.65	505.82	478.74	4.16
Tropical corn	1999	CCR-M	192.43	160.99	353.43	516.09	6.84
Yearly average of tropical corn			265.06	166.90	431.96	448.32	4.99
Rye/Clover	1997	CBR-M	86.02	36.56	122.58	230.30	1.89
Rye/Clover	1997	CCR-M	72.74	45.98	118.72	117.10	0.96
Rye/Clover	1998	CBR-M	95.90	74.77	170.67	281.44	2.76
Rye/Clover	1998	CCR-M	93.27	70.77	164.04	290.07	2.27
Rye/Clover	1999	CBR-M	99.52	75.41	174.93	347.13	2.43
Rye/Clover	1999	CCR-M	96.27	71.11	167.38	353.35	2.43
Yearly average of rye/clover			90.62	62.43	153.05	269.90	2.12

In practice, the operation can also lease additional land when needed to meet manure nutrient application restrictions, and cropped and harvested this land the same ways as existing owned lands. The model considers temperate corn-bermudagrass-rye/clover and temperate corn-tropical corn-rye/clover as two intensive (triple cropping) forage cropping patterns. However, it also allows crop acreages to change by period to reflect differences in forage needs and manure utilization requirements. In other words, acreage is adjusted so that all manure nutrients are available for plant uptake.

Alternative Management Scenarios

Several options are available to dairy farms facing restriction on land application of manure based on plant nutrient needs (Huang, Magleby and Somwaru, 2001). These include (1) applying manure to crops and cropping systems; (2) expanding the existing crop acres through ownership or leasing additional acreage for manure application; (3) adopting technologies such as composting to reduce nutrient loading on existing land; (4) disposing of manure on non-agricultural lands; or (5) reducing the number of cows on the farm, and hence the amount of manure, to comply with the regulation.

This analysis limits itself to the assumption that the dairy operator would utilize all the manure for a year-round forage and crop production on the farm. A baseline scenario and alternative restriction scenarios were subsequently simulated to assess the farm-level impacts. The indicators used to assess the farm-level impacts included (i) net farm profit from the dairy operation, (ii) acres of crop needed with manure loading restrictions, and (iii) the influence on herd size for given acreage by manure N, P and K loading restriction. The acres cropped depend upon animal nutrient requirements, manure nutrient use and the profitability of non-forage cropping systems utilizing inorganic fertilizers. The economic impacts on the farm are the changes of these two indicators between the baseline scenario and the restriction scenarios.

Under the baseline scenario the number of cows and manure application rate were unrestricted and the actual land application of manure was determined. One alternative scenario required meeting the nutrient uptake requirement on the least amount of acreage possible. In other words, the number of cows and manure application rates were unrestricted but land available for application is limited. This land restriction would simulate the additional crop needed to use up all the manure produced. For the second alternative, cow number was fixed, and the cropped acreages were based on animal nutrient requirement, manure nutrient use and the profitability of non-forage cropping systems utilizing fertilizers.

Manure application rates were restricted to not exceeding the nitrogen and/or the phosphorus needs of individual crops and acres receiving manure were bounded by cropland owned by the farm. This restriction is part of CNMP for the areas where P in soil is low (N-restriction) or high (P-restriction). In addition to the N and P restriction comparisons, K restrictions were also evaluated even though they are not part of the CNMP programs. The K/N ratio in manure is higher than the K/N ratio used by most crops.

Sources of Risk

Sensitivity analyses are performed to determine the model behavioral response to changes in input variables. Variables analyzed included DM production per acre over year by specific forage, milk production level and cow capacity.

The use of linear programming to develop least-cost feeds is a well established industry practice. In fact, the primary task of researchers are no longer to persuade industry of the benefits of using LP for least-cost feed mixes, but to assist industry in using the tool more effectively (Bender, Kahan and Mylander, 1992). Our purpose was to take the model beyond the traditional formulation of least-cost feed mix by including manure production, manure nutrient utilization by crop and ration nutrient production from forage crops in order to consider risk elements that are always present but often overlook.

We consider here (1) balancing nutrients in manure with crop nutrients produced for ration requirement and/or crops for sale, and (2) risk of variation in yield and nutrient levels in the crop produced for feed. The cost of crop shortage results from not utilizing all the manure nutrients applied and leaving carry over for succeeding crops and also not producing the energy and other nutrients projected for the ration. The first risk (surplus nutrient carry over) can be alleviated by soil testing after each cropping period and adjusting succeeding nutrient application rate based on the soil test results. The second risk (nutrient shortage) will show up as increase cost (due to buying more feed ingredients) and/or decrease milk production (due to energy deficiency).

The risk of nutrient variations in crop would be either surplus nutrients or a lower level of nutrient fed than planned and thus lower milk production level and consequently lower return. In general forage crops have more nutrient variation than grain crops. Analyzing the harvested crops for nutrient content can reduce the risk of nutrient variability in the ration. The magnitude of quantity variation can be estimated by evaluating historical data. Similarly, the nutrient variation can be estimated from historical data where nutrient measurement in feed ingredient has been recorded over years. The triple cropping study that has provided the database for this research does have historical yield data and historical nutrient density measurements. There are other studies that measured ration nutrient density that can be used to supplement these data.

Quite often an individual faces a situation in which the usual assumptions of linear programming do not hold. For example, the assumption that the input-output coefficients (**a_{ij}**) are known and constant is not valid. In the regular linear programming formulation of this problem the estimates of the population means of nutrient contents, derived from numerous samples of feedstuffs (e.g., forage feed and corn grain, soybean, cotton and mineral supplements), are used as **a_{ij}**'s. These **a_{ij}** values are then the estimates of population means describing the percent nutrient content of each potential ingredient for the final feed ration. Once estimated, these coefficients are rarely changed even though some variability among samples is known to exist.

Given a finite number of samples of a feed ingredient, some variability among the results of the analyses for the various nutrient components is expected. If this variability is ignored, as commonly is done in solving a least-cost feed mix problem using the regular LP formulation, the solution on the average will meet the requirement only 50 percent of the time, assuming normal distributions of the sample means (Bender, Kahan and Mylander, 1992). It may be observed here that the nutrient contents of the ingredients are not interdependent. For instance, the DM content of corn silage does not influence that of bermudagrass haylage. Therefore their covariance must be zero reducing the variance to the following quadratic expression:

$$\sigma_{bi}^2 = \sum_j \sigma_{ij}^2 x_j^2 \qquad (4.13)$$

In order to account for the variability of nutrient content and still use commonly available linear programming algorithms, this equation must be linearized.

Consider the following relation:

$$\sigma_{bi}^* = \sum_j \sigma_{ij} x_j \qquad (4.14)$$

By squaring both sides, we obtain

$$\sigma_{b_i}^{*2} = \sum_j \sigma_{ij}^2 x_j^2 + \sum_j \sum_k \sigma_{ij}\sigma_{ik}x_j x_k \quad j \neq k \tag{4.15}$$

$$\sigma_{b_i}^{*2} = \sigma_{b_j}^2 + \sum_j \sum_k \sigma_{ij}\sigma_{ik}x_j x_k \quad j \neq k \tag{4.16}$$

This differs from equation (4.13) by the second term, which (being a sum of a positive cross-product) is positive. Therefore, $\sigma_{b_j}^{*2} \geq \sigma_{b_i}^2$ (4.17)

If σ_{b_i} is approximated by $\sigma_{b_i}^*$, the result, as a consequence of the relation (4.17), would be biased. The practical consequence of this bias is that the actual probability of meeting the requirement would generally be more than the specified value, and equation (4.14) can be an acceptable linear approximation. To raise the probability of meeting the requirement of any nutrient restriction level, the requirement level of that nutrient must be modified as a function of its standard deviation.

CHAPTER 5

MODEL IMPLEMENTATION

The linear program model used in estimating crop acreage response and total returns to land and management for the impact of manure nutrient loading restrictions on a dairy farm is presented in this chapter. Model sensitivity analysis and parameter estimate results are presented and discussed.

Dairy Farm Profit Optimization Model

The economic model of the whole dairy farm is specified as in equation (5.1):

$$\underset{Ma,Ac}{Maximize}\,\pi = \left[\sum_t (m_t Milk - LOC_t)cow\right]$$
$$+\left[\sum_i (p_i CRPY_i - CO_i)AC - \sum_i\sum_j (f_j Fer_{ij} ACM_i) - MAC - \sum_i\sum_j (f_j d_{ij} ACRPY_i ACF_i) - rLS\right]$$
$$-\left[\sum_h\sum_t z_{ht} Fed_{ht} + \sum_p\sum_t w_{pt} Min_{pt}\right] - \left[\sum_i\sum_t v_{it} CRPTran_{it} + \sum_t s_t ManTran_t\right] + \varepsilon_{ijt}$$

where

$\boldsymbol{m_t}$ = price of milk in period $\boldsymbol{t}$ ($\boldsymbol{t}$ = 1,2,3,4),

$\boldsymbol{LOC_s}$ = livestock management cost,

$\boldsymbol{p_i}$ = price of crop $\boldsymbol{i}$ grown,

$\boldsymbol{CRPY_i}$ = crop $\boldsymbol{i}$ yield,

$\boldsymbol{CO_i}$ = production costs other than nutrient and land ownership costs of crop $\boldsymbol{i}$,

$\boldsymbol{ACM_i}$ = cropping acreages with manure application (including supplemental fertilizers to meet crop nutrients requirement),

$\boldsymbol{ACF_i}$ = cropping acreages without manure application,

$\boldsymbol{f_j}$ = cost of the $\boldsymbol{j}$ nutrient of commercial NPK fertilizers,

$\boldsymbol{d_{ij}}$ = unit of $\boldsymbol{j}$ nutrient needed to produce one unit of $\boldsymbol{i}$ crop,

MAC = manure application cost,

r = land rent ($/acre),

$\boldsymbol{Fed_{ht}}$ = unit of commodity ***h*** fed in period ***t*** (determined by dairy ration requirement),

$\boldsymbol{z_{ht}}$ = price ($/unit) of commodity ***h*** in period ***t***,

$\boldsymbol{Min_{pt}}$ = amount of concentrated mineral nutrients ***p*** purchased in period ***t***,

$\boldsymbol{w_{p}}$ = cost ($/unit) of concentrated mineral nutrients ***p*** purchased

$\boldsymbol{CRPTran_{it}}$ = unit of crop produced for ration transferred from production period to other periods,

$\boldsymbol{v_{i}}$ = cost ($/unit) of storing forage ***i*** per period,

ManTran = unit of manure transferred from period ***t*** to ***t+1***,

$\boldsymbol{s_{t}}$ = cost ($/unit) of storing manure per period.

ε_{ijt} = stochastic error term

This model is applied to simulate the economic impacts of enforcing environmental constraints for a dairy farm in South Georgia. The simulation is implemented following the imposed constraints on the objective function. One aspect of a dairy operation is dealing with uncertain crop performance affected by stochastic manure nutrient supply. Nitrogen and phosphorus runoff are two primary water quality problems caused by land application of dairy manure for crop production. As a result, all sensitivity analyses are specified as functions of acreage response to nutrient loading restrictions and net returns to land and management

This study limited itself to the assumption that the dairy operator would utilize all the manure for a year-round forage and crop production in the farm. A baseline scenario and alternative restriction scenarios were subsequently simulated to assess the farm-level impacts. The indicators used to assess the farm-level impacts included (i) net farm profit from dairy operation, (ii) acres of crop needed with manure loading restrictions, and (iii) the influence on herd size for given acreage by manure N, P and K loading restriction. The acres cropped depended upon animal nutrient requirements, manure nutrient use and the profitability of non-forage cropping systems utilizing inorganic fertilizers. The manure disposal capacity per year was determined by requiring all effluent to be used within a 12-month period but by allowing storage over cropping periods. The feed ration nutrients were based on the requirements of milking cow at the 150th day during the lactation period. The milk production capacity by cow was 60 lbs per day except during the summer period where it was reduced to 50 lbs per day. The economic impacts on the farm were the changes of the indicators between alternative scenarios.

Decision Based on Available Cropland

In this section the model was applied to the case where a dairy farmer has 600 acres of available cropland and maximizes expected returns from milk and crop production by selecting a range of manure levels under both nitrogen and phosphorus-based nutrient management standards. Under a baseline scenario, the number of cows and manure application rate were unrestricted and the actual land application of manure was determined. Alternative scenarios required meeting the crop nutrient uptake requirement on the least amount of acreage possible. In other words, the number of cows and manure application rates were unrestricted but land available for application was limited. This land restriction would simulate the additional crop needed to use up all the manure produced. Manure application rates were restricted to not exceeding the nitrogen and/or the phosphorus needs of individual crops and acres receiving manure were bounded by cropland owned by the farm. This restriction is part of CNMP for the areas where P in soil is low (N-restriction) or high (P-restriction). In addition to the N and P restriction comparisons, K restrictions were also evaluated even though they are not part of the CNMP programs.

The impact of manure application policy changes was measured by calculating the differences in returns above variable cost levels between the results of three runs of the model reflecting three alternative policies: N-based, P-based and K-based manure management polices. The base run had no restriction on manure nutrients application rates except the number of animals was restricted to 5 cows per acre. The second run represents the management decisions the farmer would be expected to make on applying manure based on N-restriction. This would then allow for manure P and K to be greater than the P and K needs of crops. The third run represents the management decisions made by the farmer where land application of manure is based on meeting the P needs of the crops. Alternatively, P-restriction does not allow for manure P to exceed the P needs of crops. The fourth run represents a K-based restriction where the manure application rate would not exceed the crop K uptake rate. Comparing the results of all runs would illustrate what actions the representative farmer would take in order to mitigate the costs of the new regulations.

Model estimates of four cropping seasons (1997-2000) are presented in Table 5.1. In general, the representative farm net returns above variable costs were reduced as a result of the imposition of nutrient loading restrictions. The average net return during the four seasons was highest ($2633.71 per acre) when the manure application rate was not restricted, but decreased when the application rate was based on crop N ($2482.16 per acre), P ($1138.58 per acre), and K ($489.89 per acre) demands. Similar trends were observed for net revenues per cow management and milk production.

Table 5.1. Expected costs and net returns to land and management under different nutrient loading restrictions for a dairy farm with 600 acres available for manure application.

Items	1997	1998	1999	2000	Yearly average	Std dev.
No restriction						
Net return per acre	1940.72	3207.66	2453.07	2933.39	2633.71	557.40
Net return per cow	1430.25	1564.49	1487.79	1528.84	1502.87	57.61
Cost per cow	4085.64	3834.51	3911.21	3870.16	3925.38	111.34
Net return per cwt milk	4.35	4.76	4.53	4.65	4.57	0.17
Cost per cwt milk	12.44	11.67	11.91	11.78	11.95	0.34
N-based restriction						
Net return per acre	1940.72	3035.98	2399.38	2552.56	2482.16	451.55
Net return per cow	1430.35	1548.61	1490.66	1510.64	1495.07	49.39
Cost per cow	4085.64	3850.39	3932.43	3917.84	3946.57	99.36
Net return per cwt milk	4.35	4.71	4.54	4.60	4.55	0.15
Cost per cwt milk	12.44	11.72	11.97	11.93	12.01	0.30
P-based restriction						
Net return per acre	1406.34	1062.65	1015.36	1069.99	1138.58	180.14
Net return per cow	1499.13	1620.10	1461.11	1063.58	1411.73	241.53
Cost per cow	4125.85	3988.58	3758.14	3602.73	3868.83	233.43
Net return per cwt milk	4.56	4.93	4.77	3.94	4.55	0.44
Cost per cwt milk	12.54	12.14	12.24	13.34	12.57	0.54
K-based restriction						
Net return per acre	663.56	568.92	526.52	200.54	489.89	201.22
Net return per cow	1428.73	1562.55	1379.75	397.39	1192.10	535.41
Cost per cow	4323.48	4225.62	4080.22	2910.89	3885.05	657.09
Net return per cwt milk	4.35	4.76	4.47	2.18	3.94	1.19
Cost per cwt milk	13.16	12.86	13.21	15.95	13.80	1.44

However, returns per acre were greater than returns per cow with unrestricted and N-standard manure management, but lower when the manure management was based on crop P and K requirements. This resulted mainly from the fact that there were also corn, wheat and hay crops grown for sale in order to utilize the surplus manure under the more restrictive P and K scenarios (Table 5.2). Under the least restrictive N-based management, only hay crop was grown for sale.

Requiring a P-based nutrient management plan generally increases the cost of manure management because more land is needed to meet the requirements of a P-based plan. Under a P-standard, manure application rates are reduced (relative to an N-standard) such that manure P is not applied in excess of crop uptake requirement. As a result, farms grow hay and wheat for sale in order to utilize the surplus manure. In other words, the cropland is expanded while the number of cows remains constant (Table 5.3). Although the land carrying capacity is high under the unrestricted (1.74 cows per acre) and N-restricted (1.65 cows per acre) manure application plans, both P and K may be over-applied. The land carrying capacity was substantially reduced to about 0.82 and 0.43 cows per acre under P-based and K-based manure management policies, respectively.

One of the interesting outcomes from the change in manure disposal policies is the change in manure transfer between production and utilization periods. This includes the timing of when and on what crops it is applied. The most significant change occurred under the N-restriction scenario when manure is stored for 20.60 to 45.53 cow days during the summer periods. This was equivalent to approximately 783.73 to 1724.43 cwt of stored manure that was used for the following spring crop production. In addition to the forage crops, only hay crop was grown for sale under the N-based manure management.

Table 5.2. Acreages of crops grown for sale under different nutrient loading restrictions for a dairy farm with 600 acres available for manure application

Cropping year	Crop grown for sale	No restriction	N-based restriction	P-based restriction	K-based restriction
		---------------------- acres	---------------------------		
1997					
	Corn for grain	0.00	0.00	0.00	0.00
	Cotton	0.00	0.00	0.00	0.00
	Hay	449.27	449.27	600.00	300.17
	Wheat	0.00	0.00	0.00	287.53
1998					
	Corn for grain	0.00	0.00	19.92	47.24
	Cotton	0.00	0.00	0.00	0.00
	Hay	0.00	0.00	187.36	98.50
	Wheat	0.00	0.00	297.59	396.89
1999					
	Corn for grain	0.00	0.00	30.18	54.03
	Cotton	0.00	0.00	0.00	0.00
	Hay	0.00	109.74	127.44	100.10
	Wheat	0.00	0.00	267.94	384.63
2000					
	Corn for grain	0.00	0.00	0.00	25.10
	Cotton	0.00	0.00	0.00	0.00
	Hay	0.00	140.99	570.31	104.80
	Wheat	0.00	0.00	29.69	385.02

Table 5.3. Land carrying capacity and nutrient loading restriction costs for a dairy farm with 600 acres available for manure application

Items	1997	1998	1999	2000	Yearly average	Std dev.
			No restriction			
Total number of cows	814.09	1230.17	989.28	1151.23	1046.19	184.38
Number of cows per acre	1.36	2.05	1.65	1.92	1.74	0.31
Restriction cost						
Per cow	-	-	-	-	-	-
Per cwt milk produced	-	-	-	-	-	-
		N-based restriction				
Total number of cows	814.09	1176.27	965.77	1013.83	992.49	149.19
Number of cows per acre	1.36	1.96	1.61	1.69	1.65	0.25
Restriction cost						
Per cow	0.00	0.00	24.09	29.48	13.39	
Per cwt milk produced	0.00	0.00	0.07	0.09	0.04	
		P-based restriction				
Total number of cows	562.86	393.55	416.10	603.61	494.03	104.75
Number of cows per acre	0.94	0.66	0.69	1.01	0.82	0.17
Restriction cost						
Per cow	225.99	209.69	167.58	206.25	202.38	24.75
Per cwt milk produced	0.69	0.64	0.55	0.76	0.66	0.09
		K-based restriction				
Total number of cows	278.66	218.46	228.96	302.79	257.22	40.16
Number of cows per acre	0.46	0.36	0.38	0.50	0.43	0.07
Restriction cost						
Per cow	353.21	389.17	376.42	255.50	343.58	60.57
Per cwt milk produced	1.08	1.18	1.22	1.40	1.22	0.13

Data collected from the triple, year-round forage systems study at the University of Georgia (Newton et al., 2003) included manure nutrient composition and the application rates and forage yields and nutrient composition. On average, the manure N, P and K concentrations were 103.8, 37.7 and 107.6 ppm, respectively. It is interesting to indicate that the manure N recoveries were about 77% compared to 41% of P recoveries. Mean forage K concentrations were 1.35 to 1.57% with the primary difference being higher K concentrations in bermudagrass than tropical. Rye forage contained the highest concentrations of K, which averaged 2.8%. However, the ratios of K and N uptake for most crops were relatively lower than the manure K and K ratios, which could explain the low net returns under the K-based manure management.

The social or environmental benefits derived from a farmer complying with a nutrient standard policy can be estimated by the additional costs of a specific manure management policy relative to the baseline scenario. For this purpose, it is assumed that the pollution reduction cost is zero under unrestricted nutrient loading policy. Alternatively, pollution reduction costs under N-based policy were approximately 78% and 88% lower than those under P and K restrictions, respectively (Table 5.3).

It is noteworthy to also indicate that K is not a major element of environmental concern. Potassium may or may not be in excess, depending on the crop. However, excess K in forage feed could affect the dairy cow health and therefore capability to produce milk resulting in lower total farm net returns. From environmental policy point of view, there is no regulation requiring manure management based on K-standard. Therefore, the following simulation analyses will focus on the impact of N and P loading restrictions on dairy farm profitability.

Decision Based on Cropping Systems

The evaluation reported in this section compares triple and double forage cropping systems. Five N and P restriction scenarios were used to determine the sensitivity the forage had to restrictions on surplus applications of these plant nutrients. The five restriction levels are: a) P application rate is limited to 125% of the minimum P requirement, b) both N and P restricted to 125% of the crop needs, and only N is restricted to c) 100%, d) 150%, and e) 200% of the minimum crop N requirement. The comparisons were performed under two production levels: 70 and 90 pounds of milk per cow per day.

The simulation results in Tables 5.4 and 5.5 showed the distributions of acreage use across the cropping systems. The results indicate that the phosphorus surplus restriction was the most constraining. Adding the N surplus restriction to the P restriction caused no changes to the double cropping scenario but reduced slightly the cow carrying capacity and income above that imposed by the P restriction on triple cropping systems. The most restrictive impact was with the lower milk production levels. The N surplus restriction at the minimum crop requirement was considerably less constraining in carrying capacity and on cost of production and profit than the P restriction. Under the P restriction (including N and P restriction), crops were produced for sale at negative profits to permit increased manure utilization capacity with the loss being compensated by increased milk revenue. These costs ranging from \$0.089 to \$0.890 per cwt milk are shown under restriction cost in Tables 5.4 and 5.5. The larger cost resulted from the triple cropping systems. Relaxing the N surplus constraint to 150% of the minimum requirement increased carrying capacity and profit slightly, but relaxing the N constraint up to 200% caused insignificant additional changes. In these situations, the diet restrictions of percent ration energy from roughage had more impact than amount of excess N allowed for application.

Table 5.4. Comparison of effects on cow carrying capacity, costs per cow and profits per acre of limits on surplus phosphorus and nitrogen applications through manure on double cropping and triple cropping systems, for cows producing 90 pounds of milk per day

Nitrogen limit	Phosphorus limit	Cows per acre		#Cost per cow		Profit per acre		Restriction cost
% of minimum requirement		Number	% of maximum	US $	% of maximum	US $	% of maximum	US $ per cwt milk
Double cropping systems								
None	125	1.09	68	3858	96	3075	74	0.089
125	125	1.09	68	3858	96	3075	74	0.089
100	None	1.33	85	4074	100	3510	100	0.000
150	None	1.57	100	3910	100	4060	100	0.000
200	None	1.57	100	3910	100	4060	100	0.000
Triple cropping systems								
None	125	0.77	44	4061	100	1155	46	0.890
125	125	0.81	44	3974	91	1104	43	0.890
100	None	1.70	96	3904	96	2560	98	0.000
150	None	1.74	99	3899	96	2603	100	0.000
200	None	1.74	100	3900	96	2613	100	0.000

#Land and manure storage costs not included.

Table 5.5. Comparison of effects on cow carrying capacity, costs per cow and profits per acre of limits on surplus phosphorus and nitrogen applications through manure on double cropping and triple cropping systems, for cows producing 70 pounds of milk per day

Nitrogen limit	Phosphorus limit	Cows per acre		#Cost per cow		Profit per acre		Restriction cost
% of minimum requirement		Number	% of maximum	US $	% of maximum	US $	% of maximum	US $ per cwt milk
				Double cropping systems				
None	125	1.23	77	3135	77	2656	74	0.445
125	125	1.23	77	3135	77	2656	74	0.445
100	None	1.76	109	2921	96	2717	76	0.00
150	None	1.59	100	3164	100	3557	100	0.00
200	None	1.59	100	3162	100	3557	100	0.00
				Triple cropping systems				
None	125	0.78	34	3281	100	1047	44	0.890
125	125	0.78	34	3281	100	1047	44	0.890
100	None	2.21	97	3177	97	2333	98	0.00
150	None	2.25	99	3175	97	2379	100	0.00
200	None	2.29	100	3177	97	2386	100	0.00

#Land and manure storage costs not included.

By comparing double cropping versus triple cropping systems, the results showed that the triple cropping systems had more carrying capacities than double cropping only with N restrictions. Under the P restriction scenario, the carrying capacity of the double cropping systems was 40 % higher than that of the triple cropping systems. The additional carrying capacity came at a cost. The profit per cow and per hectare was greater for the double cropping when land rent and costs of larger manure storage capacities were not included. Under the triple cropping systems, crops are grown year round for manure application. Only with P restrictions was corn grain grown for sale under the double cropping systems and hay and wheat crops grown for sale under the triple cropping systems.

Since a fixed land situation was used, no land rent was included in the analyses. Temperate corn silage yields under the intensive triple cropping systems were lower than those reported by Georgia dairy farmers using double cropping systems. Therefore temperate corn silage and rye-clover yields were increased 15% above those used with triple cropping to adjust for less restrictive planting and harvesting time regimes. Plant nutrient requirements were also increased 15%. The farm prices for cotton lint, soybeans, wheat, and corn for grain were low in time period being analyzed. Dairy ration ingredients of corn and cottonseeds were also low in this period. As a result, producing these crops for feed ingredients or for sale was not profitable.

In summary, the farm profit model is very effective in handling dairy ration formulation, milk production level, and manure utilization for plant nutrients. Phosphorus surplus application restrictions were more constraining than nitrogen restrictions. Although having crops growing year round, the triple cropping systems was less profitable than the double cropping systems because slightly lower yields and manure utilization capacity of temperate corn silage and rye-clover. The high cost of tropical corn silage and the low feeding value of coastal bermuda green chop were added disadvantages.

Decision Based on Dairy Herd Size

In this section the simulation model was implemented following an imposed limit on the number of dairy cows on the farm. As in the previous section, each alternative was described by total acres and associated land utilization per cropping period, specific crops grown for sale, and returns to land and management. However, three nutrient restriction types were selected to implement the farm model based on 500 cows. The sensitivity analyses were simulated to estimate the minimum land requirement, costs of production, and net returns for each management alternative assuming constant crop and milk prices during the four years of the study period (i.e., 1997 to 2000). Alternatively, the dairy feed ration was a function of forage dry matter per rotation period. As a result, the simulation model was calibrated to predict the annual returns using two parameters: the expected forage yield variability and the nutrient loading restrictions.

Analysis showed that the simulation results were highly sensitive to these parameters. Based on the maximization of expected returns shown in Table 5.6, the model selected 378.5 to 480.8 acres for crop production without any restriction on manure application rate. Under the N-based manure management policy, the farmer is required to have at least 404 acres available for crop production. The acreage requirement was even higher (640.3 to 850 acres) when P-based management policy was simulated. The average cropland carrying capacity decreased from 1.20 cows per acre for the baseline scenario to only 0.65 cows per acre for the P-standard alternative. By construction of the model, spring, summer and winter forage crops and corn for grain, cotton, hay, or wheat cropping options are selected based on expected returns maximization.

Table 5.6. Expected costs and net returns to land and management under different nutrient loading restrictions for a dairy farm operating 500 milking cows

Item	Nutrient Restriction	1997	1998	1999	2000	Means	Std. dev
Acreage required	None	480.78	378.53	428.39	390.11	419.45	46.10
	N	480.78	403.98	437.20	429.10	437.76	31.97
	P	640.31	849.98	805.86	834.20	782.59	96.59
Carrying capacity (cow/acre)	None	1.04	1.32	1.17	1.28	1.20	0.13
	N	1.04	1.24	1.14	1.17	1.15	0.08
	P	0.78	0.59	0.62	0.60	0.65	0.09
Returns per acre ($)	None	1643.58	2282.05	1890.36	2097.10	1978.27	274.56
	N	1643.58	2118.55	1828.14	1824.15	1853.60	196.49
	P	1219.82	972.16	933.47	893.46	1004.73	146.95
Returns per cow ($)	None	1580.40	1717.64	1619.63	1636.20	1640.97	62.34
	N	1580.40	1711.72	1598.51	1565.48	1614.03	66.51
	P	1562.13	1652.62	1501.55	1490.66	1551.74	74.24
Returns per cwt milk ($)	None	4.81	5.26	4.93	4.98	5.00	0.19
	N	4.81	5.21	4.87	4.77	4.91	0.20
	P	4.76	5.03	4.58	4.54	4.73	0.22
Costs per cow ($)	None	4002.90	3717.40	3818.02	3825.99	3841.08	118.67
	N	4002.90	3778.49	3839.62	3939.85	3904.47	94.65
	P	4059.78	3972.59	4095.82	4138.33	4066.63	70.43
Costs per cwt milk ($)	None	12.19	11.32	11.62	11.65	11.69	0.36
	N	12.19	11.50	11.86	11.99	11.89	0.29
	P	12.36	12.09	12.49	12.60	12.39	0.22
Restriction cost per cow ($)	None	-	-	-	-	-	
	N	0	45.17	57.49	43.15	36.45	
	P	38.61	180.18	170.02	166.80	138.90	

As discussed earlier, the expected value of returns to land and management depends on the severity of the environmental constraints imposed on the manure application rates. Specifically, expected net returns to land and management under N-based and P-based standards averaged about 6.7% and 9.7% lower relative to that obtained with no restriction on manure application rate, respectively. Similarly, average returns per cow were reduced by 1.7% and 5.8%. It is useful to note that returns per acre included cash from crops grown to utilize the manure nutrients that could not been taken up by the forage crops.

The simulation results indicated that manure production during the summer period exceeds the amount needed for land application. This excess manure (about 1901.85 cwt), equivalent to 50-day manure produced by a cow, could be stored and then used to produce winter small grain and spring crops. Table 5.7 showed the acreages of crops grown to utilize the surplus manure nutrients. The number and total acreage of crop grown for sale varied with the severity of nutrient loading restrictions. If there is no restriction on the manure application rate, only corn grain was produced on about 72 acres. The average land used to grow crops for sale under the N- based restriction was 74 acres of corn grain and 100 acres of hay crops compared to 102 acres for corn grain, 380 acres for wheat and 142 acres for hay crops under the P-based manure management. It is important to note that even with more crops and acreage of these additional crops, the expected farm total net returns decreased when more stringent restrictions were implemented. This finding reflects the fact that changes in manure management policy can induce a farmer to shift between reducing the herd size and expanding the cropland.

Table 5.7. Acreages of crops grown for sale under different nutrient loading restrictions for a dairy farm operation with 500 milking cows

Cropping Year	Crop grown for sale	No restriction	N-based restriction	P–based restriction
		------------------------acres-------------------------		
1997- 98				
	Corn for grain	0.00	0.00	0.00
	Cotton	0.00	0.00	0.00
	Hay	434.69	434.69	434.53
	Wheat	0.00	0.00	159.53
1998 – 99				
	Corn for grain	67.49		
	Cotton	0.00	0.00	0.00
	Hay	0.00	100.69	142.56
	Wheat	0.00	0.00	410.68
1999 – 00				
	Corn for grain	56.67	78.36	88.42
	Cotton	0.00	0.00	0.00
	Hay	0.00	100.69	141.57
	Wheat	0.00	0.00	366.71
2000 - 01				
	Corn for grain	92.65	93.32	119.94
	Cotton	0.00	0.00	0.00
	Hay	0.00	100.69	142.56
	Wheat	0.00	0.00	362.54
1997-01[a]				
	Corn for grain	57.99	57.38	82.35
	Cotton	0.00	0.00	0.00
	Hay	0.00	0.00	142.56
	Wheat	0.00	0.00	314.33

[a]Simulation based on the four-year average forage dry matter and nutrient composition

Sensitivity to Changes in Milk Prices

Additional simulation of the model was made by calculating expected returns based on 1997 to 2000 milk prices in Georgia. The monthly prices of cwt milk sold during the study period were collected from the *Georgia Agricultural Facts* published NASS. The minimum milk price was $13.35 in 1997 and the maximum was $19.60 in 1999. However, the average milk price varied slightly from $14.41 to $16.45 during the study period. The main interest here is to assess the sensitivity of the model to changes in milk prices, *ceteris paribus*. This analysis showed that the model correctly predict higher returns to land and management with increasing milk prices, regardless of nutrient loading restrictions.

Based on the yearly average milk prices from 1997 to 2000, the expected total net returns per cow averaged about $1515 when there were no nutrient loading restrictions compared to $1489 and $1428 when the manure application rate was based on crop N and P uptake, respectively (Figure 5.1). By comparing the manure management alternatives, imposing restrictions on N and P also reduced the expected net returns per acre. It is useful to mention that the returns per cow were 14% to 18% lower than the expected net returns per acre of cropland management, except under the most stringent P-based management alternative where average returns per acre ($880) were 38% lower (Table 5.8).

The model was able to use the actual milk price in each cropping period to predict changes in the dairy farm profitability when making decisions at the time of crop planting. In that case, the simulation results showed approximately 37% higher returns relative to the simulation using the yearly minimum milk prices, but 48% lower returns in comparison to using the maximum milk prices.

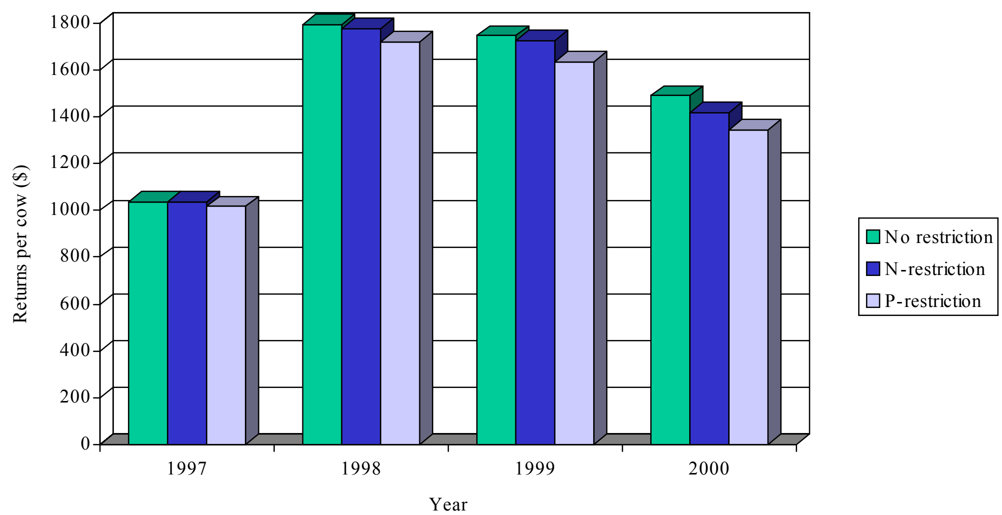

Figure 5.1. Impacts of yearly average milk prices and manure nutrient loading restriction on net returns per cow

Table 5.8. Impact of milk price changes on expected net returns per cow and land management under different nutrient loading restrictions for a dairy farm operation with 500 milking cows

Forage cropping year	Milk price	value ($/cwt)	No restriction		N-based restriction		P-based restriction	
			Returns per cow	Returns per acre	Returns per cow	Returns per acre	Returns per cow	Returns per acre
1997- 98								
	Minimum	13.35	686.88	714.34	686.88	714.34	668.61	522.10
	Maximum	15.90	1524.56	1595.50	1524.56	1585.50	1506.28	1176.22
	Average	14.41	1035.09	1076.47	1035.09	1076.47	1016.82	794.06
	Seasonal		1115.23	1159.82	1115.24	1159.82	1096.96	856.59
1998– 99								
	Minimum	13.90	1014.79	1340.45	998.87	1236.28	939.78	552.83
	Maximum	18.45	2509.47	3314.77	2493.55	3086.20	2434.45	1432.07
	Average	16.27	1793.34	2368.83	1777.42	2199.87	1718.32	1010.81
	Seasonal		1896.70	2505.37	1880.78	2327.80	1821.69	1071.61
1999– 00								
	Minimum	14.15	988.91	1154.21	967.79	1106.82	886.60	498.24
	Maximum	19.60	2779.23	3243.80	2758.12	3154.33	2666.65	1450.65
	Average	16.45	1744.46	2036.06	1723.34	1970.90	1632.50	908.70
	Seasonal		1376.00	1606.01	1354.88	1549.51	1275.95	690.29
2000– 01								
	Minimum	14.40	1087.60	1393.97	1016.89	1184.91	942.06	564.65
	Maximum	16.80	1876.00	2404.46	1805.29	2103.58	1730.46	1037.20
	Average	15.62	1488.37	1907.63	1417.66	1651.90	1342.83	804.86
	Seasonal		1540.39	1974.31	1469.68	1712.51	1394.85	836.04

The model also estimates land use and the production costs. These estimates were identical to those reported in Table 5.6. In both situations, the simulation used a fixed number of cows (500) to estimate the land required for crop production and manure utilization. The actual costs for land application depend on the shares of land under each nutrient standard. Since the application rate for P is lower than for N, less manure can be applied on a given land base with resulting higher costs because lower per acre application rate means more acres must be spread. These findings suggest that the greater costs under the P-standard were due to the lower per-acre application rates and increased acreages of crop with lower marginal revenue.

The current model specification focuses on an option of primary policy focus on land application of manure not to exceed the crop nutrients demand. As a result, total manure management costs will depend on option(s) selected to address the manure quantity that exceeds the land application potential in the model.

Probabilistic Estimation of Residual Soil Nutrients

In this section, we explore the variability in land adjustments implied by changes in crop nutrient uptake. For this purpose a baseline scenario corresponding to the highest expected crop yields is contrasted with harvested crop yield levels for which the nutrient content is below the actual amount applied to fields during each cropping period. Each scenario consisted of spring-summer-fall/winter-spring production cycles. A one-year cycle was found adequate to represent the dynamics of the crop rotation. Spring cropping period was used to represent the equilibrium in nutrients use by crop rotation.

Changes in crop yield by period provide the basis for relating the nutrient application rates to the next crop nutrient uptake. Here, the environmental goals were to reduce N and P runoff while maximizing the total farm net returns. The environmental goals were established by maximizing expected crop nutrient uptake subject to manure nutrient application rates. At the end of each cropping period, decisions were made to reduce the manure application to the next crop by the amount of nutrients applied to soil but not taken up by the crops. For example, if the spring crop yield is below the target level, a decision is made to reduce the manure application rate in the summer. It is assumed that if a field is fallowed in the current cropping period then a crop is produced the following season with next cropping period's nutrient demands adjusted by the amount harvested in crops grown on a field that is not fallowed. In other words, the manure application rate was also adjusted on the additional acreages used to dispose any surplus manure.

Presumably, the variance of crop yield expectations is function of production technology, soil fertility level and other environmental factors. As a result, crop nutrient uptake may not reflect correctly the soil nutrient levels. In this exercise, three levels of forage yield by period were considered: high (H), average (A), and below average (L). In other words, each spring, summer and winter crop yields were graded as H, A or L with a probability of occurrence over the four-year period. The observed frequencies of H, A and L occurrence were 37.5%, 37.5% and 25% for the spring and winter forage crops, but 25%, 50% and 25% for summer crops, respectively. These allowed us to simulate 27 possible yield scenarios by rotation cycle along with the probabilities of outcome.

The results presented in Tables 5.9 and 5.10 indicated that the probabilities associated with HHH, AAA and LLL outcomes were 0.035, 0.070 and 0.016, respectively. Only eight expected yield events had higher probabilities of occurrence than that of HHH. On another hand, 11 events occurred with lower probability levels and the other 8 events had the same probability (0.035) of outcome as HHH. Based on expected yields and their probabilities of occurrence, it was possible to estimate the relative magnitude of soil applied N and P not removed by the crops.

Table 5.9. Spring (P), summer (S) and fall/winter crop yield levels and cumulative frequencies of occurrence and estimated amount of manure nitrogen applied to soil and not removed by crops, 1997 – 2000

Yield level (P)-(S)-(F)	Probability of occurrence	Estimated excess nitrogen applied			
		Spring (P)	Summer (S)	Fall/winter (F)	Total year
		lb N per acre			
H-H-H	0.035	0.00	0.00	0.00	0.00
H-H-L	0.023	0.00	0.00	23.53	23.53
H-H-A	0.035	0.00	0.00	13.76	13.76
H-L-H	0.035	0.00	16.70	0.00	16.70
H-L-A	0.035	0.00	16.70	13.76	30.46
H-L-L	0.070	0.00	22.95	0.00	22.95
H-A-H	0.047	0.00	22.95	23.53	46.48
H-A-L	0.023	0.00	16.70	23.53	40.23
H-A-A	0.070	0.00	22.95	13.76	36.71
A-A-A	0.070	9.38	22.95	13.76	46.09
A-A-L	0.047	9.38	22.95	23.53	55.85
A-A-H	0.070	9.38	22.95	0.00	32.33
A-L-A	0.035	9.38	16.70	13.76	39.84
A-L-H	0.035	9.38	16.70	0.00	26.08
A-L-L	0.035	9.38	0.00	13.76	23.14
A-H-A	0.023	9.38	0.00	23.53	32.90
A-H-L	0.023	9.38	16.70	23.53	49.60
A-H-H	0.035	9.38	0.00	0.00	9.38
L-L-L	0.016	12.73	16.70	23.53	52.95
L-L-A	0.023	12.73	16.70	13.76	43.19
L-L-H	0.023	12.73	16.70	0.00	29.43
L-A-L	0.031	12.73	22.95	23.53	59.20
L-A-H	0.047	12.73	22.95	0.00	35.68
L-A-A	0.016	12.73	0.00	23.53	36.25
L-H-L	0.023	12.73	0.00	13.76	26.49
L-H-A	0.047	12.73	22.95	13.76	49.44
L-H-H	0.023	12.73	0.00	0.00	12.73
Means		7.37	13.22	12.43	33.01
Std dev		5.49	9.87	9.83	14.98

Table 5.10. Spring (P), summer (S) and fall/winter crop yield levels and cumulative frequencies of occurrence and estimated amount of manure phosphorus applied to soil and not removed by crops, 1997 – 2000

Yield level (P)-(S)-(F)	Probability of occurrence	Estimated excess phosphorus applied			
		Spring	Summer	Fall/winter	Total year
		---------------------------------- lb P per acre	---------------------------		
H-H-H	0.035	0.00	0.00	0.00	0.00
H-H-L	0.023	0.00	0.00	7.53	7.53
H-H-A	0.035	0.00	0.00	4.39	4.39
H-L-H	0.035	0.00	11.88	0.00	11.88
H-L-A	0.035	0.00	11.88	4.39	16.26
H-L-L	0.070	0.00	16.10	0.00	16.10
H-A-H	0.047	0.00	16.10	7.53	23.63
H-A-L	0.023	0.00	11.88	7.53	19.40
H-A-A	0.070	0.00	16.10	4.39	20.49
A-A-A	0.070	5.44	16.10	4.39	25.93
A-A-L	0.047	5.44	16.10	7.53	29.06
A-A-H	0.070	5.44	16.10	0.00	21.54
A-L-A	0.035	5.44	11.88	4.39	21.70
A-L-H	0.035	5.44	11.88	0.00	17.31
A-L-L	0.035	5.44	0.00	4.39	9.83
A-H-A	0.023	5.44	0.00	7.53	12.96
A-H-L	0.023	5.44	11.88	7.53	24.84
A-H-H	0.035	5.44	0.00	0.00	5.44
L-L-L	0.016	7.38	11.88	7.53	26.78
L-L-A	0.023	7.38	11.88	4.39	23.64
L-L-H	0.023	7.38	11.88	0.00	19.25
L-A-L	0.031	7.38	16.10	7.53	31.00
L-A-H	0.047	7.38	16.10	0.00	23.48
L-A-A	0.016	7.38	0.00	7.53	14.90
L-H-L	0.023	7.38	0.00	4.39	11.76
L-H-A	0.047	7.38	16.10	4.39	27.86
L-H-H	0.023	7.38	0.00	0.00	7.38
Means		4.27	9.33	3.97	17.57
Std dev		3.18	6.95	3.14	8.26

It was assumed that there were no excess N and P applied when the target threshold (H) yield level was realized. In contrast, crop yields below the target levels would result in excess amounts of N and P in soil. As a result, environmental goals incorporate not only the magnitude but also the probability of having excess nutrients for runoff due to marginal changes in crop yield.

The effect of a change in crop nutrients uptake on the probability to apply excess manure nutrients was found to be significant. It means that for crops grown in each period, marginal reductions in yield below the target threshold level will increase the probability of applying some positive amount of nutrients for runoff. In that case, the estimated cumulative amount of nutrients applied in excess for crop uptake per rotation per year ranged from 9.38 to 59.20 lb N per acre and 4.39 to 31.00 lb P per acre (Tables 5.9 and 5.10). Regarding the magnitudes per cropping period, it was found that the summer and fall/winter were by far the most responsive periods with respect to changes in the size of the crop yield and excess manure nutrient application. For spring cropping period, the estimated magnitudes of excess nutrients in soil after event A were 9.38 lb N and 5.44 lb P compared to 12.73 lb N and 7.38 lb P when event L was realized. The corresponding values for summer cropping period were 16.70 lb N and 11.88 lb P after event A and 22.95 lb N and 16.10 lb P with the occurrence of event L. Similar value ranges were observed for the fall/winter cropping period. In summary, these results indicated the potential risk of excess nutrient application, with probabilities of 7.3% for excess less than 10 lb N and 5 lb P per acre, 50% for excess amounts ranging from 20-40 lb N and 15-25 lb P, and 32.7% and 21.1% for applying over 40 lb N and 25 lb P, respectively.

Proposed policies require a P-based standard (P-standard) on fields with high soil phosphorus levels, and an N-based standard (N-standard) elsewhere. Under a P-standard, manure application rates are reduced (relative to an N-standard) such that manure phosphorus is not applied in excess of crop uptake requirements. The P-standard implies greater acreage requirements and hauling distances for a given quantity of manure. Options other long-distance hauling for reducing the quantity of (or disposal of) the excreted manure nutrients, include industrial processing, increasing crop nutrient uptake, and reducing the quantity of manure nutrients produced. However, total manure management costs will depend on option(s) selected to address the quantity of manure nutrients that exceeds the land application potential in the model.

Impact of changes in Expected Crop Yields and Soil Nutrient Levels

The previous section reported the probability and magnitude of excess N and P in soil by realizing lower crop yields than the expected high yield levels. This section explored the ability of the model to represent the variability in economic returns and land use patterns due to the relative changes in yield outputs and nutrient uptake level. For this purpose the model was applied to a dairy farm operating 500 milking cows for a range of crop yield levels under both N and P-based standard. Because of the uncertainty associated with realizing a single crop yield mix, results are presented for the widest set possible representing extreme-cases of management in order to bracket the actual levels of yield realized in practice. Alternatively, changes in crop yield by period provide the basis for relating the nutrient application rates to environmental pollution. The environmental goals are to reduce N and P runoff while the economic goals are to maximize the total farm net returns.

From this point of view, two forage production systems were simulated subject to realized forage yield levels and the standard and adjusted nutrient application rates in subsequent cropping periods. Based on the maximization of expected crop yields, a spring, summer and winter decisions are made to apply manure in order to meet the crop nutrient needs. Under the standard practice, the nutrient application rate was kept constant, regardless of the variations in crop yield from one cropping period to another. As a result, the amount of nutrients in soil can be in excess of the crop needs. The base decision corresponded to expected high yield levels for which the crop N, P and K uptake is approximately equal to the applied amount. This implied insignificant amount of soil nutrients carried over between production periods. Since soil analysis data were not available for this study, an alternative decision (hereafter, adjusted fertility) was to reduce the next crop nutrient application rate proportionally to the amount not taken up by the current crop by assuming no nutrient losses occurred during the production periods. In that case, the excess N, P and K amounts in soil after the spring, summer and winter crops were computed and then subtracted from the summer, winter and spring application rates, respectively. For each option, sensitivity analyses are simulated to estimate land use requirement and expected returns above variable costs of production with a widest range of yield outputs and nutrient uptake. The results derived from the individual runs are depicted, for each restriction group in Tables 5.11 to 5.14.

In general, the estimated net returns per acre were highest with unconstrained manure management scenario and lowest with the imposition of N and P application standards. By comparing the different yield scenarios, the lowest net returns per acre were associated with reduced winter crop yields and the adjustment of the nutrient application rates did not change the relationship between N and P restriction.

The estimated average net returns per acre were \$1960.62 and \$1827.17 with the standard and adjusted nutrient application rates, respectively (Table 5.11). This difference in returns (\$133.45) represented the average cost of the additional land management in response to the excess nutrients in soil when the crop yields were reduced below the threshold levels. The average net returns per acre were $1888.83 and $1761.18 for N-based manure management and only $1027.83 and $739.81 for P-based management with standard and adjusted nutrient application rates, respectively. Based on the adjusted nutrient application rates, the average costs per acre to the farm executing manure N restriction policy was only $65.99 compared to $1087.36 when P restriction policy was implemented.

By considering the total farm enterprise, the magnitude of net returns and costs varied slightly due to crop yields and the imposition of the manure management standards. The average net returns per cow and land management were $1621.35 and $1631.82 under unconstrained manure management policy compared to $1608 and $1616.72 for N-based and $1564.40 and 1538.21 for P-based management with standard and adjusted nutrient application rates, respectively (Table 5.12). The returns from the milk production could have partially offset the manure management costs. As a result, the average net costs of implementing the N and P were only $15.10 and $93.61, respectively. The environmental costs were reduced even more when comparing the returns per cwt of milk production (Table 5.13).

As described earlier, the manure disposal capacity per rotation per year was determined by the expectation of high yield output. Since the milking herd manure output per year is constant, *ceteris paribus*, the environmental goal of 0% excess nutrients application becomes more restrictive as yields were reduced below the target threshold levels. Because the proportion of additional acreage required to meet more stringent N-based and P-based nutrient standards is not known at priori, reducing the manure application rate following a crop failure would be an acceptable alternative to achieve this goal. As a result, the simulation model was calibrated to predict the maximum acreage requirements subjected to different nutrient application rates.

The P-based restriction showed the most significant effects in the decision to increase crop acreages. The expected crop acreage responses also varied with the relative change in yield outputs for each restriction group. Under the unrestricted manure application rate scenario, the average land use by rotation period was 415.1 acres using the standard nutrient application rates and an additional 38.7 acres were required to supply sufficient forage for the least cost rations under reduced yields (Table 5.14).

Under N-based manure management, as crop yield output varied, the simulated land use ranged from 402.3 to 530.1 acres and from 403.9 to 545.2 acres with the standard and adjusted nutrient application rates, respectively. The corresponding acreages under the P-based manure management varied from 619.8 to 859.9 and 833.6 to 1368.8 acres. This indicated that about 346.3 more acres would be allocated for crop production by implemented the P-based policy compared to only 38.5 acres with the less stringent N-based policy. These additional acreages were required to dispose of the excess manure nutrients (9.38 to 59.20 lb N and 5.44 to 31.28 lb P per acre) when crop yields were reduced below the threshold level (see Table 5.12).

In summary, the effects of crop acreage were evaluated with standard and adjusted manure application rates to meet crop nutrient uptake. The standard and nutrient-adjusted land-use data and total farm net returns provide sufficient information for assessing land requirements and management costs associated with the disposal of excess manure in accordance to the environmental policy. In other words, the difference between the standard and the nutrient-adjusted simulations represents implicitly the magnitude of social benefits derived from implementing an environmental policy. The model estimate results indicate that additional crop acreages are required, particularly under the P-based standard, to apply manure not in excess to crop nutrient needs.

The model specification focused on an option of primary policy of land application. The simulation results were consistent with expectations or with animal input-output relationships. The model formulated rations from expected yields under both standard and adjusted nutrient application rates. This analysis did not measure the increased forage ingredients that would be required from purchased feed or from previously stored forage to fulfill the rations requirements under forage shortfalls. The model as implemented is a useful tool to forecast the economic returns and environmental impacts of manure nutrient loading restrictions that may be imposed in following cropping periods.

Table 5.11. Expected net returns per cropland due to changes in crop yields and standard and adjusted nutrient application rates

Crop	No restriction			N restriction			P restriction		
Yield	Standard	Adjusted	Diff	Standard	Adjusted	Diff	Standard	Adjusted	Diff
				Net returns per acre					
H-H-H	2183.91	2183.91	0.00	2042.74	2042.74	0.00	940.38	940.38	0.00
H-H-L	1908.46	1638.76	-269.70	1803.15	1558.82	-244.33	891.81	874.30	-17.51
H-H-A	2068.78	1916.49	-152.29	1935.9	1804.17	-131.73	922.14	935.98	13.84
H-L-H	2183.91	2202.64	18.73	2042.74	2061.64	18.90	940.38	573.16	-367.22
H-L-A	2068.78	1934.27	-134.51	1935.9	1822.18	-113.72	922.14	555.03	-367.11
H-A-H	2183.91	2196.89	12.98	2042.74	2055.75	13.01	940.38	657.40	-282.98
H-A-L	1908.46	1650.19	-258.27	1803.15	1569.63	-233.52	891.81	586.75	-305.06
H-L-L	1908.46	1655.39	-253.07	1803.15	1575.81	-227.34	891.81	513.28	-378.53
H-A-A	2068.78	1928.76	-140.02	1935.9	1816.52	-119.38	922.14	640.72	-281.42
A-A-A	1937.35	1801.49	-135.86	1855.96	1720.49	-135.47	1010.25	654.67	-355.58
A-A-L	1802.02	1539.57	-262.45	1721.87	1472.33	-249.54	984.07	602.61	-381.46
A-A-H	2130.51	2144.38	13.87	2101.83	2083.13	-18.70	1013.44	672.66	-340.78
A-L-A	1937.35	1807.47	-129.88	1855.96	1726.54	-129.42	1010.25	556.87	-453.38
A-L-H	2130.51	2150.73	20.22	2101.83	2089.82	-12.01	1013.44	577.08	-436.36
A-H-A	1937.35	1788.53	-148.82	1855.96	1707.37	-148.59	1010.25	1019.08	8.83
A-H-L	1802.02	1527.45	-274.57	1721.87	1460.04	-261.83	984.34	946.55	-37.79
A-L-L	1802.02	1545.15	-256.87	1721.87	1478.00	-243.87	984.07	511.84	-472.23
A-H-A	2130.51	2130.51	0.00	2101.83	2068.61	-33.22	1013.44	1016.38	2.94
L-L-L	1689.80	1429.28	-260.52	1689.80	1429.28	-260.52	1225.28	528.69	-696.59
L-L-A	1856.47	1700.33	-156.14	1670.42	1697.16	26.74	1185.52	570.46	-615.06
L-L-H	2068.25	2090.21	21.96	2053.74	2066.99	13.25	1097.18	582.11	-515.07
L-A-L	1689.80	1430.29	-259.51	1689.80	1430.29	-259.51	1224.81	646.55	-578.26
L-A-H	2068.25	2083.28	15.03	2053.74	2059.65	5.91	1107.89	691.39	-416.50
L-H-L	1689.80	1416.01	-273.79	1689.80	1416.01	-273.79	1225.28	1175.45	-49.83
L-H-A	1856.47	1678.93	-177.54	1856.47	1704.74	-151.73	1127.76	1195.84	68.08
L-A-A	1856.47	1693.58	-162.89	1856.48	1590.84	-265.64	1175.30	691.04	-484.26
L-H-H	2068.25	2068.25	0	2053.74	2043.37	-10.37	1095.82	1058.50	-37.32
Means	1960.62	1827.17	-133.45	1888.83	1761.18	-127.65	1027.83	739.81	-288.02
Std dev	157.36	264.33		148.44	246.55		108.92	214.89	

Table 5.12. Expected net returns per cow due to changes in crop yields and standard and adjusted nutrient application rates

Crop	No restriction			N restriction			P restriction		
Yield	Standard	Adjusted	Diff	Standard	Adjusted	Diff	Standard	Adjusted	Diff
				Net returns per cow					
H-H-H	1708.30	1708.30	0.00	1681.30	1681.30	0.00	1617.36	1617.36	0.00
H-H-L	1555.15	1555.48	0.33	1534.66	1534.99	0.33	1479.79	1480.76	0.97
H-H-A	1645.61	1645.76	0.15	1620.20	1620.35	0.15	1559.42	1560.40	0.98
H-L-H	1708.30	1722.96	14.66	1681.30	1696.85	15.55	1617.36	1574.49	-42.87
H-L-A	1645.61	1661.04	15.43	1620.20	1636.53	16.33	1559.42	1515.98	-43.44
H-A-H	1708.30	1718.46	10.16	1681.30	1692.01	10.71	1617.36	1588.41	-28.95
H-A-L	1555.15	1566.33	11.18	1534.66	1546.44	11.78	1479.79	1449.83	-29.96
H-L-L	1555.15	1571.28	16.13	1534.66	1551.72	17.06	1479.79	1434.81	-44.98
H-A-A	1645.61	1656.30	10.69	1620.20	1631.44	11.24	1559.42	1530.40	-29.02
A-A-A	1638.33	1650.38	12.05	1630.23	1641.51	11.28	1536.86	1553.38	16.52
A-A-L	1553.12	1565.82	12.70	1548.29	1560.87	12.58	1509.94	1474.35	-35.59
A-A-H	1689.40	1700.40	11.00	1679.07	1688.70	9.63	1628.96	1595.17	-33.79
A-L-A	1638.33	1655.86	17.53	1630.23	1647.29	17.06	1586.86	1537.09	-49.77
A-L-H	1689.40	1705.44	16.04	1679.07	1694.13	15.06	1628.96	1579.78	-49.18
A-H-A	1638.33	1638.51	0.18	1630.23	1628.99	-1.24	1586.87	1587.28	0.41
A-H-L	1553.12	1553.50	0.38	1548.29	1547.84	-0.45	1509.93	1511.12	1.19
A-L-L	1553.12	1571.50	18.38	1548.29	1566.88	18.59	1509.94	1458.80	-51.14
A-H-A	1689.40	1689.40	0.00	1679.07	1676.94	-2.13	1628.96	1627.21	-1.75
L-L-L	1539.77	1566.78	27.01	1539.77	1566.78	27.01	1518.91	1466.48	-52.43
L-L-A	1606.44	1627.16	20.72	1562.55	1623.90	61.35	1574.49	1520.76	-53.73
L-L-H	1655.99	1673.57	17.58	1652.43	1669.58	17.15	1612.17	1561.00	-51.17
L-A-L	1539.77	1559.59	19.82	1539.77	1559.59	19.82	1518.57	1486.44	-32.13
L-A-H	1655.99	1668.03	12.04	1652.43	1663.65	11.22	1611.51	1577.75	-33.76
L-H-L	1539.77	1544.02	4.25	1539.77	1544.02	4.25	1518.91	1527.99	9.08
L-H-A	1606.44	1606.69	0.25	1606.44	1592.37	-14.07	1567.36	1579.64	12.28
L-A-A	1606.44	1620.70	14.26	1606.45	1536.27	-70.18	1560.40	1541.79	-18.61
L-H-H	1655.99	1656.00	0.01	1652.43	1650.50	-1.93	1609.42	1593.25	-16.17
Means	1621.35	1631.82	10.47	1608.64	1616.72	8.08	1564.40	1538.21	-26.19
Std dev	59.02	57.91		56.15	56.80		50.30	53.59	

Table 5.13. Expected net returns per cwt milk production due to changes in crop yields and nutrient application rates

Crop	No restriction			N restriction			P restriction		
Yield	Standard	Adjusted	Diff	Standard	Adjusted	Diff	Standard	Adjusted	Diff
				profit per cwt milk					
H-H-H	5.20	5.20	0.00	5.12	5.12	0.00	4.92	4.92	0.00
H-H-L	4.73	4.73	0.00	4.67	4.67	0.00	4.50	4.51	0.01
H-H-A	5.01	5.01	0.00	4.93	4.93	0.00	4.75	4.75	0.00
H-L-H	5.2	5.24	0.04	5.12	5.16	0.04	4.92	4.79	-0.13
H-L-A	5.01	5.06	0.05	4.93	4.98	0.05	4.75	4.61	-0.14
H-A-H	5.2	5.23	0.03	5.12	5.15	0.03	4.92	4.83	-0.09
H-A-L	4.73	4.77	0.04	4.67	4.71	0.04	4.50	4.41	-0.09
H-L-L	4.73	4.78	0.05	4.67	4.72	0.05	4.50	4.37	-0.13
H-A-A	5.01	5.04	0.03	4.93	4.97	0.04	4.75	4.66	-0.09
A-A-A	4.99	5.02	0.03	4.96	5.00	0.04	4.83	4.73	-0.10
A-A-L	4.73	4.77	0.04	4.71	4.75	0.04	4.60	4.49	-0.11
A-A-H	5.14	5.18	0.04	5.11	5.14	0.03	4.96	4.86	-0.10
A-L-A	4.99	5.04	0.05	4.96	5.01	0.05	4.83	4.68	-0.15
A-L-H	5.14	5.19	0.05	5.11	5.16	0.05	4.96	4.81	-0.15
A-H-A	4.99	4.99	0.00	4.96	4.96	0.00	4.83	4.83	0.00
A-H-L	4.73	4.73	0.00	4.71	4.71	0.00	4.60	4.60	0.00
A-L-L	4.73	4.78	0.05	4.71	4.77	0.06	4.60	4.44	-0.16
A-H-A	5.14	5.14	0.00	5.11	5.10	-0.01	4.96	4.95	-0.01
L-L-L	4.69	4.77	0.08	4.68	4.77	0.09	4.62	4.46	-0.16
L-L-A	4.89	4.95	0.06	4.76	4.94	0.18	4.79	4.63	-0.16
L-L-H	5.04	5.09	0.05	5.03	5.08	0.05	4.91	4.75	-0.16
L-A-L	4.69	4.75	0.06	4.69	4.75	0.06	4.62	4.52	-0.1
L-A-H	5.04	5.08	0.04	5.03	5.06	0.03	4.91	4.80	-0.11
L-H-L	4.69	4.70	0.01	4.69	4.70	0.01	4.62	4.65	0.03
L-H-A	4.89	4.89	0.00	4.89	4.85	-0.04	4.77	4.81	0.04
L-A-A	4.89	4.93	0.04	4.89	4.68	-0.21	4.75	4.69	-0.06
L-H-H	5.04	5.04	0.00	5.03	5.02	-0.01	4.90	4.85	-0.05
Means	4.94	4.97	0.03	4.90	4.92	0.02	4.76	4.68	-0.08
Std dev	0.18	0.18		0.17	0.17		0.15	0.16	

Table 5.14. Acreage requirement due to changes in crop yields and standard and adjusted nutrient application rates

Crop Yield	No restriction			N restriction			P restriction		
	Standard	Adjusted	Diff	Standard	Adjusted	Diff	Standard	Adjusted	Diff
				Acreage requirement					
H-H-H	391.11	391.11	0.00	411.53	411.53	0.00	859.95	859.95	0.00
H-H-L	407.43	474.59	67.16	425.55	492.36	66.81	829.66	846.83	17.17
H-H-A	397.72	429.37	31.65	418.46	449.06	30.6	845.54	833.56	-11.98
H-L-H	391.11	391.11	0.00	411.53	411.53	0.00	859.95	1373.51	513.56
H-L-A	397.72	429.37	31.65	418.46	449.06	30.60	845.54	1365.68	520.14
H-A-H	391.11	391.11	0.00	411.53	411.53	0.00	859.95	1208.09	348.14
H-A-L	407.43	474.59	67.16	425.55	492.62	67.07	829.66	1235.48	405.82
H-L-L	407.43	474.59	67.16	418.46	492.36	73.90	845.54	1397.67	552.13
H-A-A	397.72	429.37	31.65	492.36	449.06	-43.30	829.66	1194.28	364.62
A-A-A	422.83	458.06	35.23	439.19	477.05	37.86	785.38	1186.38	401.00
A-A-L	430.94	508.53	77.59	449.59	530.07	80.48	767.19	1223.30	456.11
A-A-H	396.48	396.48	0.00	399.43	405.33	5.90	803.68	1185.72	382.04
A-L-A	422.83	458.06	35.23	430.19	477.05	46.86	785.38	1380.10	594.72
A-L-H	396.48	396.48	0.00	399.43	405.33	5.90	803.68	1368.75	565.07
A-H-A	422.83	458.06	35.23	439.19	477.05	37.86	785.38	778.78	-6.60
A-H-L	430.94	508.53	77.59	449.59	530.07	80.48	766.96	798.23	31.27
A-L-L	430.94	508.53	77.59	449.59	530.07	80.48	767.19	1425.05	657.86
A-H-H	396.48	396.48	0.00	399.43	405.33	5.90	803.68	800.50	-3.18
L-L-L	455.61	548.1	92.49	455.61	548.1	92.49	619.82	1386.89	767.07
L-L-A	432.66	478.48	45.82	467.71	478.48	10.77	664.05	1332.91	668.86
L-L-H	400.34	400.34	0.00	402.30	403.87	1.57	734.68	1340.61	605.93
L-A-L	455.61	545.2	89.59	455.61	545.2	89.59	619.92	1149.52	529.60
L-A-H	400.34	400.34	0.00	402.30	403.87	1.57	727.28	1141.00	413.72
L-H-L	455.61	545.2	89.59	455.61	545.2	89.59	619.82	649.96	30.14
L-H-A	432.66	478.48	45.82	432.66	467.04	34.38	694.9	660.47	-34.43
L-A-A	432.66	478.48	45.82	432.66	482.84	50.18	663.83	1115.55	451.72
L-H-H	400.34	400.34	0.00	402.30	403.87	1.57	734.35	752.60	18.25
Means	415.01	453.68	38.67	427.33	465.73	38.40	768.62	1110.80	342.18
Std dev	20.83	51.8		20.76	50.72		77.53	259.30	

CHAPTER 6

SUMMARY, CONCLUSIONS AND IMPLICATIONS

Summary

Georgia agriculture, livestock and poultry operations are major contributors to increasing levels of nutrients in waterways. Many livestock farmers in the United States, including, Georgia, are applying surplus N and P to their soils and/or depositing N and P in runoff and drainage water. Environmental policy-makers are continuously seeking ways to limit the impact of manure nutrients on the environmental (EPA-Finale Rule, 2003). In Georgia, the Board of Natural Resources has instruct its Environmental Protection Division (EPD) to develop plans outlining how farmers will dispose of manure without polluting nearby waterways. As a result, the EPD requires the state's approximately 406 dairy farms with over 85 thousand cows to get waste-disposal permits and to implement comprehensive nutrient management plans, complying with federal mandate handed down to the states. Despite these efforts, the precise costs of manure disposal on a farm basis are generally unknown. Such costs may be substantial and dramatically affect the economic viability of the operation. In the absence of integrated economic and environmental model, policy proposals and decisions regarding dairy manure management are potentially biased.

To summarize the problems, while efforts have been directed toward better understanding of animal manure issues associated with agronomic uses in Georgia, the economic dimensions are missing from this discourse. Many management tools, including the Georgia's dairy nutrient management generator, have been developed to assist farmers in making decision about nutrient management. These nutrient management tools are limited in their use in the sense they focused on nutrient system and not the overall economic of the farm enterprise. A whole farm economic model can aid future projection of water pollution problems related to dairy operation. This dissertation addresses three main problems associated with providing information for dairy manure management decisions: manure nutrients utilization for crop production, forage feed utilization for dairy ration, and the environmental and financial goals.

A review of dairy operation in Georgia showed that the spatial and temporal trends in manure nutrients and the capacity of cropland to assimilate nutrients changed dramatically between 1990 and 2002 as the number of dairy cows concentrated in fewer counties. The literature also indicated that trends in manure nutrients production are directly related to trends in animal units. The quantities of unrecoverable manure nutrients produced each year can be large. It is assumed that farms that produce more manure nutrients than can be applied to the land without accumulating nutrients in the soil have excess manure nutrients. Therefore, it is possible that they contribute to water quality degradation in livestock production counties.

The goal of this research is to develop a management tool to aid dairy farmers utilizing their manure in environmentally safe and most profitable manner. Specifically, the present study develops a model for evaluating the economic performance of a dairy operation considering milk production, manure production, crop production and nutrient loading restrictions. First, a linear programming model is constructed and then utilized to determine the economically optimal dairy herd intensities, manure land use, and crop mix for unrestricted and restricted scenarios of N and P losses on dairy farms. The model is the combining of standard of dairy ration model and manure and crop nutrient balance model with some supplementary activities. Data are obtained from three main sources: manure nutrients and crop yields data from experimental field study at the UGA-Coastal Plain Experiment Station, enterprise budget data from Georgia Branch Experiment Station and Georgia farm gate prices of crop commodities and fertilizers.

The constructed linear program model is used to simulate alternative situations where manure application rates are restricted to meet crop nutrient needs utilizing the Microsoft Excel spreadsheet Solver as the mathematical optimizer source.

The theoretical framework of the analysis is based on expected utility maximization of a representative dairy farm operation. The producer maximizes the total farm expected net returns above variable production costs subject to a land resource constraint. The resulting model is linear in input and output prices, nutrient application rates, total acreage and number of milk cows. Size of milking herd and cropland acres are flexible constraints. Animal diet relationships are modified by period to reflect seasonal changes in requirements and heat stress effects on diet energy levels concentrations. Constraints for animal feed requirements allow transfers of forage between periods as well as buying and/or selling additional feed. The manure nutrient constraints are developed to allow storage and transfers of manure from one period to another, but force a balance between manure and crop nutrients by the end of the crop rotation cycle. Environmental goals are to reduce N and P runoff by maintaining a zero-nutrient balance in the system over the planning horizon. The environmental constraint becomes more restrictive as the reduction level and the probability of compliance increase.

The sensitivity analysis of the linear program model used to estimate the impact of manure nutrient loading restrictions on a dairy farm is presented and discussed in chapter 6. Based on the maximization of expect net returns, the simulation model is implemented for a farm with (1) 500 dairy cows and (2) 600 acres of available cropland. Given the assumption of risk aversion, expected yield variability and uncertainty associated with selecting a single crop mix, additional sensitivity analyses were performed for a representative dairy farm with 500 cows based on (1) variable milk prices, (2) double versus triple cropping systems, and (3) nutrient application program following crop yield levels. The indicators used to assess the farm-level impacts included total farm expected net returns per cropland and milk cow, cropland use and carrying capacity.

The manure disposal capacity per rotation cycle was determined by proportion of land available for crop production using the milking herd effluent as nutrients source. In the case where a dairy farmer has 600 acres of available cropland, the total farm expected net returns above variable costs were reduced as a result of the imposition of nutrient loading restrictions. The estimation results indicated that requiring a P-based nutrient management plan generally increases the cost of manure management because more land is needed to meet the requirements of a P-based plan. Optimal cow numbers per acre decreased on the farm as restrictions on P loss intensified.

The evaluation comparing triple and double forage cropping systems showed that the triple cropping systems had more carrying capacities than double cropping under N restrictions, but the reverse was also true under the P restrictions. Although having crops growing year round, the triple cropping systems was less profitable than the double cropping systems when the manure application rates were based on N and P standards. When the model was implemented with fixed cows number, the acreage requirements for the disposal of the manure generated in the farm increased substantially by complying the P-standard manure management.

Sensitivity analyses were performed using milk prices from 1997 to 2000 to investigate the impact of milk prices and nutrient loading restrictions on the farm total expected net income. In this case, the model correctly predicted higher net returns with increasing milk prices. The effect of a change in crop nutrients uptake from yield variation was found to be significant. It means that for crops grown in each period, marginal reductions in yield below the target threshold level will increase the probability of applying some positive amount of nutrients for runoff. We explored the ability of the model to represent the variability in economic returns and land use patterns due to the relative changes in yield outputs and nutrient uptake level for unrestricted and restricted scenarios of N and P losses. Again, the P-based restriction showed the most significant effects in the decision to increase crop acreages.

The effects of crop acreage were evaluated with standard and adjusted manure application rates to meet crop nutrient uptake. The standard and nutrient-adjusted land-use data and total farm net returns are sufficient statistics for assessing land requirements and management costs associated with the disposal of excess manure in accordance to the environmental policy. In other words, the difference between the standard and the nutrient-adjusted simulations represents implicitly the magnitude of social benefits derived from implementing an environmental policy. The model estimate results indicate that additional crop acreages are required, particularly under the P-based standard, to apply manure not in excess to crop nutrient needs.

Conclusion, Implication and Further Research

A dairy farm management tool was developed based on the expected utility maximization theory and a linear programming approach. The model was utilized to compare profitability for changes in agronomic, economic and environmental determinants from dairy farms. The simulations results were consistent with expectations or with animal input-output relationships and could be explained with economic logic. The study also showed that there exists a potential environmental risk even with modeling the relationships when plant nutrient application rates are not adjusted for reductions in previous crop yields.

A major contribution of this study is integrating agronomic, economic and environmental components in a dairy farm decision model. Linear programming has long proved its merits as a significant model of numerous allocation problems and phenomena. The continuously expanding literature of applications repeatedly demonstrates the importance of linear programming as a general framework for problem formulation and solvency. This approach was utilized to determine the economically optimal dairy herd intensities, land use, manure application rates, and crop mix for unrestricted and restricted scenarios of N and P losses on dairy farms.

The nutrient loading restrictions have an important bearing on the availability of spreadable area and resulting farm net returns. Proposed policies require a P-based standard (P-standard) on fields with high soil phosphorus levels, and an N-based standard (N-standard) elsewhere. Under a P-standard, manure application rates are reduced such that manure phosphorus is not applied in excess of crop uptake requirements. The P-standard implies greater spreadable acreage requirements, storage facility and hauling distances for a give quantity of manure.

Options other long-distance hauling for reducing the quantity of (or disposal of) the excess manure, include increasing crop nutrient uptake by growing year-round crops for feed and/or for sale, increasing industrial processing and reducing the quantity of manure nutrients produced. The current model specification, however, focuses on an option of primary policy focus land application. Total farm net returns (manure management costs) will depend on policy option(s) selected to address the manure quantity that exceeds the application potential in the model. Actual manure management costs for land application depend on the shares of land under each nutrient standard policy. Whether producers are able to made cropland adjustments under N-standard or P-standard policy may well determine future sustainability and survival of the farming operations. If additional acreages are not available or feasible to acquire, herd reduction may be necessary to meet the policy goals.

This study presents an analytical framework for jointly determining optimal milk output and evaluating the opportunity to manage manure and crops within a dairy operation. It is expected to complement earlier spreadsheet models on animal manure nutrient management in Georgia. Because no attempt was made to restrict acreage requirements by crop when lower (higher) than expected yields were realized, the analysis as done is more application to next cropping period conditions rather than to the current production period. The use of the model as an on-farm management tool would require additional runs of the model using the realized forage yields and the acreages determined from runs using the expected yields when realized yields fall below expected yields.

Even though it is presented in the context of dairy management, the model can be extended to other situations where animal and poultry wastes are involved. Georgia's environmental policy-makers are moving to make sure poultry farms keep track of their wastes. The state Board of Natural Resources require has instructed its Environmental Protection Division's staff to prepare an inventory of large, medium and small-size poultry farms, including which farms are using voluntary "nutrient management plans" to prevent their activities from polluting rivers and lakes. Large poultry farms are required by Georgia's legislature to get waste-disposal permits specifying how they will dispose of chicken litter without polluting nearby waterways. Thus not only will the farm expenditure increase, but also the probability constraints for achieving these environmental goals will increase as livestock and poultry operators are continuously shifting their location from counties to counties.

The optimal manure-crop system will depend on the farm characteristics and specific local conditions. Failure to make adjustments as suggested in this dissertation would lead to ineffective manure management and less economically and environmentally attractive policy. Buffers and nutrient sinks can protect streams and water bodies from migrating nutrients and should be considered in future economic analysis.

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